STUDY OF THE BY-CATCH OF THE NSW EAST COAST TRAWL FISHERY

FINAL REPORT TO THE FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project No.: 88/108.

STEVEN J. KENNELLY

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H - Broadhurst, M.K. and S.J. Kennelly. A trouser-trawl experiment to assess codends that exclude small fish (mulloway) in the Hawkesbury River prawn-trawl fishery. Submitted to ICES Journal of Marine Science.

I - Graham, K.J., G.W. Liggins, J. Wildforster and S.J. Kennelly, 1993. Kapala Cruise Report No. 110. Fisheries Research Institute, NSW Fisheries, 69 pp.

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FINAL REPORT OF PROJECT TO FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project title:	Study of the by-catch of the New South Wales east coast trawl fishery.
Project reference no.:	88/108.
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Funding organisation:	Fishing Industry Research & Development Council followed by the Fisheries Research & Development Corporation

NON-TECHNICAL SUMMARY

For many years, by-catch from prawn trawling has been known to be large in quantity and diversity. Recently, quite negative aspects of prawn-trawl by-catch have been emphasised as the mortality of by-caught juvenile fish is thought to reduce the subsequent stocks of fisheries which target such species. Over the past 10 years, this issue has become of increasing concern to a broad cross-section of the community, particularly commercial fishers other than trawlers (e.g. fish trappers, set and hand-liners, mesh netters, beach seiners), recreational fishers, conservationists, environmentalists, fisheries managers, scientists and politicians from all levels of government. Of major concern in NSW have been complaints regarding prawn and fish trawlers catching and discarding large numbers of undersize fish that, when larger, are targetted in other commercial and recreational fisheries. In particular, these observations are made with respect to prawn trawlers working in estuarine and oceanic locations thought to be nursery grounds for important finfish species.

In 1988 we recognised this increasing conflict and discovered that, despite a great deal of anecdotal and observational information, there existed virtually no data on the identities, quantities, timing or locations of the by-catches of estuarine and oceanic prawn trawlers. As a first step in providing management recommendations concerning this issue, we therefore applied for and received funding for this project which was to assist us in identifying and quantifying spatial and temporal differences in the by-catch from these trawlers. This was done through intensive observer programmes which determined average catch rates (and associated variances) by trawlers per day/night of fishing. From these catch rates and estimates of effort by whole fleets (available as total trawler days/nights), we extrapolated estimates of the total catches and by-catches by fleets for different regions and times. This work was done between late 1989 and mid 1992, onboard randomly-selected boats in each of 5 estuaries (Botany Bay, Sydney Harbour, the Hawkesbury and Clarence Rivers and Lake Woolooweyah) and out of 4 oceanic ports (Port Stephens, Coffs Harbour, the Clarence River and Ballina).

We also did an independent oceanic survey with FRV Kapala (funded by NSW Fisheries) using a stratified randomized design in school and king prawn grounds offshore from Brunswick Heads, Iluka/Yamba, Forster and Newcastle. This work produced estimates of the relative abundances of species caught by oceanic prawn trawling and will be compared to repeats of this survey to assess the relative status of these populations over time.

In a series of field experiments, various modifications to trawl gears were examined for their potential to reduce by-catch. The first involved an examination of the effects of different lengths of sweeps on the by-catch of oceanic prawn trawlers using FRV Kapala. The second involved assessing the utility of soft TEDs (Trash Elimination Devices) in reducing by-catch on oceanic prawn grounds and was done using commercial vessels operating out of Iluka/Yamba on the north coast. Some assessment of the utility of soft TEDs in estuaries was possible by comparing catch rates obtained during our observer work on trawlers that did/did not use TEDs in Botany Bay, where large numbers of juvenile snapper are sometimes taken as by-catch. Another gear modification that we investigated aimed to reduce the by-catch of juvenile mulloway in the Hawkesbury River by incorporating various square mesh panels in codends.

The results from the study revealed that several key species, locations and times have the potential to be involved in significant impacts of prawn trawling on other fisheries. These are the large numbers of snapper by-caught by the Botany Bay and Yamba/Iluka fleets in summer, the eastern blue-spot, dusky and northern sand flatheads, tarwhine, trumpeter and red spot whiting, silver trevally, large-tooth flounder and blue-swimmer crabs by-caught in Botany Bay during the trawling season, the mulloway by-caught by the Hawkesbury River prawn trawlers between late spring and early autumn, the tarwhine by-caught by the Yamba/Iluka fleet in winter, the redfish by-caught by the Port Stephens oceanic fleet and the bream, tailor, sand whiting and dusky flathead by-caught by the Clarence River and Lake Wooloweyah prawn fleets.

To make any definitive statements about the actual effect that such by-catches may have on subsequent stocks of these species, one requires information on the post-trawl mortalities of these discards, rates of natural mortalities of the various species as they grow to legal size and the relative proportion of the biomasses of juveniles that are taken as by-catch. At present such information is not available. Despite these uncertainties however, we feel that the estimates of by-catches made during this project suggest that it would be unwise for fisheries managers and the prawn-trawl industry to ignore ways that may minimize the potentially deleterious effects of by-catch. The involvement of industry in developing ways to minimize any deleterious effects of by-catch is an important first step in circumventing any future outcries from fishers operating in interacting fisheries.

We feel that this project has been a marked success as it has identified the nature, size, spatial and temporal variabilities and the species involved in this large and complex issue - a huge improvement on what was known previously. Whether the magnitude of by-catches of juvenile finfishes is a real or merely a perceived problem, we believe that it would be a good idea (from the point of view of the prawn-trawl fishers, the interacting fishers and the public as a whole) to try to reduce it as much as possible. Preliminary work done in this area during this project has shown the relative merits of the main management tools available.

Large spatial and temporal variabilities in by-catches of the various key species makes the management of the by-catch issue using fixed spatial and temporal closures very difficult. Such management strategies could, however, be useful on a flexible basis where ongoing monitoring determines where and when various fisheries should be closed. This strategy has a large cost, however, as such monitoring programmes (which ideally would be fishery-independent) are expensive and any option that reduces prawn trawling will probably lead to reduced catches and sales of prawns. Another closure strategy that could be considered is large-scale closures of whole fisheries. Such a strategy would remove any problems of trying to predict appropriate closures given large spatial and temporal variabilites in by-catches of key species and may therefore be appropriate for any fisheries where there are many key by-catch species occurring in large numbers (a possible candidate detected in this project would be the Botany Bay fishery). This strategy does, however, have an enormous cost in terms of the value of the particular fishery, individual fishers' incomes and the availability of prawns to the public.

The other management strategy for reducing prawn-trawl by-catch concerns gear selectivity and fishing practices and is the preferred option in the majority of the world's prawn-trawl fisheries and the preferred solution recommended here. Modifications to prawn-trawl nets, codends, sweeps and fishing practices are all alternatives that have been, and will continue to be invoked throughout the world as means for solving by-catch problems. Work done in other countries and in NSW indicate that it is possible to develop modifications to trawl gear and fishing practices that negate a great deal of the capture of by-caught finfish. Work done in this project has shown the very real potential of TED (Trash Elimination Device) panels, square-mesh panels and reducing sweep lengths as means for reducing the incidental capture of finfish. We feel that it is important that industry be actively involved in such developments so that (i) they are seen to be the driving force in addressing any conflicts that may come from the publication of large by-catches of finfishes and (ii) we can fully utilize industry's unique practical knowledge of the relevant gear technology.

These conclusions have resulted in our application to FRDC to fund a 3 year project to develop by-catch reducing fishing gears and practices for NSW's various prawn-trawl fisheries. At the time of writing this final report, we have just begun that new project (FRDC project 93/180).

BACKGROUND AND INTRODUCTORY INFORMATION CONCERNING THE RESEARCH NEED

The background and introductory information for this project are described in detail in three of our publications. Andrew & Pepperell (1992) (Appendix A) and Kennelly (in press) (Appendix B) are reviews of the literature concerning trawl by-catch. The former reviews some of the international literature dealing with prawn-trawl by-catch and the latter reviews the Australian literature dealing with fish and prawn-trawl by-catch. A third paper (Kennelly et al., 1992) (Appendix C) summarizes the specific background for our particular project and I provide a summary below.

For many years, by-catch from prawn trawling (defined here as the trawled fauna that are not prawns) has been known to be large in both its quantity and diversity (Slavin, 1982; Gulland & Rothschild, 1984). In most countries and fisheries, some or all of this by-catch is considered as a "bonus from the sea" and it is utilized as a source of protein for human or animal consumption (IDRC, 1982; Saila, 1983). Recently, however, more negative aspects of prawn-trawl by-catch have been emphasised as the mortality of by-caught fish is thought to reduce the subsequent stocks of fisheries which target such species (Gordon, 1988; Foldren, 1989; Cooper, 1990; Ohaus, 1990). These negative aspects may range from relatively simple effects (such as the direct mortality of juveniles due to trawling and discarding practices) through to more complex effects on community structure such as habitat degradation, influences on species interactions and their consequent cascading effects throughout the food web (see Andrew & Pepperell, 1992 - Appendix A). In the last few years, there has been an increased awareness of such problems of prawn-trawl by-catch, making this one of the most important and critical issues facing commercial and recreational fisheries throughout the world.

In New South Wales, Australia, demersal trawling for prawns and fish accounts for the majority of the production (in weight and value) of our commercial fisheries (approx. $A45m per annum). Over the past 10 years the by-catch from these activities has become of increasing concern to a broad cross-section of the community, particularly commercial fishers other than trawlers (e.g. fish trappers, set and hand-liners, mesh netters, beach seiners), recreational fishers, conservationists, environmentalists, fisheries managers, scientists and politicians from all levels of government. Of major concern in NSW have been complaints regarding prawn and fish trawlers catching and discarding large numbers of undersize fish that, when larger, are targetted in other commercial and recreational fisheries. In particular, these observations are made with respect to prawn trawlers working in estuarine and oceanic locations thought to be nursery grounds for several important finfish species.

In 1988 we recognised this increasing conflict and discovered that, despite a great deal of anecdotal and observational information, there existed virtually no data on the identities, quantities, timing or locations of the by-catches of estuarine and oceanic prawn trawlers (but see Gray et al., 1990). As a first step in providing management recommendations concerning this issue, we therefore approached FRDC for funding for a project which would assist us in identifying and quantifying spatial and temporal differences in the by-catch from these trawlers. This was to be done through intensive observer programmes in several of NSW's prawn-trawl fisheries.

ORIGINAL OBJECTIVES

(i) To describe the distribution and abundance of by-catch species in NSW's prawn-trawl fisheries.

(ii) To compare this by-catch between regions, seasons and gear-types presently used by the commercial fleet.

(iii) To provide basic biological data on the most common species, both adult and juvenile, within the overall objective of assessing the interaction between trawl fisheries and other commercial (e.g. trap and handline) and recreational fisheries.

RESEARCH METHODOLOGY

The methods used during this project are described in Kennelly et al (1992), Kennelly et al. (1993), Andrew et al (1991), Andrew et al. (1993), Broadhurst & Kennelly (in press) and Broadhurst & Kennelly (sub. ms.) (Appendices C, D, E, F, G & H). These papers describe the methods used in the three broad components of the project: the estuarine and oceanic observer programmes; the independent survey done by FRV Kapala; and independent experimental evaluations of various by-catch reducing trawl modifications. I provide summaries of these various methods below.

Estuarine and oceanic observer programmes

The major prawn-trawl fisheries in NSW target two species, the eastern king prawn (*Penaeus plebejus*) at night and the eastern school prawn (*Metapenaeus macleayi*) during the day or night. Estuarine prawn trawling occurs in 5 estuaries in NSW, mainly during the summer period. Oceanic prawn trawling occurs out of 11 ports along the coast in all seasons.

In each month that prawn trawling occurred between late 1989 and mid 1992, we attempted to place scientific observers on board 4 randomly-selected boats during a typical day's (or night's) trawling in each of 5 estuaries (Botany Bay, Sydney Harbour, the Hawkesbury and Clarence Rivers and Lake Woolooweyah). Similarly, in each season, we aimed to have observers on 12 randomly-selected vessels doing a typical day's (or night's) trawling out of 4 oceanic ports (Port Stephens, Coffs Harbour, the Clarence River and Ballina). During these trips, the catch and by-catch from each tow were placed on the sorting tray and then sorted by the crew and our observer, separating the various species. All the commerically and recreationally-important species were counted and measured. Other non-commercial species were identified and in estuaries they were counted. Because of the quantities of catch and by-catch caught in oceanic waters, we randomly subsampled the catch and took detailed measurements and weights on a known fraction of the total. For each tow, we also recorded the time, location, depth and duration of the tow, as well as the gear configuration used. Because boat-trips were randomly sampled each month (in estuaries) and each season (on oceanic grounds), average catch rates and variances were calculated per month/season from replicate boat-trips rather than replicate tows. Whilst the latter method would have provided greater replication (and smaller variances), one cannot assume that individual tows were independent - in fact, usual fishing practices indicate the opposite. Further, estimates of effort by fleets (used below in extrapolating by-catch rates to whole fleets) are only available in units of boat-trips.

The catch rates per trip (and associated variances) for each port/estuary for each month/season can be extrapolated to estimate catches by whole fleets for each location in each month/season using the total numbers of boat-trips done by the fleet (using rules for the derivation of standard errors of combination estimates, e.g. Myers and Shelton, 1980). These estimates of trawling effort are available in NSW via reports that fishers are legally required to submit on a monthly basis. Whilst such effort data may be innaccurate due to incorrect completion of forms by fishers, they are the best available.

Independent oceanic survey by FRV Kapala

This survey employed a stratified randomized design in the school prawn grounds and king prawn grounds offshore from Brunswick Heads, Iluka/Yamba, Forster and Newcastle (see Kennelly et al., 1993 - (Appendix D). Catches from 4 replicate 30 minute prawn trawls (using commercial prawn gear) were censussed in detail on 3 replicate days (school prawn grounds) or nights (king prawn grounds) in each place every season over a 2 year period. In this way, we obtained accurate estimates of the relative abundances of species caught by prawn trawling.

Comparisons of alternative gears

In a series of experiments various gear modifications were examined for their potential to reduce by-catch. The first involved an examination of the effects of different lengths of sweeps on the by-catch of oceanic prawn trawlers using FRV Kapala (see Andrew et. al., 1992 - Appendix E).

The second experiment involved assessing the utility of soft TEDs (Trash Elimination Devices - similar to the Morrison Soft TED - Kendall, 1990) in reducing by-catch on oceanic prawn grounds (Andrew et al., 1993 - Appendix F) and was done using commercial vessels operating out of Iluka on the north coast.

Some assessment of the utility of soft TEDs in estuaries was possible by comparing catch rates by trawlers in one of the estuaries sampled during the observer programme - Botany Bay, where large numbers of juvenile snapper are sometimes caught as by-catch. Fortuitously, approximately half the fleet in this estuary use TEDs to exclude unwanted jellyfish which often occur in the bay and hinder the effectiveness of the trawls. The other half of the fleet choose not to use TEDs. A comparison of the data obtained from our random sampling of these two groups of vessels (with and without TEDs) over the past few seasons gave us some information on the potential for TEDs to reduce the impact of prawn trawling on these juvenile snapper (Kennelly et al., 1992 - Appendix C).

Another gear modification that we investigated aimed to reduce the by-catch of juvenile mulloway in the Hawkesbury River (Broadhurst & Kennelly, in press - Appendix G; and Broadhurst & Kennelly, sub. ms. - Appendix H). The first experiment involved a comparison of 3 designs of codend. The control codend (the conventional one used in this fishery) was hung such that the 40mm meshes were diamond-shaped. The second codend had the netting hung such that the whole codend was comprised of square-shaped meshes. The third codend was a combination of these, with the basal half of the codend hung with diamond-shaped meshes and the upper half hung with square-shaped meshes. This latter configuration was designed to retain prawns in the back of the codend, whilst allowing juvenile mulloway to escape from the anterior, square-shaped openings where water flows out of the codend (see also Briggs, 1992). The second experiment involved the use of trouser trawls to examine 2 new types of square mesh panel in codends. These were panels made of large and small square-meshes placed in the top of the anterior portion of the codend and were designed to maintain prawn catches whilst excluding free-swimming fish through the square mesh panels.

RESULTS

The results from this project are contained in a variety of publications and reports (Kennelly et al, 1992 - Appendix C, Kennelly et al, 1993 - Appendix D, Andrew et al, 1991 - Appendix E, Andrew et al, 1993 - Appendix F, Broadhurst & Kennelly, in press - Appendix G, Broadhurst & Kennelly, sub. ms. - Appendix H, Kapala Cruise Reports 110 & 112 - Appendices I & J, preliminary reports produced during the project - Kennelly & Liggins, 1992 a & b - Appendices K & L and 12 summary reports sent to the 160 fishers whose vessels we sampled during the observer programmes (Appendix M). More detailed analyses of the data (including analyses of variance of subsets of the observer data) will be included in 7 additional papers that are currently in preparation.

Estuarine and oceanic observer programmes

Most of the results from this part of the work can be found in Kennelly et al., 1992, Kennelly & Liggins, 1992 a & b and the 12 summary reports sent to the 160 fishers whose vessels we sampled during the observer programmes (Appendices C, K, L & M). In addition to these results, the most important sets of data from that part of the project funded by FRDC are those that deal with the extrapolated summaries of catches and by-catches by whole fleets. These estimates combine the estimated mean catch rates (per trip) and the total number of trips done by the fleet in a given estuary/port. A summary of these estimates for whole fleets is contained in the figures supplied immediately after page 12 (Figs. 1 - 13) and provide a picture of where and when the largest and most important by-catches occurred.

In the estuaries examined, it is clear from Figs 1 - 5 that the key fishery in terms of potential problems of prawn-trawl by-catch in a fisheries-interaction sense is the Botany Bay fishery where large numbers of snapper and other species are by-caught and discarded. Botany Bay recorded the largest weights of by-catches, numbers of individuals and numbers of commercially-important individuals of all the estuaries examined. It also recorded relatively low catches of prawns. The most important species that were by-caught in large numbers by this fishery were snapper, eastern blue-spot, dusky and northern sand flatheads, tarwhine, trumpeter and red spot whiting, silver trevally, large-tooth flounder and blue-swimmer crabs.

Other estuaries showed smaller potential impacts of prawn-trawl by-catch. The Port Jackson fishery had very little by-catches of importance with only dusky flathead by-caught in any appreciable quantities. In the Hawkesbury River prawn-trawl fishery, the key by-catch species was clearly mulloway which was by-caught in large numbers in each year of the study. The Clarence River and Lake Woolooweyah showed significant by-catches of bream, tailor, dusky flathead and sand whiting.

For those oceanic fleets we sampled (Figs 6 - 13), the Yamba/Iluka fleet showed the largest extrapolated by-catches due to the overall size of that fleet and the consequent large number of days fished as recorded on the Form 49/19 database. By-catches from oceanic trawling generally contained large numbers of species that are landed for sale and are considered desirable. Key species which may have fisheries-interaction implications for the Yamba/Iluka fleet are snapper (in the summers of 1990-91 and 1991-92), tarwhine (in the winters), teraglin, john dory, the flounders, eastern blue-spot and marble flatheads and blue-swimmer crabs. For other fleets, fishing effort and therefore extrapolated by-catches were much smaller.

Key species for the Port Stephens fishery were ocean perch, hairtail, john dory, redfish and tiger flathead. Ballina and Coffs Harbour had relatively few by-catches of significant importance to fishery interaction issues.

By examining the extrapolations presented in Figs. 1-13 and the catch rates provided in the summary reports to fishers (Appendix M), several key species, locations and times become evident in terms of potential impacts of prawn trawling. These are the large numbers of snapper by-caught by the Botany Bay and Yamba/Iluka fleets in summer, the eastern blue-spot, dusky and northern sand flatheads, tarwhine, trumpeter and red spot whiting, silver trevally, large-tooth flounder and blue-swimmer crabs by-caught in Botany Bay during the trawling season, the mulloway by-caught by the Hawkesbury River prawn trawlers during non-summer months, the tarwhine by-caught by the Yamba/Iluka fleet in winter, the redfish by-caught by the Port Stephens oceanic fleet and the bream, tailor, sand whiting and dusky flathead by-caught by the Clarence River and Lake Wooloweyah prawn fleets.

As a reference source, I provide a complete list of species recorded from each fishery during the project (Appendix N).

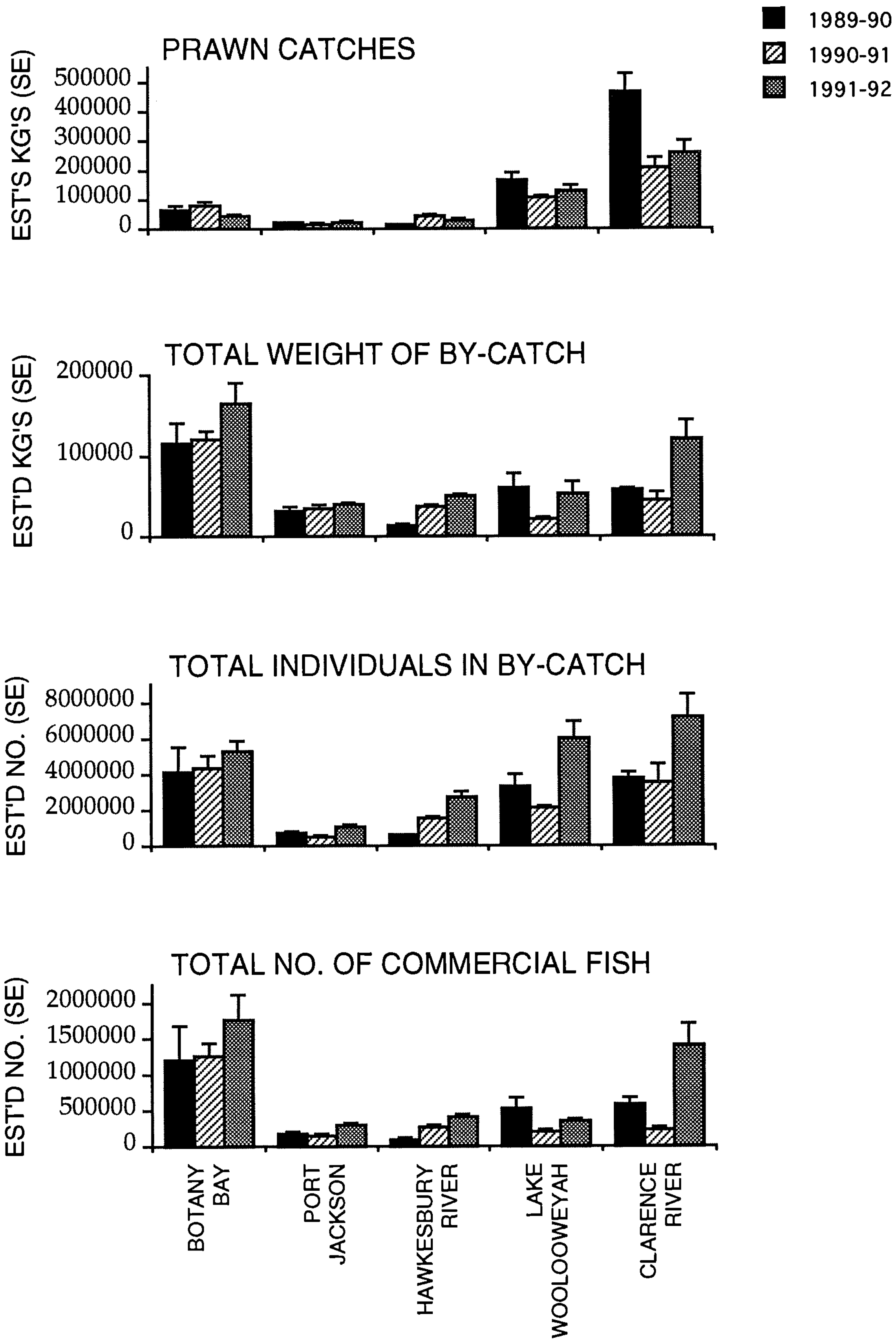
Independent oceanic survey by FRV Kapala

The results from this survey are described in Kennelly et al., 1993 (Appendix D) and in Kapala Cruise Reports 110 & 112 (Appendices I & J).

Comparisons of alternative gears

The results from these various experiments are supplied in Kennelly et al., 1992 (Appendix C), Andrew et al, 1991 & 1993 (Appendices E & F), Broadhurst & Kennelly, in press, sub. ms. (Appendices G & H).

FIGURE 1



1989-90
1990-91
1991-92
PRAWN CATCHES
EST'S KG'S (SE)
500000
400000
300000
200000
100000
0
TOTAL WEIGHT OF BY-CATCH
EST'D KG'S (SE)
200000
100000
0
TOTAL INDIVIDUALS IN BY-CATCH
EST'D NO. (SE)
8000000
6000000
4000000
2000000
0
TOTAL NO. OF COMMERCIAL FISH
EST'D NO. (SE)
2000000
1500000
1000000
500000
0
BOTANY BAY
PORT JACKSON
HAWKESBURY RIVER
LAKE WOOLOOWEYAH
CLARENCE RIVER

FIGURE 2

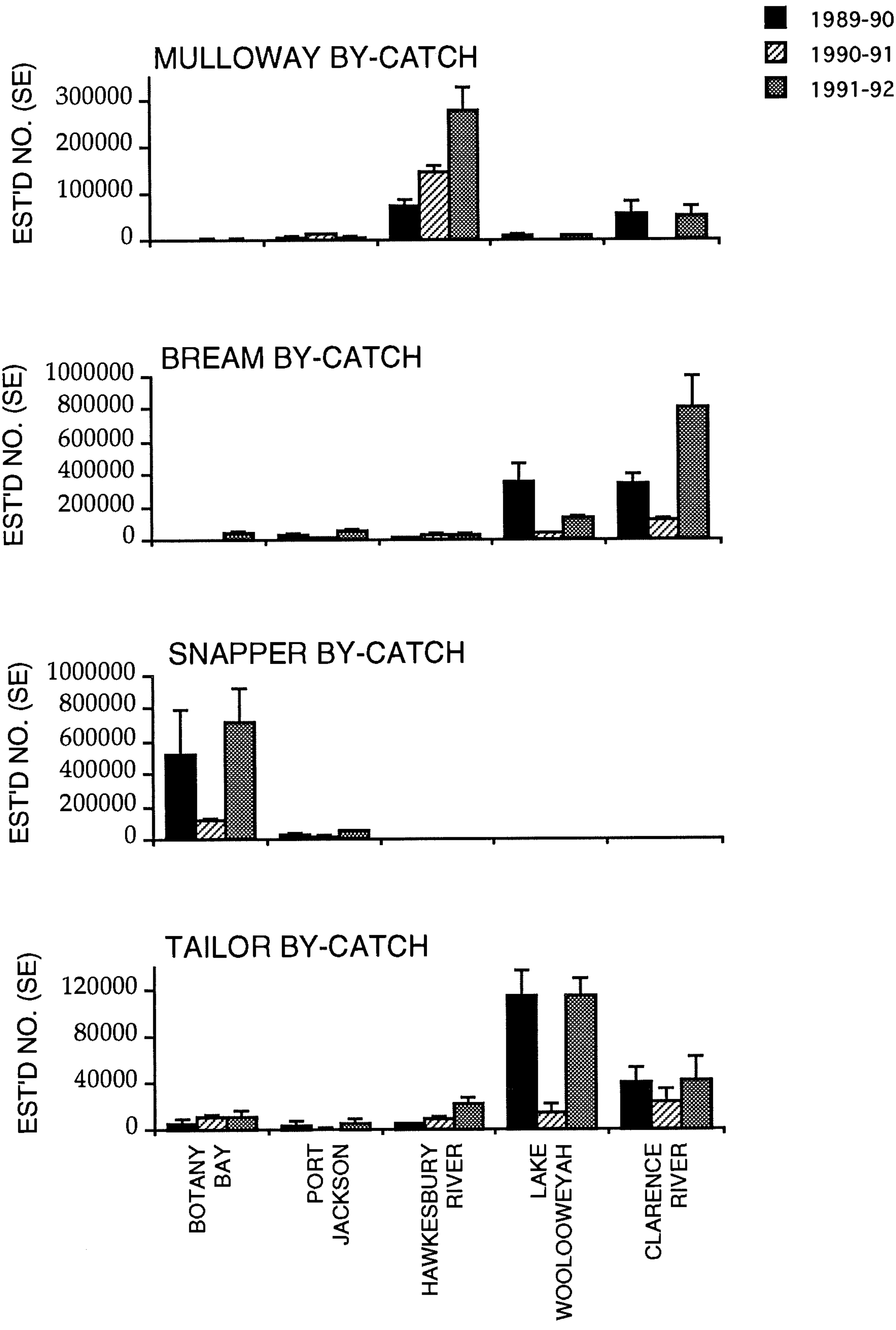

1989-90
1990-91
1991-92
MULLOWAY BY-CATCH
EST'D NO. (SE)
300000
200000
100000
0
BREAM BY-CATCH
EST'D NO. (SE)
1000000
800000
600000
400000
200000
0
SNAPPER BY-CATCH
EST'D NO. (SE)
1000000
800000
600000
400000
200000
0
TAILOR BY-CATCH
EST'D NO. (SE)
120000
80000
40000
0
BOTANY BAY
PORT JACKSON
HAWKESBURY RIVER
LAKE WOOLOOWEYAH
CLARENCE RIVER

FIGURE 3

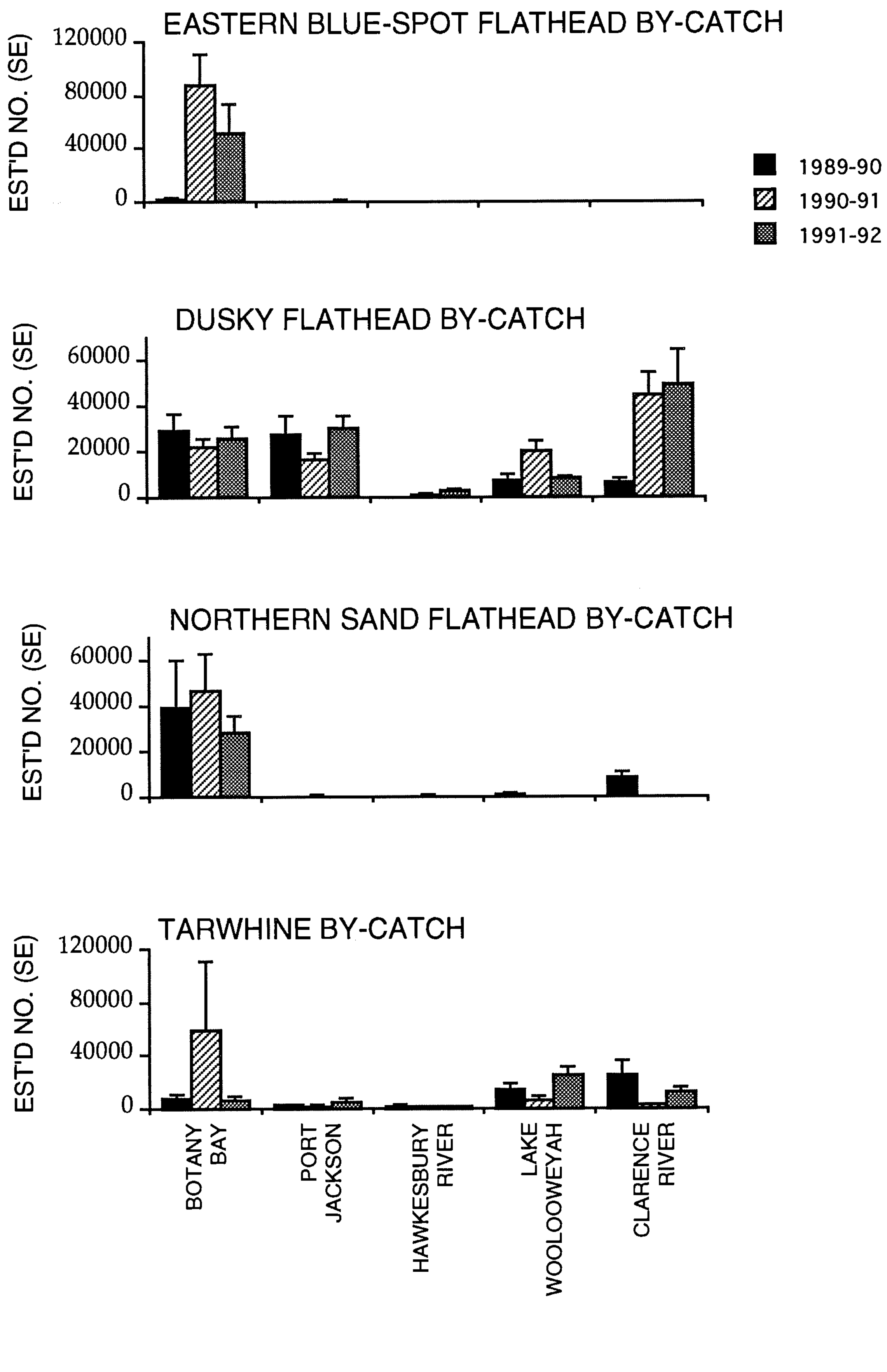

EASTERN BLUE-SPOT FLATHEAD BY-CATCH
DUSKY FLATHEAD BY-CATCH
NORTHERN SAND FLATHEAD BY-CATCH
TARWHINE BY-CATCH
EST'D NO. (SE)
120000
80000
40000
60000
20000
0
1989-90
1990-91
1991-92
BOTANY BAY
PORT JACKSON
HAWKESBURY RIVER
LAKE WOOLOOWEYAH
CLARENCE RIVER

FIGURE 4

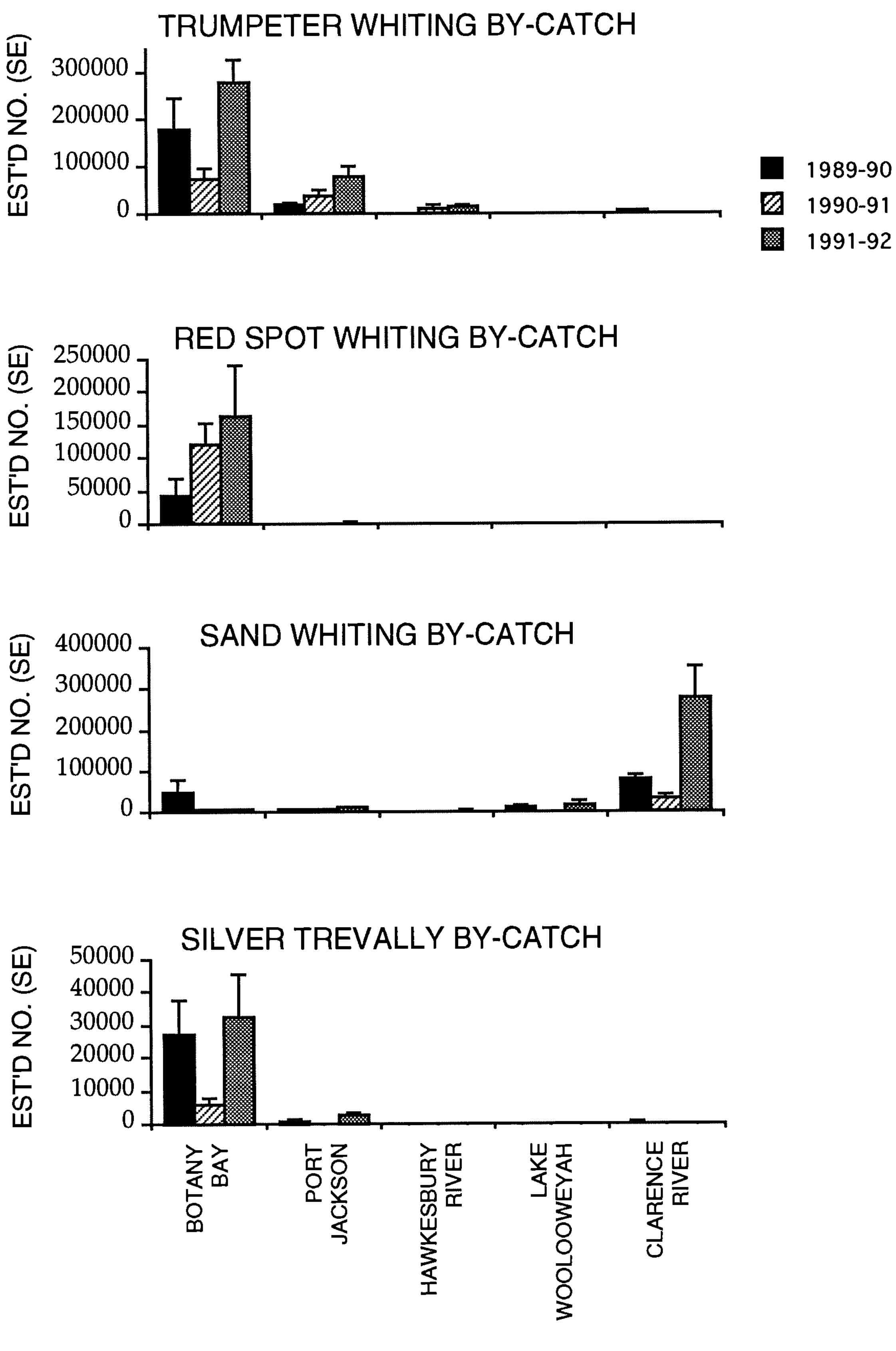
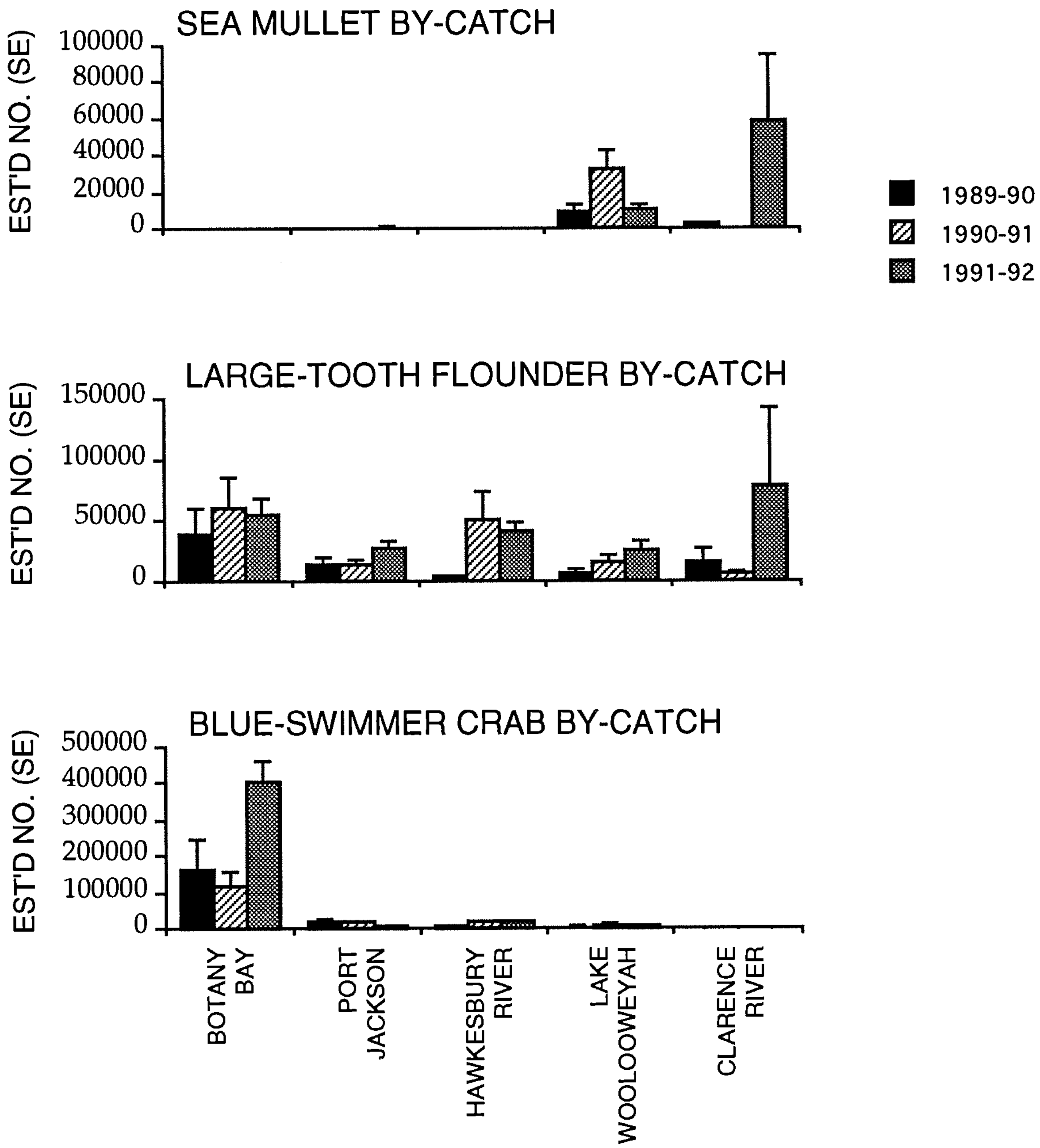

TRUMPETER WHITING BY-CATCH
EST'D NO. (SE)
300000
200000
100000
0
1989-90
1990-91
1991-92
RED SPOT WHITING BY-CATCH
EST'D NO. (SE)
250000
200000
150000
100000
50000
0
SAND WHITING BY-CATCH
EST'D NO. (SE)
400000
300000
200000
100000
0
SILVER TREVALLY BY-CATCH
EST'D NO. (SE)
50000
40000
30000
20000
10000
0
BOTANY BAY
PORT JACKSON
HAWKESBURY RIVER
LAKE WOOLOOWEYAH
CLARENCE RIVER

FIGURE 5



SEA MULLET BY-CATCH
EST'D NO. (SE)
100000
80000
60000
40000
20000
0
1989-90
1990-91
1991-92
LARGE-TOOTH FLOUNDER BY-CATCH
EST'D NO. (SE)
150000
100000
50000
0
BLUE-SWIMMER CRAB BY-CATCH
EST'D NO. (SE)
500000
400000
300000
200000
100000
0
BOTANY BAY
PORT JACKSON
HAWKESBURY RIVER
LAKE WOOLOOWEYAH
CLARENCE RIVER

FIGURE 6

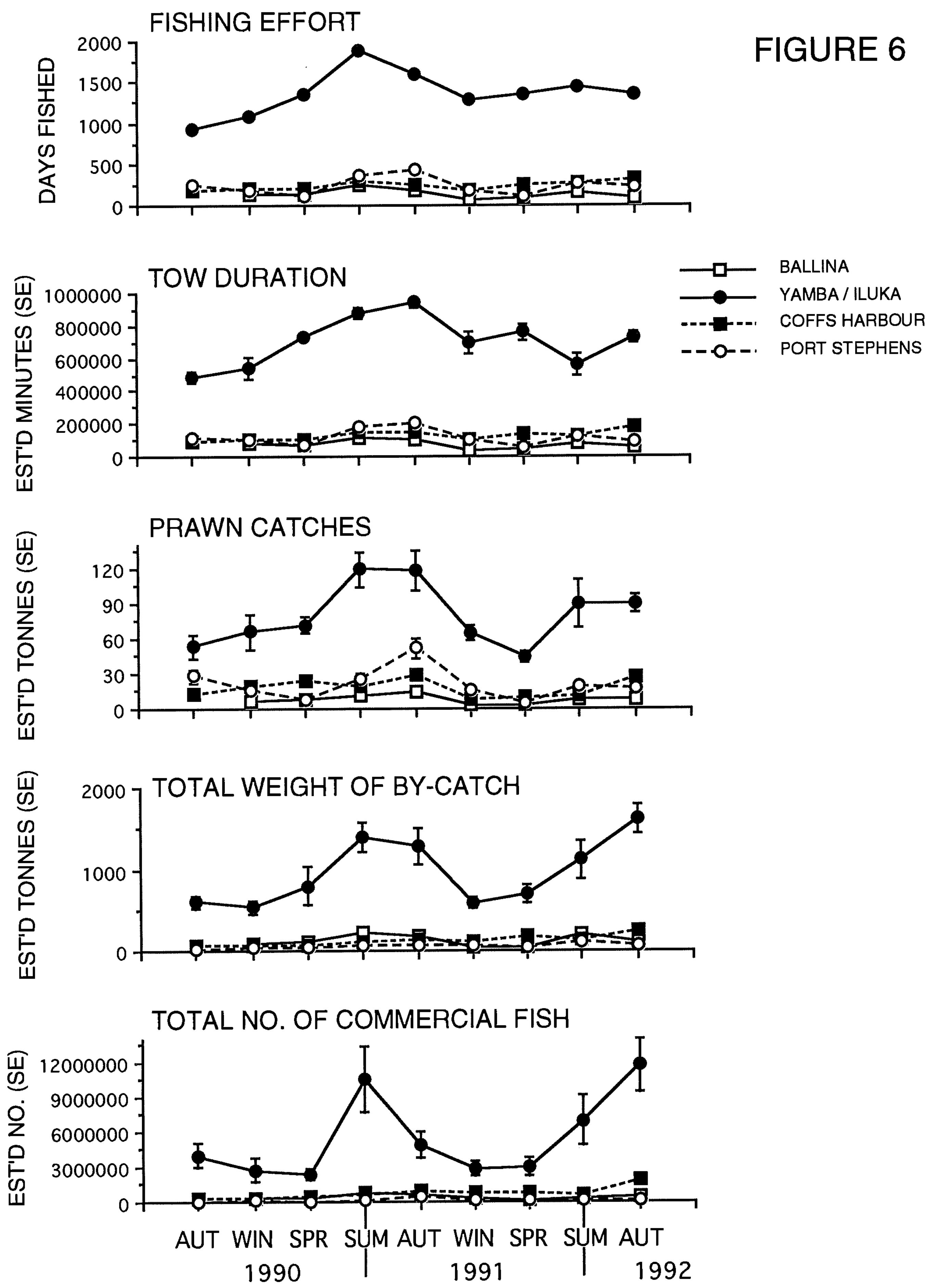

FISHING EFFORT
DAYS FISHED
2000
1500
1000
500
0
TOW DURATION
EST'D MINUTES (SE)
1000000
800000
600000
400000
200000
0
BALLINA
YAMBA / ILUKA
COFFS HARBOUR
PORT STEPHENS
PRAWN CATCHES
EST'D TONNES (SE)
120
90
60
30
0
TOTAL WEIGHT OF BY-CATCH
EST'D TONNES (SE)
2000
1000
0
TOTAL NO. OF COMMERCIAL FISH
EST'D NO. (SE)
12000000
9000000
6000000
3000000
0
AUT WIN SPR SUM AUT WIN SPR SUM AUT
1990
1991
1992

FIGURE 7

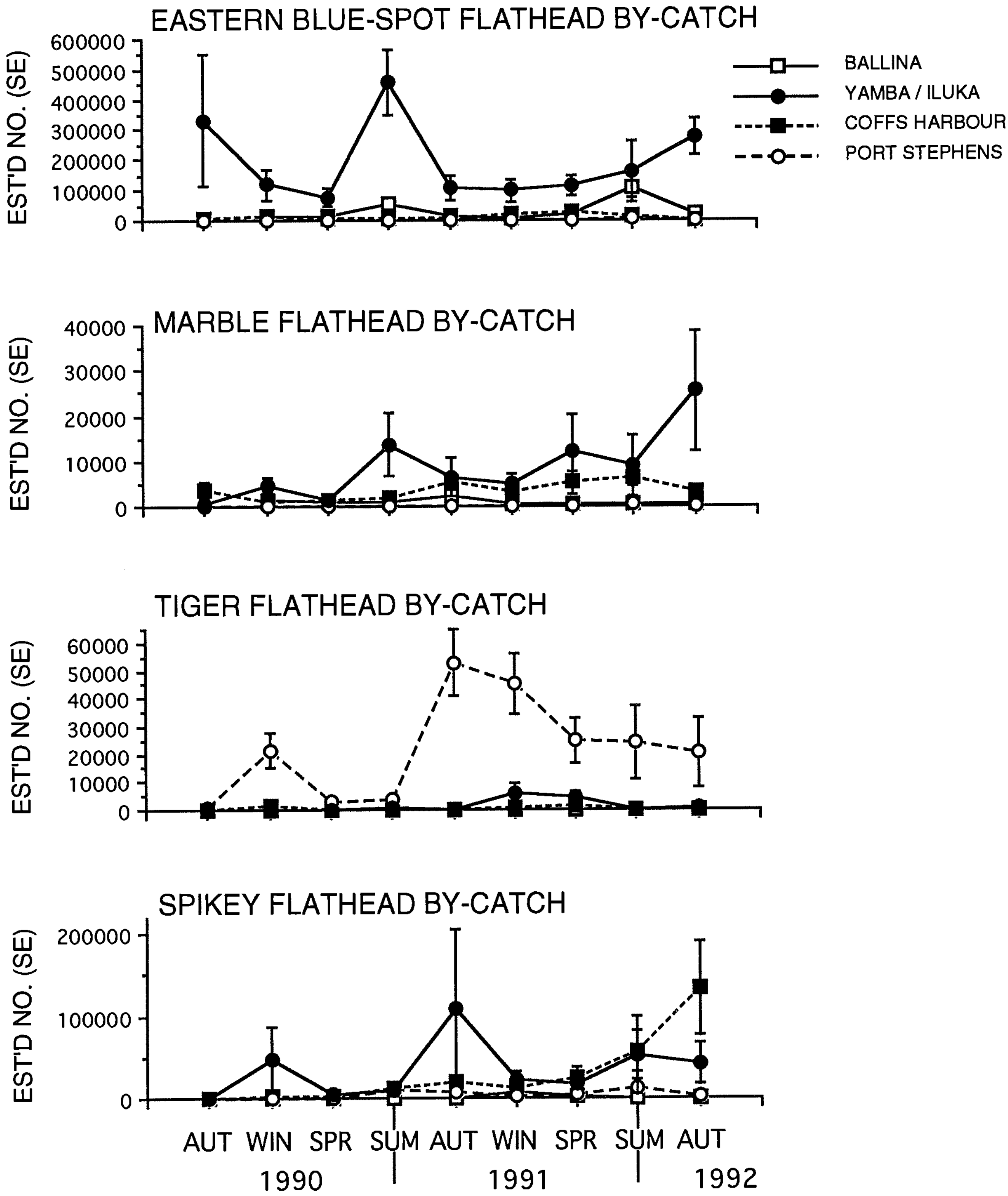
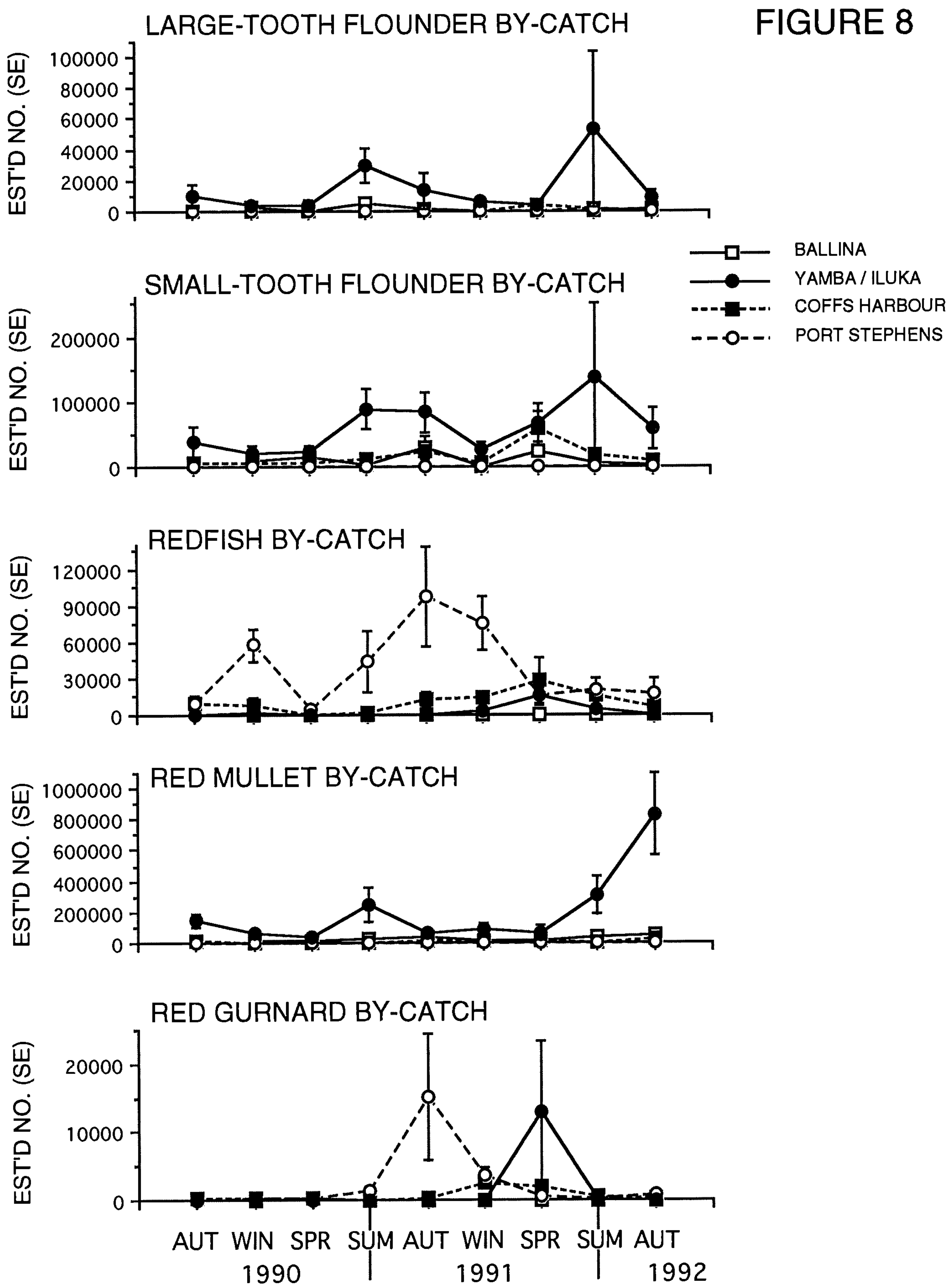
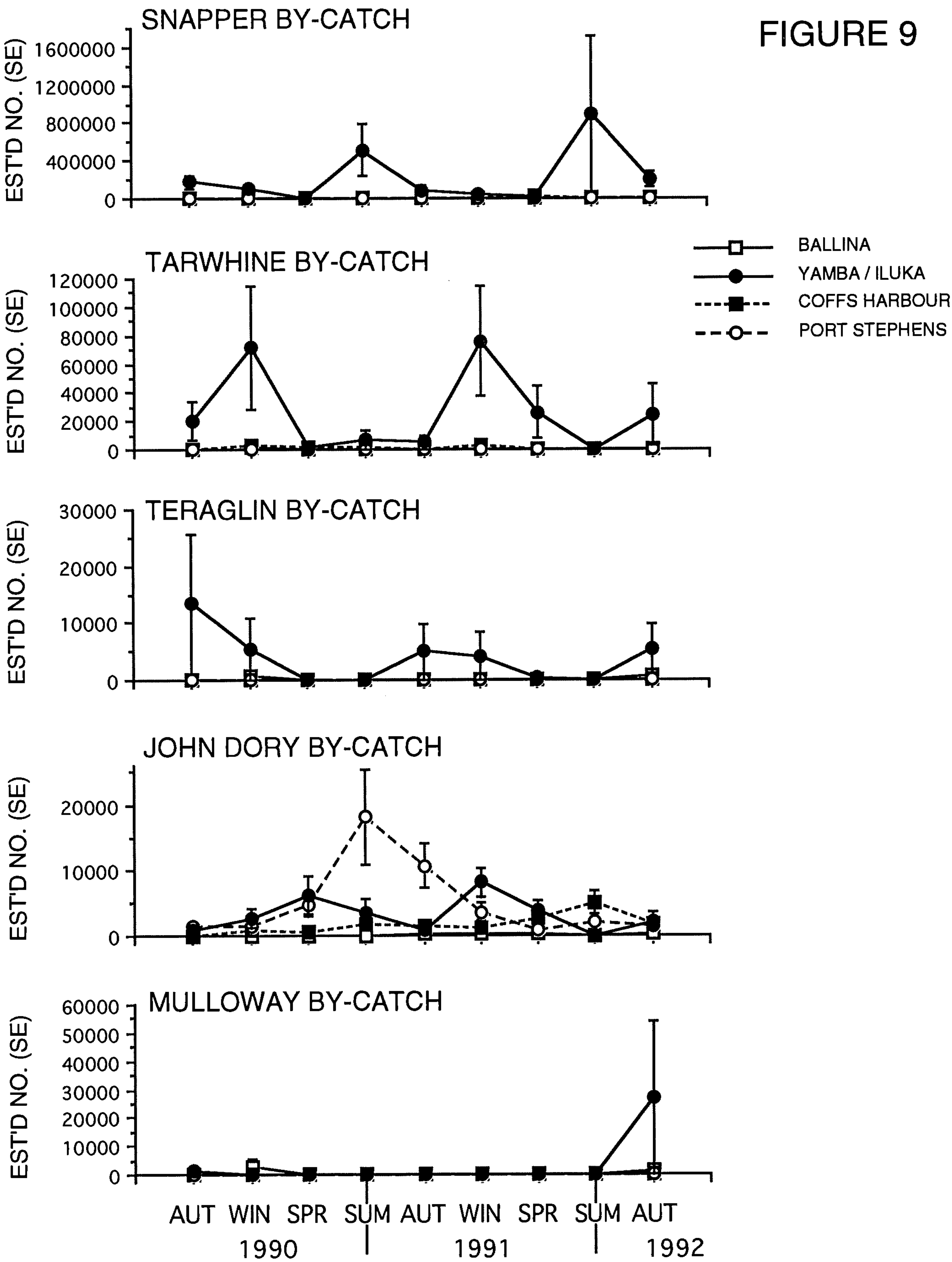

EASTERN BLUE-SPOT FLATHEAD BY-CATCH
EST'D NO. (SE)
600000
500000
400000
300000
200000
100000
0
BALLINA
YAMBA / ILUKA
COFFS HARBOUR
PORT STEPHENS
MARBLE FLATHEAD BY-CATCH
EST'D NO. (SE)
40000
30000
20000
10000
0
TIGER FLATHEAD BY-CATCH
EST'D NO. (SE)
60000
50000
40000
30000
20000
10000
0
SPIKEY FLATHEAD BY-CATCH
EST'D NO. (SE)
200000
100000
0
AUT WIN SPR SUM AUT WIN SPR SUM AUT
1990
1991
1992

FIGURE 8



LARGE-TOOTH FLOUNDER BY-CATCH
EST'D NO. (SE)
100000
80000
60000
40000
20000
0
BALLINA
YAMBA / ILUKA
COFFS HARBOUR
PORT STEPHENS
SMALL-TOOTH FLOUNDER BY-CATCH
EST'D NO. (SE)
200000
100000
0
REDFISH BY-CATCH
EST'D NO. (SE)
120000
90000
60000
30000
0
RED MULLET BY-CATCH
EST'D NO. (SE)
1000000
800000
600000
400000
200000
0
RED GURNARD BY-CATCH
EST'D NO. (SE)
20000
10000
0
AUT WIN SPR SUM AUT WIN SPR SUM AUT
1990
1991
1992

FIGURE 9



SNAPPER BY-CATCH
EST'D NO. (SE)
1600000
1200000
800000
400000
0
TARWHINE BY-CATCH
120000
100000
80000
60000
40000
20000
TERAGLIN BY-CATCH
30000
10000
JOHN DORY BY-CATCH
MULLOWAY BY-CATCH
50000
BALLINA
YAMBA / ILUKA
COFFS HARBOUR
PORT STEPHENS
AUT WIN SPR SUM AUT WIN SPR SUM AUT
1990
1991
1992

FIGURE 10

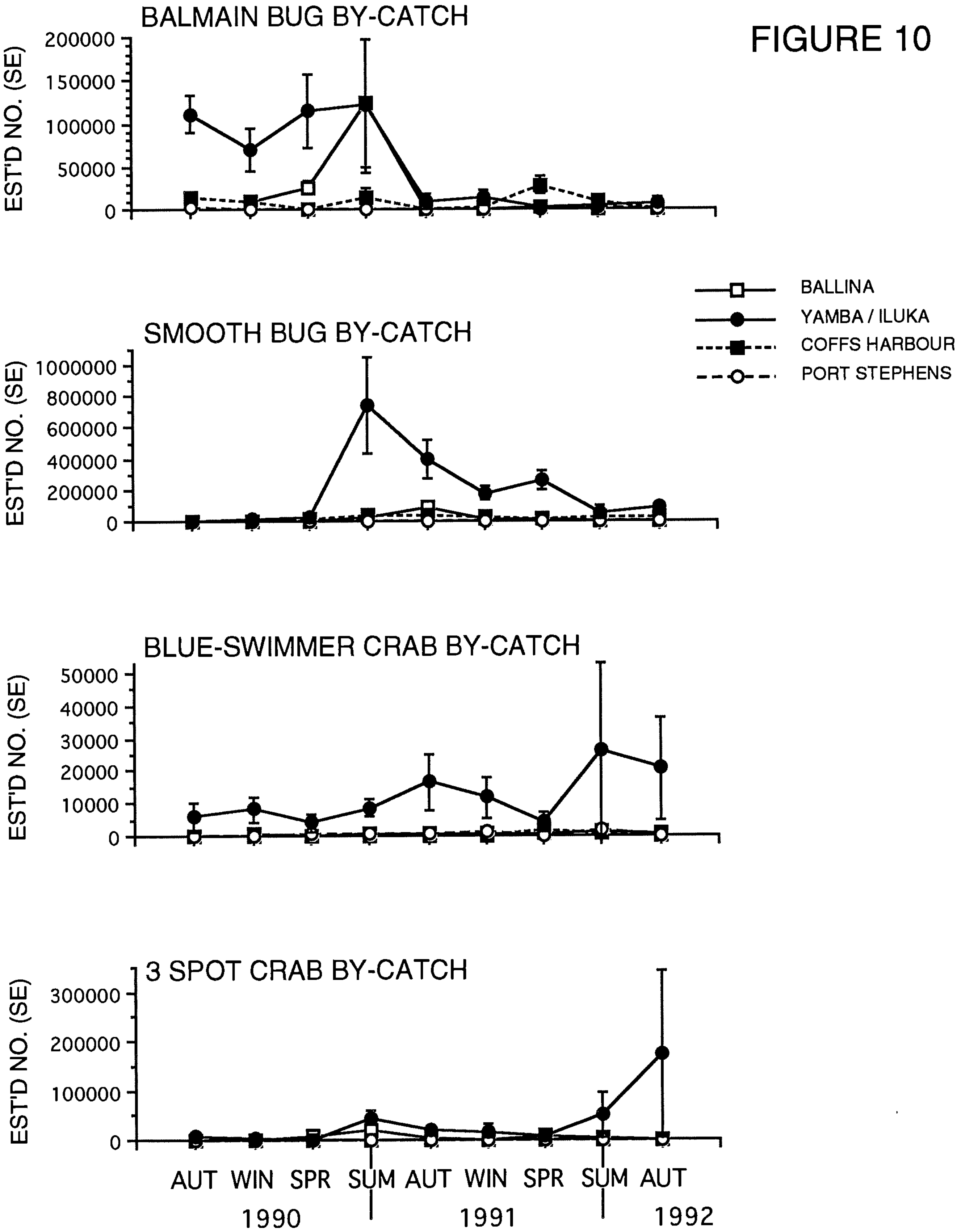

BALMAIN BUG BY-CATCH
EST'D NO. (SE)
200000
150000
100000
50000
0
BALLINA
YAMBA / ILUKA
COFFS HARBOUR
PORT STEPHENS
SMOOTH BUG BY-CATCH
EST'D NO. (SE)
1000000
800000
600000
400000
200000
0
BLUE-SWIMMER CRAB BY-CATCH
EST'D NO. (SE)
50000
40000
30000
20000
10000
0
3 SPOT CRAB BY-CATCH
EST'D NO. (SE)
300000
200000
100000
0
AUT WIN SPR SUM AUT WIN SPR SUM AUT
1990
1991
1992

FIGURE 11

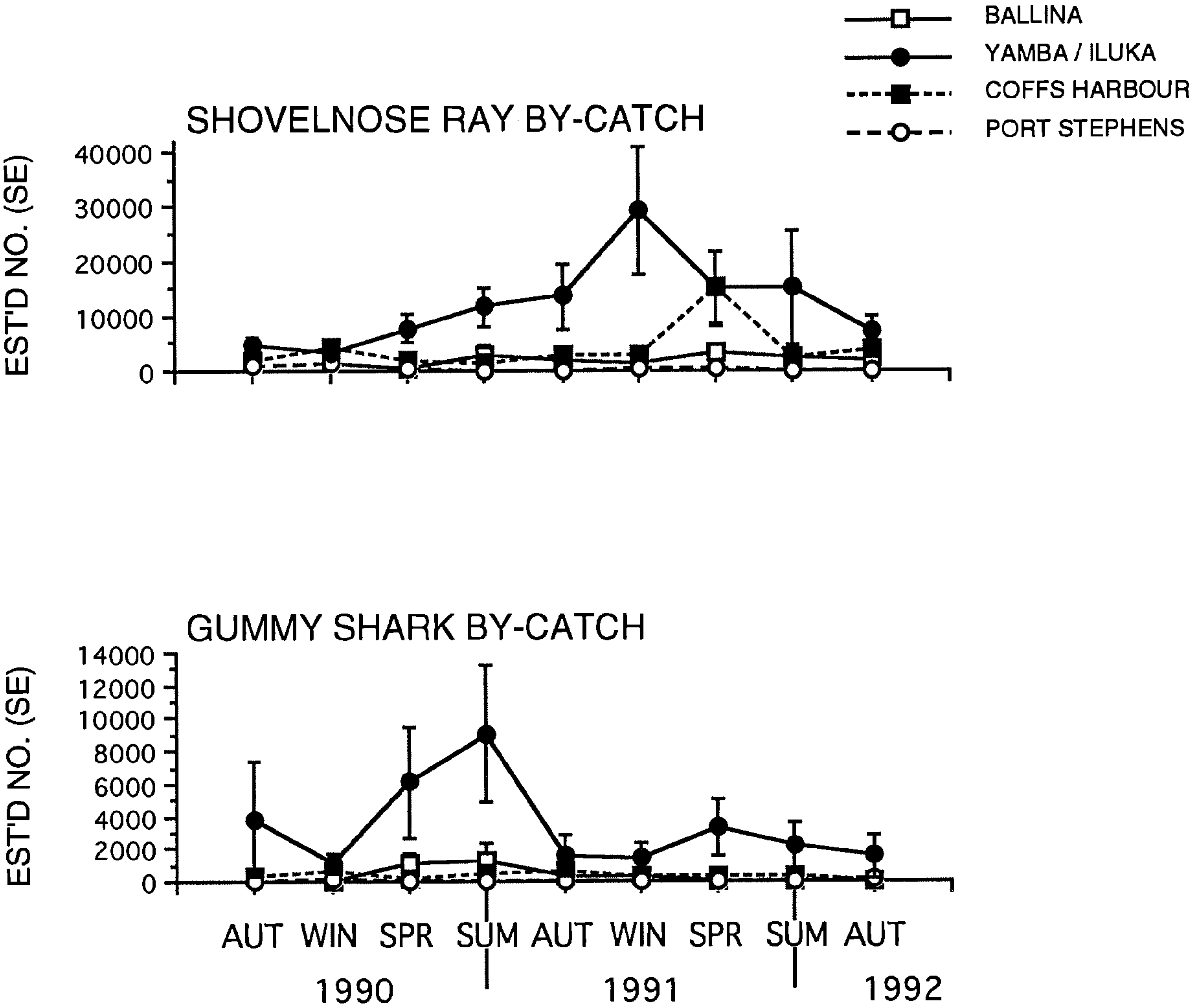

BALLINA
YAMBA / ILUKA
COFFS HARBOUR
PORT STEPHENS
SHOVELNOSE RAY BY-CATCH
EST'D NO. (SE)
40000
30000
20000
10000
0
GUMMY SHARK BY-CATCH
EST'D NO. (SE)
14000
12000
10000
8000
6000
4000
2000
0
AUT WIN SPR SUM AUT WIN SPR SUM AUT
1990
1991
1992

FIGURE 12

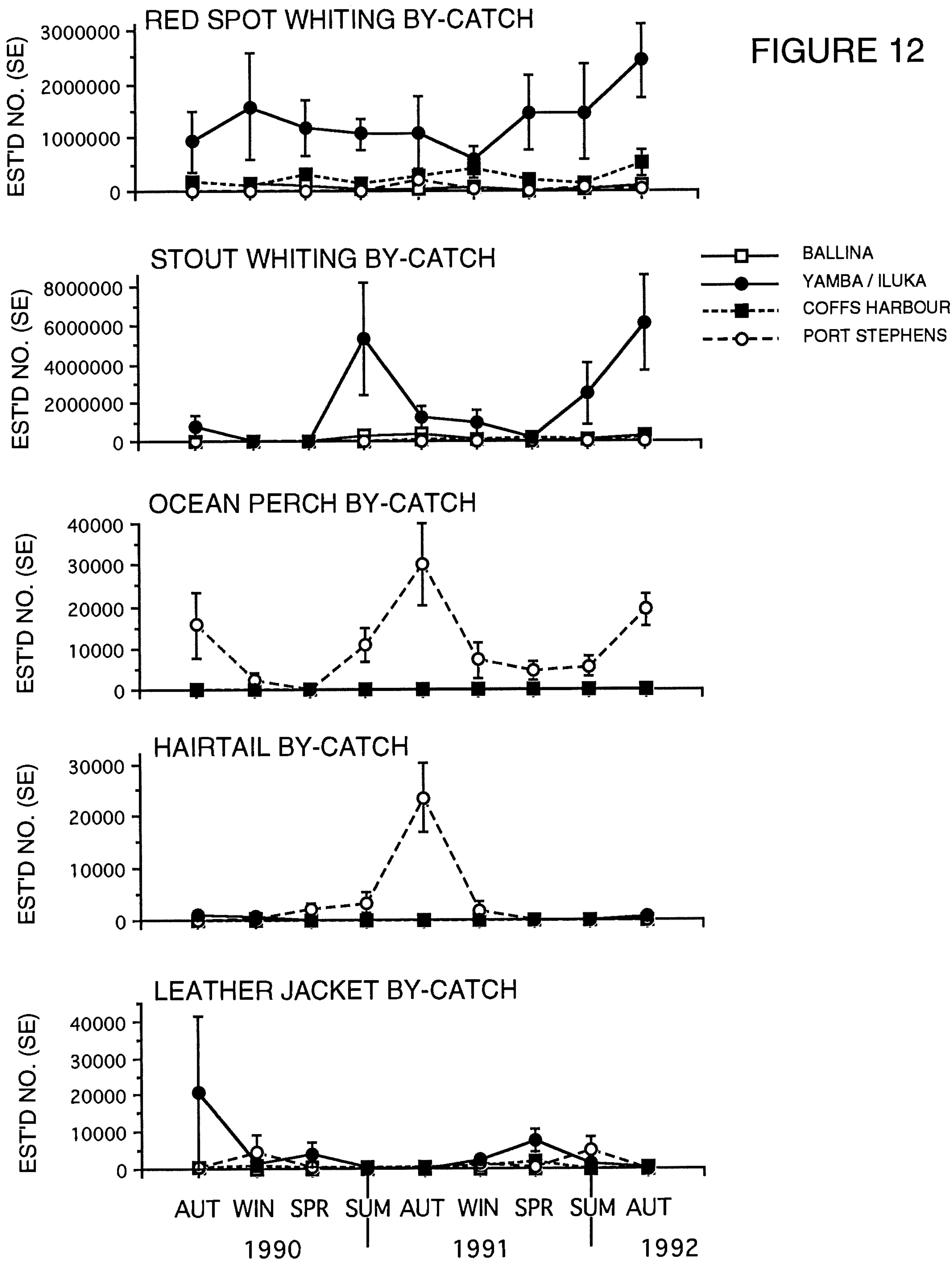
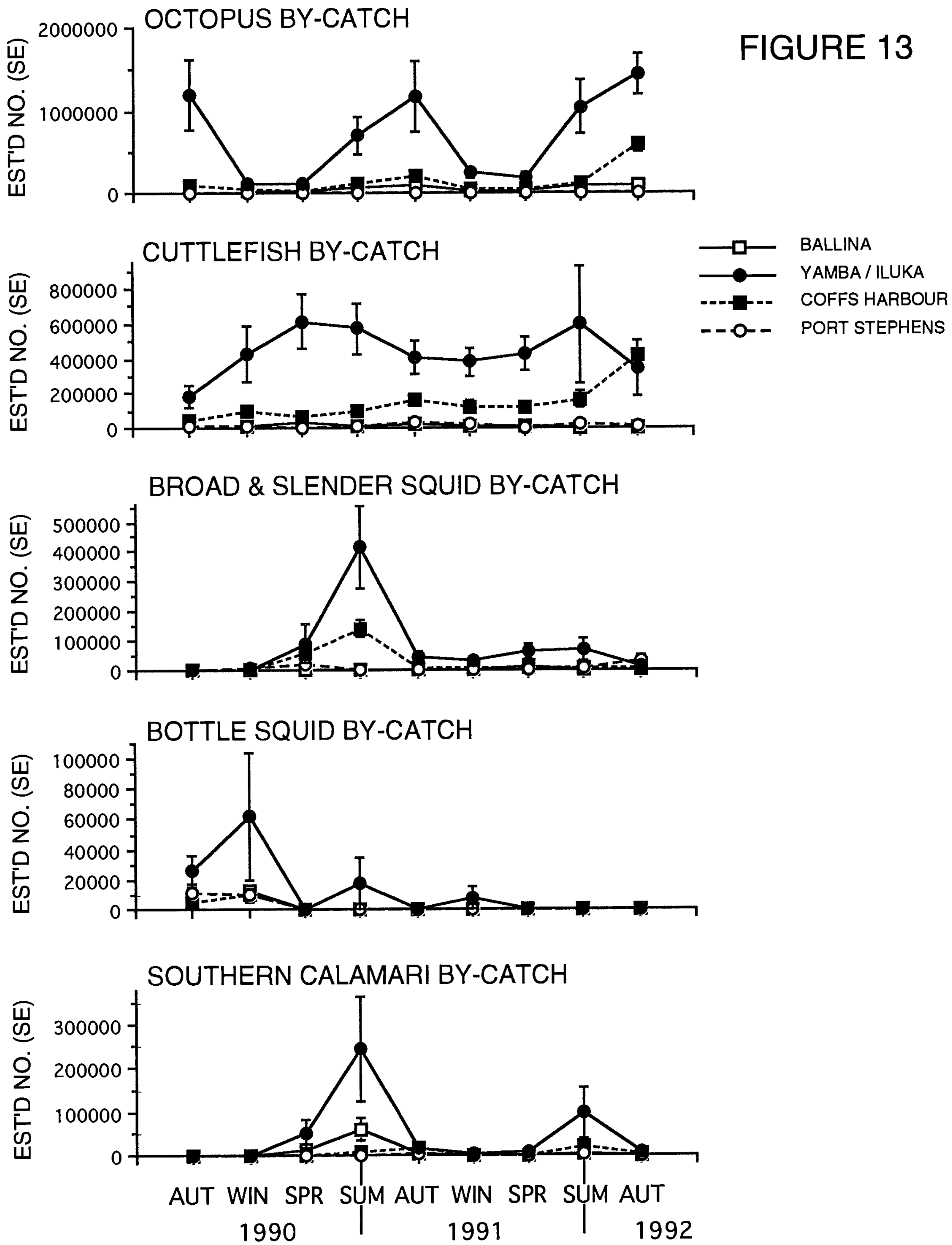

RED SPOT WHITING BY-CATCH
EST'D NO. (SE)
3000000
2000000
1000000
0
STOUT WHITING BY-CATCH
8000000
6000000
4000000
2000000
OCEAN PERCH BY-CATCH
40000
30000
20000
10000
HAIRTAIL BY-CATCH
LEATHER JACKET BY-CATCH
BALLINA
YAMBA / ILUKA
COFFS HARBOUR
PORT STEPHENS
AUT WIN SPR SUM AUT WIN SPR SUM AUT
1990
1991
1992

FIGURE 13



OCTOPUS BY-CATCH
EST'D NO. (SE)
2000000
1000000
0
CUTTLEFISH BY-CATCH
EST'D NO. (SE)
800000
600000
400000
200000
0
BROAD & SLENDER SQUID BY-CATCH
EST'D NO. (SE)
500000
400000
300000
200000
100000
0
BOTTLE SQUID BY-CATCH
EST'D NO. (SE)
100000
80000
60000
40000
20000
0
SOUTHERN CALAMARI BY-CATCH
EST'D NO. (SE)
300000
200000
100000
0
AUT WIN SPR SUM AUT WIN SPR SUM AUT
1990
1991
1992
BALLINA
YAMBA / ILUKA
COFFS HARBOUR
PORT STEPHENS

DISCUSSION OF RESULTS

Discussion of the various results from this project are provided in the attached papers (Kennelly et al, 1992 - Appendix C, Kennelly et al, 1993 - Appendix D, Andrew et al, 1991 - Appendix E, Andrew et al, 1993 - Appendix F, Broadhurst & Kennelly, in press - Appendix G, Broadhurst & Kennelly, sub. ms. - Appendix H, Kapala Cruise Reports 110 & 112 - Appendices I & J, preliminary reports produced during the project - Kennelly & Liggins, 1992 a & b - Appendices K & L and 12 summary reports sent to the 160 fishers whose vessels we sampled during the observer programmes - Appendix M).

As mentioned above, the most important sets of data from that part of the project funded by FRDC are those that deal with the extrapolated summaries of catches and by-catches by whole fleets (presented in Figs. 1 - 13 above). Because of their obvious importance and integral nature to this project and fisheries managers, I provide a summary discussion of these results below.

The data on by-catches from our various observer programmes have successfully identified the key commercially-important species which occur in many of NSW's prawn-trawl fisheries in addition to the main locations and times of their occurrence. Many species are by-caught in quite small, almost trivial quantities, whilst a handful of species stand out as quite abundant. These abundant species (and therefore key species in any assessment of the fisheries-interaction issue) include: the large numbers of snapper by-caught by the Botany Bay and Yamba/Iluka fleets in summer, the eastern blue-spot, dusky and northern sand flatheads, tarwhine, trumpeter and red spot whiting, silver trevally, large-tooth flounder and blue-swimmer crabs by-caught in Botany Bay during the trawling season, the mulloway by-caught by the Hawkesbury River prawn trawlers during non-summer months, the tarwhine by-caught by the Yamba/Iluka fleet in winter, the redfish by-caught by the Port Stephens oceanic fleet and the bream, tailor, sand whiting and dusky flathead by-caught by the Clarence River and Lake Wooloweyah prawn fleet.

Studies such as ours often assume that all discarded by-catch dies as a result of the trauma associated with capture, removal from the water and handling. Whilst our study has not examined the fate of discards, those few studies that have considered the mortality of such by-catch have concluded that a small but variable proportion of the by-catch survives. Survival of capture and discard depends on species-specific vulnerabilities and operational factors (soak time and sorting time). Our own observations have been mixed: for example, it does appear common for bream, snapper and tarwhine to swim more actively when returned to the water than mulloway and tailor and whilst we have not attempted to quantify the actual mortality of discarded by-catch in this project, it is an obvious area for any subsequent research in this field. With this in mind, we have had very positive discussions with the Hawkesbury trawlers concerning their ideas on how to quantify and possibly minimize this impact (through the practice of sorting catches in water).

Even if all the juvenile finfish discarded by prawn trawlers die, this may mean very little to subsequent stocks of commercial and recreational fisheries for these species if most of these juveniles would have died of natural causes anyway (i.e. in the absence of prawn trawling). Only by incorporating estimates of the natural mortalities of by-catch species, their ages at legal-size and estimates of mortality due to prawn trawling, can we begin to estimate any causal effects of prawn-trawl by-catch on subsequent stocks in fisheries for these species. Unfortunately, we have virtually no estimates of the natural mortalities of key by-caught finfishes and the very large research initiatives necessary to obtain such estimates (including intensive tagging programmes, size/age surveys and population modelling on a species-specific level) are clearly required in the near future.

It is also relevant to have some understanding of the relative proportion of available biomasses of different species that the by-catch from prawn trawling represents. For example, estimates of by-catches of particular species in particular areas that are in the order of hundreds of thousands of fish may be negligible if the biomass of these fish in these places are orders of magnitude larger. Unfortunately, we have no estimates of these biomasses for the relevant species and, like estimates of natural mortalities, should be the focus of future species-specific research projects.

Despite the above uncertainties however, we feel that estimates of by-catches made during our surveys and the large extrapolations that arise from these suggest that it would be unwise for NSW Fisheries and the prawn-trawl industry to ignore ways that may minimize the potentially deleterious effects of by-catch. That is, the fact that our study resulted in the publication (in scientific papers, reports, newspapers and on television) of by-catches of juvenile finfish numbering in the hundreds of thousands of fish per year per fleet, has led and probably will continue to lead to serious reactions from other commercial and recreational fisheries, despite a lack of information concerning mortalities of discards, their natural mortalities and their overall biomasses (as discussed above). The involvement of industry in developing ways to minimize any deleterious effects of by-catch is an important first step in circumventing any conflict with interacting fisheries.

The catch rates derived from our study illustrate the utility of this type of data in examining spatial and temporal patterns in the magnitudes of by-catch. The data reveal that catch rates of key commercial and recreational by-catch species vary markedly between fisheries and among species. Moreover, even for particular species, there is considerable variability in the magnitudes of by-catches across months and across years. Further, the pattern across months varies across years. There appear, therefore, to be no obvious periods within the various seasons when rates of by-catch of key species (and groups of species) are consistently higher than at other times. This is an important observation to bear in mind if spatial and temporal closures are considered as possible management options.

Other experiments we have done (offshore and in the Hawkesbury River) illustrate the very great potential for modifications to trawl gear in minimizing negative aspects of prawn-trawl by-catch (Kennelly et al., 1992 - Appendix C, Andrew et al, 1991 & 1993 - Appendices E & F, Broadhurst & Kennelly, in press, sub. ms. - Appendices G & H). Data from these experiments which assessed TEDs and square-mesh codends and our knowledge of different gears used in other parts of the world suggest that there is scope to reduce by-catch in NSW through the use of such modified gears. Whilst such modifications may reduce by-catch, there remains a question surrounding the physical trauma associated with by-catch escaping from TED or square mesh panels. For example, Briggs (1992) observed that clupeoids lost scales during escape through netting. In addition, fish may also damage fins and gills during movement through square meshes, contributing to overall stress and possibly post-trawl mortality. In two of the few studies which have examined such mortalities, DeAlteris and Reifsteck (in press) found negligible mortalities of fishes that had passed through square-mesh panels and Main and Sangster (1988) showed that fish passing through square-meshes had greater rates of survival than those passing through diamond-meshes. Obviously, any future research involving modifications to trawl gears should include an assessment of such effects. We feel that it is important that industry be actively involved in any future research on alternative gears so that (i) they are seen to be the driving force in addressing any conflicts that may come from our publication of large by-catches of finfishes and (ii) we can fully utilize industry's unique practical knowledge of the relevant gear technology.

IMPLICATIONS AND RECOMMENDATIONS

This study involved identifying and quantifying the by-catch of estuarine and oceanic prawn trawlers in NSW. We feel that the project has been a marked success as we now know the appropriate spatial and temporal scales of this issue, which is the first and most vital pre-requisite for eventually solving the issue. The question most asked by managers, prawn-trawl fishers and recreational fishers is whether this project has determined if, in fact, prawn-trawl by-catch **is a problem**. There are two basic answers to that question, depending on the point of view of whoever is asking it.

If one wishes to know whether the prawn-trawl by-catch of hundreds of thousands of juveniles of species that, in a few years are targeted in other commercial and recreational fisheries **has an effect** on the sizes of those subsequent stocks, then the short answer is "we don't know". This is because we don't have enough information on those various species (snapper, bream, mulloway, the flatheads, the whitings, flounders, blue-swimmer crabs etc.) with respect to their rates of natural mortalities, their survival after trawling and discarding nor their overall biomasses (see above points in Discussion). Without these details on individual species, it is impossible to determine what the impact of trawling will have on their subsequent stocks: i.e. it could be as much as hundreds of thousands of individuals being removed from the exploitable stock or it could be as little as zero.

If, however, one wishes to know whether the prawn-trawl by-catch of hundreds of thousands of juveniles of species that, in a few years are targeted in other commercial and recreational fisheries **is a problem to the community of NSW**, then the short answer to that is "yes", simply because recreational fishers, other commercial fishers and members of the general public **think** that it is a problem. Without scientific information to say that it **isn't** a problem (see the conclusion of "we don't know" in the above paragraph), there is no scientific basis upon which one can attempt to change the thinking of those people who percieve this issue as a problem. All one can hope to do is illustrate the information as best as possible, pointing out the necessity that before any real appreciation of the size of the problem can be made, one must take account of the unknown rates of trawl mortalities, natural mortalities and overall biomasses.

Before the reader gets too disappointed, the above paragraphs do not leave the conclusions from this project as trivial nor as uncertain as one might first think. This project has identified the size, nature, spatial and temporal variabilities and the species involved in this large and complex issue. This is a huge improvement on what was known before the project began. For example, we now have good information on the best way to go about examining various species-specific interactions in many of NSW's prawn-trawl fisheries. Further, the identity of many of these key interactions is now available: i.e. the large numbers of snapper by-caught by the Botany Bay and Yamba/Iluka fleets in summer, the eastern blue-spot, dusky and northern sand flatheads, tarwhine, trumpeter and red spot whiting, silver trevally, large-tooth flounder and blue-swimmer crabs by-caught in Botany Bay during the trawling season, the mulloway by-caught by the Hawkesbury River prawn trawlers during non-summer months, the tarwhine by-caught by the Yamba/Iluka fleet in winter, the redfish by-caught by the Port Stephens oceanic fleet and the bream, tailor, sand whiting and dusky flathead by-caught by the Clarence River and Lake Wooloweyah prawn fleet.

Whether prawn trawling by-catch of juvenile finfishes in large numbers is a real or merely a perceived problem, we **do** know that it would be a particularly good idea (from the point of view of prawn-trawl fishers, interacting fishers and the public as a whole) to try to reduce it as much as possible. Preliminary work done in this area during this project has shown the relative merits of the main management tools available.

Large spatial and temporal variabilities in by-catches of the various key species makes the management of the by-catch issue using fixed spatial and temporal closures very difficult. Such management strategies could, however, be useful on a flexible basis where ongoing monitoring determines where and when various fisheries should be closed. This strategy has a large cost, however, as such monitoring programmes (which ideally would be fishery-independent) are expensive and any option that reduces prawn trawling may lead to reduced catches and sales of prawns. Another closure strategy that could also be considered are large-scale closures of whole fisheries. Such a management measure would remove any problems of trying to predict appropriate closures given large spatial and temporal variabilites in by-catches of key species and would therefore be appropriate for any fisheries where many key by-catch species occur in large numbers (a possible candidate detected in this project would be the Botany Bay prawn-trawl fishery). This strategy does, however, have an enormous cost equal to the value of the particular fishery in terms of fishers' incomes and the availability of prawns to the public. (It should be borne in mind, however, that for the Botany Bay fishery in particular, such a cost may not be relatively large in terms of overall prawn production and the yield per recruit of king prawns in NSW. Such a conclusion falls outside the boundaries of this project but is being addressed by an ancillary project at FRI.)

The other suite of management strategies for reducing prawn-trawl by-catch is the preferred option in the majority of the world's prawn-trawl fisheries and the preferred solution recommended here. The most obvious management strategy that arises whenever people discuss prawn-trawl by-catch of unwanted juvenile finfish concerns gear selectivity and fishing practices. Modifications to prawn-trawl nets, codends, sweeps and fishing practices are all alternatives that have been, and will continue to be invoked throughout the world as means for solving by-catch problems. Work done in other countries and in NSW indicate that it is possible to develop modifications to trawl gear and fishing practices that will negate a great deal of the capture of by-caught finfish but more work needs to be done to assess the fate of fish that escape from modified trawls (in terms of post-trawl trauma/damage). Work already done in this project has shown the very real potential of TED (Trash Elimination Device) panels, square-mesh panels and varying sweep lengths as means for reducing the incidental capture of finfish. Unfortunately, however, this work represents the majority of the studies concerning by-catch-reducing gears in Australia and clearly more research along these lines is required. As noted in a recent review of the Australian literature concerning trawl by-catch (Kennelly, in press - Appendix B), most work has concentrated on describing the problems of trawl by-catch via quantifications of the species and abundances taken in various prawn fisheries through surveys using onboard observers and research vessels. In Australia, we have been quite slow to move onto the next step in addressing this issue which is to examine various management strategies which may reduce by-catch.

Through the various attached papers, reports and summaries, this project supplied prawn trawlers with uncompromising information on levels of by-catches. Surprisingly, however, rather than cause long-term arguments with prawn-trawl fishers, this information has led to these fishers demanding research on new gear designs that will reduce their by-catch of juvenile finfish yet maintain existing catches of prawns. They have seen that any other alternative to reduce by-catches may involve spatial and/or temporal closures to trawling and therefore reduced catches of prawns. We have spent some time with trawl fishers describing and demonstrating various methods used overseas to reduce by-catches in addition to presentations of our own preliminary work. This has resulted in substantial support from these groups and even several new ideas on how to modify these designs further so that they can be applied in NSW's fisheries.

The other side of the conflict equation (commercial finfish fishers and recreational fishing groups) have complained about prawn-trawl by-catch for many years and the presentation of our data on large by-catches (in some places and seasons numbering in the hundreds of thousands of juvenile fish) further inflamed this issue. Rather than leave the problem there, however, we have successfully demonstrated to these groups that solutions to this problem are possible through more selective trawl designs without extensive spatial and temporal closures to prawn trawling. The user groups involved in the prawn-trawl by-catch interaction (encompassing most fishers in NSW) have seen that research into, and implemention of, by-catch reducing gears and practices by prawn trawlers should be a win-win situation for all. This type of research has effectively become one of the few areas of agreement between NSW's commercial and recreational fishing sectors and it is rather ironic that it concerns the same issue which has been at the forefront of their conflicts in recent years.

The conclusions outlined above have resulted in our application to FRDC to fund a 3 year project to develop by-catch reducing fishing gears and practices for NSW's various prawn-trawl fisheries. At the time of writing this final report, we have just begun that new project (FRDC project No. 93/180).

ACKNOWLEDGEMENTS

Many people have contributed to the success of this project. In particular, I thank Prof. Tony Underwood and Drs Derek Staples and Keith Sainsbury for forming the external steering committee for this project. Their substantial inputs at several meetings throughout the project, their comments on drafts of papers and reports and their general enthusiasm and support for this research and the project staff ensured the successful completion of the work. Without Dr Bob Kearney's initial direction and overall supervision, this project would not have occurred as he initated the project and his continued support and encouragement throughout the past 3 years has seen that direction maintained and successfully completed. Drs Neil Andrew and Julian Pepperell were involved in the project during its first year and supplied numerous inputs into the early stages of the research as well as completing the initial literature review. Ron West, Steve Montgomery, Dennis Reid and Geoff Gordon have supplied many comments and constructive advice into this research and drafts of papers. The relevant fisheries managers, Andrew Bartleet, Laurie Derwent, Steve Dunn and John Diplock have all had input into the type and form of information required from the project for use by management and industry. Max Beatson, Marty Baxter, Andrew Zybenco, John Stewart, Craig Blount and Penny Brett assisted with various aspects of the field work, often under difficult conditions.

The greatest accolades for this project, however, must go to the two groups of people without whom the project would have failed: the prawn-trawl fishers of NSW and the project staff. At the International Conference on By-catch in the Shrimp Industry held in Florida last year the following point was made many times by fishermen, scientists and managers from all around the world: that this project enjoyed a level of industry-participation and good-will that is the equal of any such project in the world. We believe that this conclusion from this very high-level conference speaks volumes for the attitude and courtesy of the 160 different prawn trawlermen we worked with over the past 3 years and we thank them and their various representatives for their continued support.

The final accolades must go to the project staff. Geoff Liggins joined us for the latter 2 years of the project and achieved remarkable results in designing and handling the various complex databases produced from the field work. He also produced quality summaries of the complex datasets in short time and contributed greatly to statistical analyses and the generation of reports. Ken Graham, Juta Wildforster and the crew of the FRV Kapala did a good job in completing a large-scale survey, often in difficult conditions and Ken also supplied substantial input and advice into the rest of the project. The Technical Assistants on the project, Jeff Nemec, Keith Chilcott and Mark Bradley collected high quality data from a variety of vessels in many fisheries usually in quite difficult and sometimes dangerous conditions. Their expertise, attention to detail and personalities ensured that the project presented a professional yet friendly face to industry. Jeff and Keith also had to work relatively independently from the rest of the staff, stationed on the far north coast of NSW and proved their value as reliable and dependable field technicians. Finally I would like to acknowledge the person who did most to see the successful completion of most aspects of this project, the Senior Technical Officer on the project, Matt Broadhurst who, from the first day of the research until the last, formed the backbone of the project.

- Dr Steve Kennelly (Senior Research Scientist and Principal Investigator)

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Kennelly, S.J. and G.W. Liggins, 1992 (Appendix L). Preliminary report on the the by-catch of prawn trawling in the Hawkesbury River. Internal publication.

N.B. Many other publications will come from this project. Already drafts of 7 additional manuscripts are under preparation by Kennelly, Liggins and Broadhurst.

APPENDICES

APPENDIX A

The by-catch of shrimp trawl fisheries.

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THE BY-CATCH OF SHRIMP TRAWL FISHERIES

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ABSTRACT Wherever shrimp trawling occurs concern is expressed about the wastage and potential impacts of catching and discarding large quantities of incidentally caught organisms (by-catch). Here we draw together the literature on shrimp by-catch and provide an assessment of the state of research.

Variability in quantity and composition of by-catch through time and space is large and methods for quantifying shrimp by-catch are mostly imprecise. Consequently, estimates of regional, country and world by-catch are poor. Although a proportion of by-catch is utilised, the majority is discarded at sea. The main obstruction to greater utilisation of by-catch is economic; in most cases target shrimp species are more valuable than the often much greater quantities of small fin-fish caught. Avoidance of by-catch through selective trawl designs is considered a high priority in many fisheries, particularly where the incidental capture of turtles is controversial.

Few studies have attempted to analyse the consequences of the shrimp trawl fisheries on populations of species caught as by-catch, especially those species exploited by other fisheries. The incidental catch of the world's shrimp fisheries is enormous and the potential conflicts that this by-catch generates will become an increasingly important issue for fisheries managers. Gaps in our current knowledge of by-catch are highlighted and possible directions for future research are discussed.

INTRODUCTION

Shrimp trawl fisheries make an important contribution to the total catch of the world's marine fisheries. In 1986, the total global landings of shrimp was 1.95 million tonnes (FAO, 1988). Excluding *Acetes* spp and other sergestids, which are not normally caught by trawling, the total world catch of shrimps was 1.72 million tonnes (FAO, 1988) and worth billions of dollars. Although shrimps such as pandalids are fished in cold temperate and sub-polar waters such as Canada and the Wadden Sea (Berghahn, 1990; Hudon, 1990), most shrimp are caught in tropical and subtropical regions, particularly off the coasts of India, central America and southeast Asia (Wickens, 1976). Penaeids constitute the greater part of catches of shrimps in tropical and sub-temperate regions.

The management of shrimp fisheries is complicated by the life-history features of this group (see references in Wickens, 1976; Edwards, 1978; Gulland & Rothschild, 1984). Many of the species caught by trawling, particularly penaeids, spend the early part of their life cycles in sheltered waters, such as estuaries, and move offshore later in their lives. Species of shrimps with this life history are often caught during both their estuarine and oceanic phases. Throughout their lives, shrimps live in areas of the sea bed with a great diversity and abundance of other invertebrates and fishes. Many of these sympatric organisms are caught in shrimp trawls. Since the early 1980s there has been an increasing awareness of the interactive nature of shrimp trawl fisheries. In many places where there are large fisheries, such as in the Gulf of Mexico, there is concern about the potential ecological impacts of catching and discarding large quantities of organisms caught incidentally (by-catch), particularly fin-fishes. In the great majority of the world's shrimp fisheries more by-catch is caught than shrimps. The resultant mortality and wastage of the discarded component of this by-catch may be readily observed.

For the purposes of this review, the term 'by-catch' is defined, after Saila (1983), as "that part of the gross catch which is captured incidentally to the species towards which there is directed effort". Some, all or none of the by-catch may be discarded. 'Discards' or 'discarded catch' refer to that part of a catch that is thrown back into the sea. The discarded catch is typically made up of by-catch, but juvenile or undersize shrimps may also be discarded. Although the by-catch from shrimp trawling is the principal concern of this review, other trawl fisheries are referred to when studies shed light on broader issues. The term 'shrimp' is used throughout for consistency and denotes any species of shrimp or prawn.

One of the primary causes for concern about by-catch in shrimp fisheries is the effect of trawling on stocks of commercially and recreationally important fin-fishes. This concern has been reflected in an increase in the number of papers in scientific journals and articles in commercial and recreational fisheries publications (e.g. Gordon, 1988; Anonymous, 1989; Foldren, 1989; Cooper, 1990; Ohaus, 1990). The effects of trawling on species caught as by-catch and the communities they come from are potentially complex and range from the direct mortality of individuals caught to more indirect and subtle impacts on benthic community structure.

The literature on shrimp trawl by-catch indicates that research into the subject has been focused on several relatively discrete topics and these are reflected in the organisation of this review. Most studies have been concerned with estimating the quantity and composition of by-catch caught in regional fisheries. Studies of this type have quantified the rate at which shrimp trawlers take, as by-catch, fish of species which are caught in other fisheries. Few studies have gone beyond description of what and how much by-catch is caught and attempted to estimate the effect of losses to shrimp trawling on the stocks of commercially important species. These studies range from empirical descriptions of mortality of by-catch organisms to theoretical discussions of the likely impacts of changed energy pathways in benthic systems.

Many studies have sought ways to minimise by-catch, particularly turtles and fin-fishes. These studies usually achieve this goal through changes in trawl design that increase the ratio of shrimps to by-catch caught. Conversely, there have been many projects aimed at better use of by-catch through expansion into non-traditional products and increased industrial usage. The extent to which by-catch is seen as something to minimise or utilise varies among fisheries. It is clear that even relatively simple questions are hard to answer because of the complexities and logistic constraints on research.

Examination of the literature on the by-catch of shrimp trawling revealed surprisingly few data. As in other fields of study where data are scarce and difficult to obtain, many estimates are derived from other estimates, often without the qualifications made by the original authors. This practice has led to generalisations in the literature being derived from few data. A large proportion of studies are reported only in the 'grey' literature that is common in fisheries science (Wilbur, 1990) and were therefore difficult to obtain. While writing this review, it became increasingly clear that citation of only the published literature and completeness were incompatible. Because we have restricted ourselves largely to the published literature there is no doubt that we have excluded some research, particularly that from regions where little research is published. A further complication in writing was that, in some instances, published papers had to be cited as if they were the primary reference for a piece of research, when in fact they were secondary to an earlier unpublished source. We could see no way to avoid this problem. As awareness of the by-catch of shrimp trawl fisheries increases, a large and readily available literature will be an essential currency for resolving issues.

AMOUNT AND COMPOSITION OF BY-CATCH

ESTIMATES OF REGIONAL BY-CATCH

By a process of observation and rough extrapolation, the volume of the by-catch from the world's shrimp fisheries has become apparent. Estimates of the total by-catch of the world's shrimp fisheries in the late 1970s ranged from 3 to 21 million tonnes per year (Slavin, 1982; Gulland & Rothschild, 1984). These estimates were reached by a variety of methods, and differ greatly in robustness. There have been few revisions of regional and world by-catch statistics since the early 1980s.

Slavin (1982) 'conservatively' estimated that 3–5 million tonnes of by-catch were discarded by the world's shrimp fisheries per year. This estimate was made from data from several sources, including the US National Academy of Science, a 1975 FAO round-table estimate and a 1980 FAO review. The estimates used by Slavin were based on shrimp catches and assumed that by-catch and shrimps were caught at ratios of 5:1 in temperate and subtropical regions and 10:1 in the tropics (see also Juhl & Drummond, 1977; Allsopp, 1982; Caddy, 1982; Cushing, 1984a).

Gulland & Rothschild (1984) have presented 'first approximations' of the quantity of discards from a number of penaeid shrimp fisheries. They estimated that approximately 2.7 million tonnes of fin-fish by-catch was caught worldwide in 1979, of which 1.4 million tonnes were discarded. The regional estimates from which this total was calculated came from a number of sources and years. Several countries and/or relatively large shrimp fisheries, including those of the US Pacific northwest, Gulf of California, Malaysia, Philippines, Japan, Korea, Spain, and Venezuela were not included in the above estimates.

Since the above estimates of regional and world by-catch were made, there has been an overall increase in the catch of shrimps and it is not unreasonable

TABLE I

Estimates of the by-catch of shrimp fisheries from those countries producing more than 5000 tonnes per year. Shrimp catch statistics are for 1986 (FAO, 1988). All weights are in tonnes (× 1000). A range of by-catch (B–C) is given, based on catch ratios of 5:1 and 10:1. Where known, a range of the quantity discarded is also given, based on the estimated percentage discarded of the cited authors. N/A indicates that no estimates were found for this country

Country	Shrimp catch	5:1 B–C: Shrimp	10:1 B–C: Shrimp	Weight Discarded	Reference
USA	183	915	1830	915–1830	Gulland & Rothschild (1984)
Mexico	73	365	730	365–730	Gulland & Rothschild (1984)
El Salvador	7.0	35	70	N/A	
Costa Rica	8.7	43.5	87	N/A	
Canada	12.8	64	128	N/A	
Honduras	5.8	29	58	N/A	
Panama	13.1	65.5	131	N/A	
Argentina	7.0	35	70	N/A	
Brazil	68.6	343	686	319–638	Jones & Villegas (1980)
Columbia	6.2	31	62	N/A	
Guyanas	6.1	30.5	61	28.3–56.7	Jones & Villegas (1980)
Ecuador	52.8	264	528	N/A	
Venezuela	5.5	27.5	55	N/A	
Cameroon	12.8	64	128	N/A	
Madagascar	7.0	35	70	N/A	
Mozambique	5.9	29.5	59	28–56	Pelgrom & Sulemane (1982)
Senegal	5.5	27.5	55	13.8–27	Gulland & Rothschild (1984)
Australia	20.1	100.5	201	100.5–201	Harris & Poiner (1990)
Burma	6.9	34.5	69	N/A	

China	24.9	124.5	249	N/A	
Hong Kong	15.8	79	158	N/A	
India	214.7	1073.5	2147	16–32	Silas *et al.* (1984)
Indonesia	149	747	1490	15–29.8	Unar & Naamin (1984)
Indon/Arafura	4.5	22.5	45	22.5–45	Unar & Naamin (1984)
Iran	5.1	25.5	51	24–48	Van Zalinge (1984)
Japan	47.9	239.5	479	N/A	
Korea Rep.	29.8	149	298	N/A	
Macau	5	25	50	N/A	
Malaysia	62.2	311	622	177–354[a]	Kong (1982)
Pakistan	26.8	134	268	N/A	
Philippines	53.9	269.5	539	N/A	
Saudi Arabia	5.4	27	54	25–50	Van Zalinge (1984)
Thailand	105.1	525.5	1051	5–10	Saisithi (1982)
Vietnam	55.4	277	554	N/A	
Asia (other)	102.3	511.5	1023	N/A	
Denmark	13.5	67.5	135	N/A	
Faroe Is.	11	55	110	N/A	
German F. R.	17	85	170	N/A	
Greenland	64.1	320.5	641	N/A	
Iceland	35.8	179	358	N/A	
Italy	14.6	73	146	N/A	
Norway	57.4	287	574	N/A	
Spain	19.4	97	194	N/A	
Totals (mt)	1648.4	8244	16484	N/A	

[a] Malaysian by-catch estimated from 1979 data. It was expected that usage would have greatly increased during the next decade (Kong, 1982).

to assume that by-catch has also increased. The published data from which the above estimates of by-catch were derived have not been greatly expanded or refined since the early 1980's. In Table I we have used 1986 FAO catch statistics (FAO, 1988) to provide an updated and expanded estimate of the by-catch of the world's shrimp fisheries. We do so in the spirit of the above extrapolations, that is, to give an indication of the likely magnitude of by-catch rather than to provide a robust estimate of the world's shrimp by-catch. Such collations are useful only in drawing attention to the magnitude of the world's shrimp by-catch; they cannot provide information at the resolution necessary for effective management. They do not, for instance, provide data with regard to individual species, nor to changes in by-catch through time, nor in different areas of a fishery.

In compiling Table I, we have only included shrimps caught in fisheries in which trawling is the only or predominant method of capture. This criterion means that we have excluded krill, *Acetes* and other sergestids. Countries that harvested less than 5000 tonnes of shrimp in 1986 were not included in the table. Collectively, these countries account for less than 6% of the total catch. In estimating by-catch, we have used the oft-cited and little-tested assumptions of 5:1 and 10:1 catch ratios as reasonable bounds. We are mindful of the dangers of perpetuating these ratios when there is relatively little evidence to support their generality. Estimates of the by-catch for each country are therefore presented as a range. Published estimates (with associated error statistics) of the by-catch: shrimp catch ratios for whole countries are virtually nonexistent. Based on the extrapolations in Table I, the total by-catch of the world's shrimp fisheries may be as much as 16.5 million tonnes per year. India has the greatest catch of shrimps in the world and an associated by-catch that could be as large as 2.1 million tonnes.

As an indication of the relative size of the by-catch of shrimp trawl fisheries, the total nominal world catch of all marine species (including fishes, molluscs, etc.) in 1986 was 80.4 million tonnes, of which 69.2 million tonnes were marine fishes, 3.6 million tonnes were crustaceans and 6.1 million tonnes were molluscs (FAO, 1988). Clearly, the by-catch of shrimp fisheries is large and warrants considerable attention from fisheries researchers and managers.

DISCARDING PRACTICES

The proportion of by-catch that is discarded has been reported in only a few instances (Table I) and may change with fishing practice and economic forces (see Variability in by-catch (p. 533) and Utilisation of By-catch (p. 541). In some countries, e.g. The United States (Keiser, 1977a, b; Pellegrin, 1982; Watts & Pellegrin, 1982), Germany (Berghahn, 1990) and Australia (Pender & Willing, 1989; Harris & Poiner, 1990; Ramm, Pender, Willing & Buckworth, 1990), there is relatively little demand for by-catch species and almost all is discarded. The amount of by-catch retained differs among regions in some countries, depending on the nature of the fisheries, e.g. Indonesia (Unar & Naamin, 1984; Chong, Dwiponggo, Ilyas & Martosubroto, 1987). In others, relatively little is discarded, e.g. India (George, Suseelan & Balan, 1981; Silas, George & Jacob, 1984) and Guyana (Grantham, 1980).

The proportion of by-catch discarded by shrimp trawlers is dependent on many factors, most importantly, the relative commercial value of shrimps and by-catch. Very little by-catch is discarded in small artisanal fisheries, but in more mechanised fisheries, boats remain at sea for longer periods and there is often a greater differential in the price of shrimps and by-catch. A greater proportion of the by-catch is discarded in these latter fisheries (Gulland & Rothschild, 1984). Within a fishery, discarding practices may also change with time. For example, increased mechanisation and the use of larger vessels in the Indian shrimp fleets has meant that fishing trips have become longer and more of the by-catch is discarded than previously because of shortage of cold-storage space (George *et al.*, 1981; Silas *et al.*, 1984; Gordon, 1988; Sivasubramaniam, 1990). In some fisheries, undersize shrimps are discarded and may constitute a significant proportion of the discarded catch, e.g. Gulf of Mexico (Berry & Benton, 1969; Baxter, 1973; Klima, Sheridan, Baxter & Patella 1986; Klima *et al.*, 1987).

VARIABILITY IN BY-CATCH

A recurrent feature of studies of by-catch is the great variability observed in the amount of by-catch caught by shrimp trawlers (e.g. Cummins & Jones, 1973; Keiser, 1977a, b; Furnell, 1982; Perez-Mellado, Romero, Young & Findley, 1982; Harris & Poiner, 1990; Ramm *et al.*, 1990; Watson, Dredge & Mayer, 1990). In the Gulf of Mexico, perhaps the most studied of the world's shrimp fisheries, the diversity of by-catch has been well documented. The relative abundance of species caught as by-catch in the Gulf of Mexico varies enormously among regions, habitats, depths and seasons (e.g. Seidel, 1975; Seidel & Watson, 1978; Moore, Blusher & Trent, 1981; Bryan, Cody & Matlock, 1982; Pellegrin, 1982; Sheridan, Browder & Powers, 1984; Gutherz & Pellegrin, 1988; see Rothschild & Brunenmeister 1984 for review). A major factor in causing this sort of variability is seasonal migration of species across trawling grounds. The red snapper (*Lutjanus campechanus*) in the Gulf of Mexico, for example, migrates offshore in the colder months and these movements are reflected in catches by commercial shrimp trawlers (Gutherz & Pellegrin, 1988).

Not only does the species composition of by-catch differ among studies, but the amount of by-catch can change dramatically. Watts & Pellegrin (1982) compared the catch rates of fin-fishes from several studies off Texas and Louisiana and found very large differences among trawls within and among samples. Estimates of the rate of catch of fin-fishes (reported as pounds/hour) varied from 92.1 (SD = 94.5, $n = 193$) in deep water (> 10fm) off Texas in 1973–74 to 474.6 ($\pm$ 689.9, $n = 23$) in shallow depths off Louisiana. Despite the large variability within a sample, Watts & Pellegrin were able to establish significant differences in the amount of by-catch caught on shallow and deep grounds.

In their discussion of the shrimp fishery of the northern Gulf of Mexico, Rothschild & Brunenmeister (1984) noted that fish:shrimp ratios calculated for the fishery between 1950 and 1980 ranged between 2:1 and 14:1. They went on to conclude that, even though a relatively large number of studies had been done in the Gulf of Mexico, "...little is known about the composition of the by-catch of the U.S. shrimp fishery in the Gulf of Mexico, and that systematic sampling will be required to improve our knowledge of this aspect of the fishery" (Rothschild & Brunenmeister, 1984, p. 166).

The northern prawn fishery in Australia operates over a large area, encompassing the Gulf of Carpentaria and Arafura and Timor Seas. The by-catch of this fishery has been described in some detail and is composed of distinct assemblages of species over a large geographic area (Rainer & Munro, 1982; Rainer, 1984; Poiner & Harris, 1986; Ramm *et al.*, 1990; Blaber, Brewer, Salini & Kerr, 1990). Overlaying these broad patterns, the distributions of other species were more related to depth (*op. cit.*). Species in the genus *Nemipterus*, for example, were distributed in all parts of the fishery, but individual species were often restricted to depth zones (Ramm *et al.*, 1990). Large-scale surveys by research vessels of species of fishes and invertebrates caught as by-catch have also revealed broad patterns in the occurrence and abundance of species caught as by-catch in shrimp fisheries. These patterns are apparently independent of the fishery, e.g. in Queensland (Cannon, Goedon & Campbell, 1987; Watson & Goedon, 1989; Watson *et al.*, 1990) and New South Wales, Australia (Gray, McDonall & Reid, 1990) and Canada (Hudon, 1990).

Despite the great variability in the amount and type of by-catch caught by shrimp trawlers, several generalisations may still be made concerning the composition of by-catch in shrimp trawl fisheries.

(1) Fin-fishes make up the majority of the by-catch in many shrimp fisheries (Perez-Mellado *et al.*, 1982; Harris & Poiner, 1990; Ramm *et al.*, 1990; but see Wassenberg & Hill, 1989).
(2) The sizes of fin-fishes in the by-catch are usually small (< 20 cm) and often of similar size to the shrimp (e.g. Perret & Caillouet, 1974; Young & Romero, 1979; Atkinson, 1984; Gutherz & Pellegrin, 1988; Jones & Derbyshire, 1988; Watson & Goeden, 1989; Wassenberg & Hill, 1989; Kulbicki & Wantiez, 1990a, b; Sivasubramaniam, 1990).
(3) A relatively small number of species of fishes may dominate the by-catch (e.g. Young & Romero, 1979, Blaber *et al.*, 1990).
(4) Several families of fish, such as sciaenids, pomadasyids, sparids, synodontids, serranids, bothids and nemipterids are abundant in the by-catch of many of the world's shrimp fisheries (Perret & Caillouet, 1974; Keiser, 1977a, b; George *et al.*, 1981; Watts & Pellegrin, 1982; Unar & Naamin, 1984; Sheridan *et al.*, 1984; Jones & Derbyshire, 1988; Wassenberg & Hill, 1989; Blaber *et al.*, 1990; Harris & Poiner, 1990; Kulbicki & Wantiez, 1990a, b).

ESTIMATION OF BY-CATCH

It is evident that there are large differences in the amount of by-catch among fisheries and among times and places within fisheries. Quantification of this variability and adequate description of the magnitude of by-catch has proved problematic. The majority of studies has attempted to quantify by-catch by indirect means, with mixed success. Adequate descriptions of by-catch within the geographic domain of a fishery are necessary for effective management of both shrimp resources and fisheries for species caught as by-catch (Watson *et al.*, 1990).

Descriptions of spatial and temporal variability in by-catch are derived from either of two sources. The incidental catch from commercial boats can be quantified by observers during normal fishing operations (e.g. Keiser, 1977b; Young & Romero, 1979; Gutherz & Pellegrin, 1988). Alternatively, the relative abundance of trawlable fauna (including by-catch species) may be estimated by research vessels or chartered fishing boats using the same gear as the commercial fleet (e.g. Keiser, 1977b; Watts & Pellegrin, 1982; Gray *et al.*, 1990; Harris & Poiner, 1990). Typically, surveys independent of the directed activities of the fleet are done in the region fished and changes in by-catch are related to fishing effort (e.g. Pellegrin, 1982; Collins & Wenner, 1988; Harris & Poiner, 1990; Ramm *et al.*, 1990; Watson *et al.*, 1990). Data from independent surveys and from the commercial fleet are, of course, complementary and complete understanding of the impact of trawling requires information from both sources.

Estimates of the total by-catch of regional fisheries gained from observer programmes and independent surveys are derived from one of two methods. The first and most common method is based on measures of the relative amounts of by-catch and shrimps caught. Using this relationship (hereafter referred to as the by-catch:shrimp ratio or ratio method), the total catch of shrimps is used to estimate the total by-catch in the fishery (e.g. Juhl & Drummond, 1977; Keiser, 1977a, b; Atkinson, 1984). Alternatively, total by-catch is calculated from the amount of by-catch per unit of fishing effort (CPUE) and extrapolated to the fleet using estimates of the total effort in the fishery (e.g. Watts & Pellegrin, 1982; Gutherz & Pellegrin, 1988; Harris & Poiner, 1990). CPUE is estimated directly by observers on commercial boats or research vessels (CPUE estimation).

The great majority of studies of the by-catch of shrimp trawling have relied on by-catch: shrimp ratios to generate estimates of total by-catch. The quality of these estimates varies enormously; at one extreme, estimates of total by-catch are derived from direct calculation of the mean ratio from a number of trawls and are accompanied by estimates of variance or range (Table II). Single estimates of by-catch: shrimp ratios are also presented without comment as to their reliability (Table II) and, finally, there are many examples in the literature of rough 'guesstimates' of the total by-catch for a fishery.

Frequency distributions of by-catch:shrimp ratios are almost always strongly positively skewed and Keiser's (1977b) data from the South Carolina shrimp fishery are a good example (Fig. 1). Although the ratios in his study ranged between 0.3 and 136:1, only 10 of 290 ratios were greater than 20:1. Because the ratio is composed of two random variables, very large ratios can occur if only a few shrimps are caught or if there is little by-catch. Very large ratios have a disproportionate influence on estimates of the mean by-catch:shrimp ratio for a fishery and produce large variances about that mean. The great imprecision of estimates of mean by-catch gained by the ratio method greatly limits its usefulness in fisheries management (see also Keiser, 1977b).

Acknowledgement of the great variability associated with estimates of by-catch usually takes the form of qualifiers attached to the ratio (e.g. 'gross', 'approximate' or 'useful generalisation'). In only a few studies has variability in the ratios been quantified (Table II). A good example of such a description is Keiser's (1977a, b) study of the fish by-catch of shrimp fisheries of the Atlantic states of the USA. Keiser sampled more than 350 trawls from the

TABLE II

Summary of estimates of by-catch:shrimp ratios from the published literature separated into those from the tropics (latitude < 23°28′) and temperate regions. Given for each study are: the estimator used (mean, median or single estimate); the estimate of variance associated with that ratio (if given); the range of estimates (if given); the type of by-catch used in the ratio (total, fin-fish). The word 'fish' is used to describe the by-catch where it was unclear whether this includes other groups, such as miscellaneous crustaceans, cephalopods, etc.; the source of the information, whether it came from landed catch statistics, observes placed on commercial vessels in the fleet, from surveys done by fisheries research vessels (FRV); the time period over which the estimates were made; and the reference from which the estimates were drawn. –indicates information not provided in publication,? indicates information unclear from reference. Whole weights of shrimps were used to calculate ratios. The references cited are often not the original publications

Location	Ratio	Statistic	Variance	Range	Type	Source	Date	Reference
Temperate regions								
USA								
N. Carolina	4.1	median	1.7–15.1[a]	–	'fish'	landed catch	1970–76	Keiser (1977a)
N. Carolina	6.3[b]	mean[b]	0.4–91.2	–	'fish'	fleet?	1972?	Wolff (1972)
S. Carolina (summer)	2.2[c]	mean	0.2–26.0[d]	0.05–265.4	'fish'	fleet/FRV	1974–75	Keiser (1977b)
S. Carolina (summer)	2.6[c]	median	1.2–5.4[b]	–	'fish'	landed catch	1970–76	Keiser (1977b)
S. Carolina (autumn)	1.2	median	0.6–2.7[b]	–	'fish'	landed catch	1971–75	Keiser (1977b)
Georgia	2.6	mean[d]	0.33–19.5[c]	0.11–49 500	'fish'	landed catch	1969–71	Keiser (1977b)
Florida	3.8	estimate	–	–	total	fleet	1951	Siebenaler (1952)
Texas (0–10 fm)	17.2	mean	40.5[g]	–	fin-fish	fleet/FRV	1973–78	Watts & Pellegrin (1982)
Texas (> 10 fm)	3.3	mean	3.5[g]	–	fin-fish	fleet/FRV	1973–78	Watts & Pellegrin (1982)
Louisiana (0–10 fm)	15.0	mean	32.7[g]	–	fin-fish	fleet/FRV	1973–78	Watts & Pellegrin (1982)
Louisiana (> 10 fm)	19.4	mean	14.6[g]	–	fin-fish	fleet/FRV	1973–78	Watts & Pellegrin (1982)
Texas (0–10 fm)	13.9	mean	12.3[g]	–	fin-fish	fleet	1980	Watts & Pellegrin (1982)
Texas (> 10 fm)	3.8	mean	1.9[g]	–	fin-fish	fleet	1980	Watts & Pellegrin (1982)
Louisiana (0–10 fm)	11.1	mean	16.0[g]	–	fin-fish	fleet	1980	Watts & Pellegrin (1982)
Louisiana (> 10 fm)	136.5	mean	176.7[g]	–	fin-fish	fleet	1980	Watts & Pellegrin (1982)
Mexico								
Gulf of California	15.5	mean	–	–	total?	fleet/FRV	1977–78	Young & Romero (1979)
Brazil								
Santos Bay	1.1	estimate	–	–	fin-fish	unknown	1981–83	Paiva-Filho & Schmiegelow (1986)

Tropical regions								
India								
West Bengal (lg boats)	14.7	estimate	–	–	total	unknown	1990	Sivasubramanian (1990)
(sm boats)	23.0	estimate	–	–	total	unknown	1990	Sivasubramanian (1990)
Gujarat	12.5	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Maharashtra	1.6	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Goa	4.2	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Karnataka	4.7	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Kerala	2.2	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Tamil Nadu	10.2	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Pondicherry	6.4	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Andhra Pradesh	4.3	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Orissa	3.4	estimate	–	–	total	landed catch	1979	Silas *et al.* (1984)
Australia								
Torres Strait	4.9[h]	mean	–	3.2–6.8	fin-fish	FRV	1985–86	Harris & Poiner (1990)
Torres Strait	6.9[h]	mean	–	4.4–9.3	total	FRV	1985–86	Harris & Poiner (1990)
Indonesia	–	estimate	–	0.3–30.0	'fish'	unknown	1970–78	Unar & Naamin (1984)
Caribbean fisheries	–	–	–	3.0–20.1	discarc ish	unknown	–	Allsopp in Sheridan *et al.* (1984)
Cuba	2.8	estimate	–	–	total	unknown	1982?	Puga *et al.* (1982)
Guyana, Surinam, French Guyana	40.2[i]	mean	64.2[g]	0.9–364	fin-fish	FRV	1972	Cummins & Jones (1973)

[a]25th and 75th percentiles.
[b]from log transformed data and largest ratio excluded from calculations.
[c]from log transformed data.
[d]11 highest ratios (4% of total) excluded from calculations.
[e]95% confidence intervals.
[f]ratios greater than 20:1 excluded (5.6% of total) from calculations.
[g]standard deviation.
[h]a range of mean ratios was given, presented above is the mean of those means.
[i]calculated from raw data as presented. Statistics pooled across depth and country because insufficient information was given to ascribe stations to countries and depths.

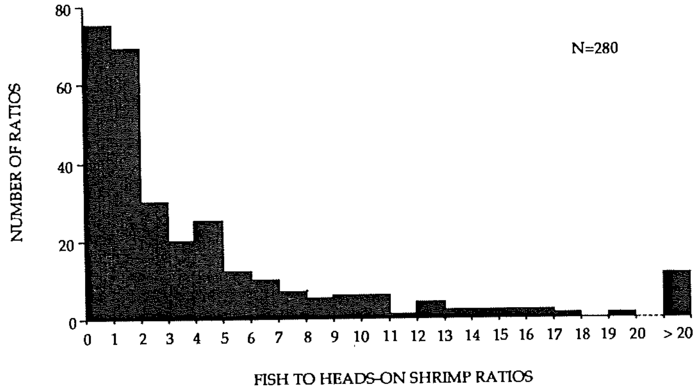

Fig 1.—Frequency distribution of ratios of whole weights of fishes and shrimps from the South Carolina shrimp fishery for the period 1974–1975 (redrawn from Keiser, 1977b).

South and North Carolina shrimp fisheries over two periods, 1969–1971 and 1974–75. The estimates of the mean ratio of shrimp to by-catch reported by Keiser had wide confidence intervals and were greatly influenced by a few very large ratios. More conservative estimates of the variance may be obtained by using percentiles around medians (Keiser, 1977a, b) and by the jacknife estimate of variance (Saila, 1983). No application of the latter statistic to a 'real' data set was found in the literature.

Attempts to reduce the influence of very large by-catch:shrimp ratios have taken several forms. Log transforms have been used prior to calculating by-catch:shrimp ratios to normalise the frequency distribution of ratios (e.g. Keiser, 1977b). Statistics other than the arithmetic mean and variance have been suggested to accommodate this variability and right-skewness, such as the median and geometric mean (e.g. Keiser, 1977b; Saila, 1983) and in some studies (Wolff, 1972; Keiser, 1977b) very large ratios were excluded from analysis because they were considered unrepresentative. A feature common to these alternatives is that they give large ratios less weight in calculations of total by-catch. In Keiser's study the median was not much smaller than the arithmetic mean and was used to estimate the total by-catch of the regional fisheries. The median ratios were further refined by taking seasonal variation into account. Thus, ratios in proximate months were usually most similar and these patterns were used to give more precise estimates of by-catch for the whole year (Keiser, 1977b). We found no studies in the literature that have used geometric means or weighted mean ratios to improve the precision of estimates of total by-catch.

Catches of shrimp are usually used as the denominator in ratios because estimates of catch are readily available. Although shrimp catch is used almost exclusively as the denominator, there is no reason why other variables could not be used. As noted by many authors (e.g. Sampford, 1962; Cochran, 1963; Saila, 1983) the form of the relationship between the two variables of a ratio estimator need not be understood, nor indeed need the denominator of the ratio have any biological meaning. For instance, if magnitude of by-catch and duration of tow were more correlated than by-catch and shrimp catch then it would be better to use the ratio by-catch:duration of tow in calculating total by-catch. We could find no example in the literature of variables other than shrimp catch being used in ratio estimators of total by-catch.

Stratification of fishing grounds has been used in several studies to reduce variance by separating areas of the fishing ground that are identifiably different in their fauna. In Hudon's (1990) study of the by-catch of the pandalid shrimp fishery in northern Canada, knowledge of current patterns and the origin of water masses was used as a basis to divide the study area into a number of regions. Subsequent sampling revealed that these regions had identifiably different fauna, the abundance of which was related to environmental conditions. Such stratification in space requires a knowledge of the fishing ground that is lacking for all but a few shrimp trawl fisheries (e.g. Gulf of Mexico, USA and Gulf of Carpentaria and eastern Queensland, Australia). Many studies have found seasonal patterns in by-catch and estimates of annual by-catch will be improved by taking seasonal differences into account (e.g. Keiser, 1977b; Gray *et al.*, 1990; Harris & Poiner, 1990).

From examination of the literature, it is evident that there is an enormous range in the ratios reported for temperate and tropical shrimp fisheries (Table II). It appears likely that there will be as much variation within a fishery as among fisheries at different latitudes (Table II). A simple *t*-test comparing estimates of the ratio between fisheries in temperate and tropical regions indicates no significant difference between the regions ($t_{(30)} = 0.67$, ns). There is currently insufficient information available to sustain any generalisations about the relative catch rates of shrimps and by-catch in temperate and tropical fisheries.

The empirical base from which the above generalisations were drawn is small and confusing. In compiling estimates of regional by-catch from many studies, it is important to establish what part of the total by-catch is being considered. For instance, it was often unclear whether total by-catch was quantified or whether only a subset was estimated (Table II). Where stated, it was usually only the fin-fish component of the by-catch that was described, although miscellaneous crustaceans, cephalopods, rays, and skates, etc., may be abundant. Often the word 'fish' was used in an inclusive sense, but in others it referred only to teleost fishes. Similarly, the terms 'discards', 'trash' and 'by-catch' were sometimes used loosely and synonymously. Such inconsistencies make it difficult to collate and generalise about the size and composition of shrimp by-catch.

Quantification of total by-catch by estimation of CPUE is considerably less common than by the ratio method. There have, however, been several detailed studies of shrimp by-catch using observers on commercial fishing vessels or research vessels, notably Keiser (1977b), Watts & Pellegrin (1982), Gutherz & Pellegrin (1988), and Harris & Poiner (1990). Estimates of total by-catch by this method is reliant on good effort data for the fishery. Because discarding is the norm in many shrimp fisheries, by-catch cannot be adequately described from landed catches. With few exceptions, none or few individuals of commercially important by-catch species below marketable size are landed. All non-commercial species are discarded at sea (see Utilisation of by-catch p. 541). Direct estimation of by-catch and discarding practices can be done only by placing observers on commercial vessels or by relying on fishermen to return details by means of a logbook system. As Gulland & Garcia (1984) pointed out, if estimates of total by-catch are based on landed catch alone, then changes in discarding practices could be misinterpreted as changes in the abundance of by-catch.

In addition to the intrinsic variability outlined in the previous section, variance will be added by observers, through sub-sampling schemes and personal biases. These sources of variation may make estimates not only less precise, but may also introduce unknown biases. Some sources of variability are obvious, such as sampling methodology and errors in estimates by fishermen if logbooks are used. The procedures by which these artefacts may be minimised are well known and need no discussion here. Other potential sources of bias are rarely, if ever, considered. Two examples falling into the latter category are the recatching of animals already discarded by other boats in the fleet, leading to over-estimates of total by-catch (Gulland & Rothschild, 1984) and the loss of animals from the trawl before it is brought on board, leading to under-estimates of by-catch. No references to this latter source of mortality were found, although quantification using secondary nets within trawls would be comparatively easy.

The relative merits of the two methods of by-catch estimation (ratio method and CPUE estimation) in estimating the total by-catch of a fishery have rarely been examined. The ratio method may be more precise than CPUE estimation if catches of by-catch and shrimps (or whatever) are correlated. The degree of association between the two variables need not be great. For the ratio method to provide more precise estimates of total by-catch than CPUE estimation, then the standard deviation of the ratio has to be a smaller proportion of its population mean than the standard deviation of the CPUE estimate of by-catch from its mean (see Sampford, 1962; Cochran, 1963 for more detailed discussions). The ratio method will provide a more precise estimate than direct estimation if the following is true:

$$r > CV_{\text{by-catch}}/2\,CV_{\text{shrimp}}$$

where r is the product-moment correlation coefficient and CV is the coefficient of variation (SD/mean) (Snedecor & Cochran, 1980; Saila, 1983).

We could find no direct comparisons of the ratio and direct estimation methods. Harris & Poiner (1990) found little correlation between by-catch and prawns in surveys in the Torres Strait and concluded that there was no gain in using ratio estimates but did not compare the methods further. Watts & Pellegrin (1982) estimated total by-catch using both CPUE estimates and ratios in their study of a closure in the shrimp fisheries of Texas and Louisiana. Where ratios were calculated, the SE of the sample was, on average, 29% of the mean of that sample (SD = 21.1, $n = 12$). This degree of precision indicates relatively little confidence about the location of the mean. Watts & Pellegrin concluded that shrimp:by-catch ratios were of questionable use in judging the effects of the closure. Direct estimation of fin-fish CPUE by observers provided more precise estimates (19% $\pm$ 9.4, $n = 12$). In this sense, desired precision becomes important to define. Both the estimates of by-catch gained by Watts & Pellegrin were sufficient to differentiate among depths in the amount of by-catch caught, but neither demonstrated significant effects of the closure when the effects of depth were removed from the regression model.

Estimates of total by-catch of fisheries derived from the ratio method have been too imprecise to be used to quantify the impact of shrimp trawling on the stocks of other commercially and recreationally important species, particularly fin-fishes (see also Allsopp, 1982). Both methods are vulnerable to the multiplication of errors associated with individual estimates. Even small imprecisions about estimates from individual boats or ports will extrapolate into large errors about estimates of total by-catch. It remains a challenge to decide upon an acceptable degree of imprecision.

Given estimates of the quantity and composition of by-catch discarded in a shrimp fishery, two broad management options are available. Irrespective of the catches of shrimps, by-catch may either be better utilised or it can be minimised. The perceived need to reduce by-catch varies among countries and fisheries. In some fisheries (e.g. northern Gulf of Mexico) awareness of by-catch has been heightened by the capture of rare and endangered species, particularly turtles. In those fisheries where a large proportion of by-catch is, or could be, utilised, by-catch is seen as a bonus (IDRC, 1982). Management of these fisheries must deal with a different problem from that where all or most of the by-catch is discarded, especially when discarded species are the basis of other, interacting, fisheries.

UTILISATION OF BY-CATCH

Much of the literature on the by-catch of shrimp fisheries has emphasised the waste of dumping large quantities of edible protein at sea, especially in or near the waters of developing countries where protein is in the short supply (IDRC, 1982; Saila, 1983; Gulland & Rothschild, 1984). Increased utilisation of by-catch is predicted to be an important area of research over the coming decades (e.g. Grantham 1980 and above references). Economic factors currently inhibit greater use of this by-catch. Because the target shrimp species are far more valuable than the often much greater quantities of fin-fish caught at the same time, there is often little incentive to land by-catch. Furthermore, much of the world's shrimp catch is taken by sea-going vessels with limited chilled or frozen storage space and priority is given to the more valuable shrimps (e.g. Silas, George & Jacob, 1984; Chong *et al.*, 1987; and references in IDRC, 1982).

There have been many suggestions for better ways to utilise by-catch. Grantham (1980) recommended filleting and general processing of the larger fin-fish by-catch of the Persian Gulf shrimp fishery. Haysom (1985) and Pender & Willing (1989) have noted the relative lack of utilisation of by-catch in the Gulf of Carpentaria (northern Australia) and noted the commercial sale of dried pipefishes as one of the only uses made of by-catch in that fishery.

Peterkin (1982) reported that the Guyanese Government reacted to the obvious waste of protein from shrimp trawlers in 1974 by offering tax incentives to encourage fishermen to land by-catch. If at least 1407 kg (converted from pounds) of edible fishes were landed per trip, the Government would waive the tax of 2.5 cents (US) per pound on shrimp exports. More recently, this quantity has been raised to at least 1814 kg (converted from pounds) of edible fishes per trip (Peterkin, 1982). Fishermen have responded to this agreement by landing much more fish, often in excess of the mandatory amount. As well as being processed in traditional ways such as smoking and canning, the fishes have been successfully used to pioneer new products such as fish paste, patties and sausages (Petersen, 1982).

There are numerous other ways in which by-catch is being utilised (see references in IDRC, 1982), including processing whole fish to extract pulped flesh which is used in a number of products such as sticks, hamburgers, spreads, croquettes and pasteurised and dried products (Bello, 1987). By-catch may also be salted, canned, dried (Young, 1982) and used to produce surimi (Min, Fujiwara, Chng & Ean, 1982). Fishmeal and fish manure (George, Suseelan & Balan, 1981), chemical fertiliser and animal food have all been produced from by-catch (e.g. Trevino *et al.*, 1982).

Brown & Waters (1982) considered the economics of processing three species of fin-fish taken as by-catch in the Gulf of Mexico shrimp fishery as whole, deboned (minced) and filleted products. They showed that the processes could be profitable, provided that fishermen were willing and able to retain, sort and land the by-catch, that market acceptance was good, that the catch mix could ensure long production runs and that all conditions existed for sufficient numbers of days per year. Because economic pragmatism is the driving force in determining whether, and how, by-catch is utilised, the situation will always vary among fisheries. It seems likely, however, that the utilisation of by-catch will increase as demand for protein escalates and the retention and processing of by-catch becomes more economically viable.

MORTALITY OF BY-CATCH CAUSED BY FISHING

It is often assumed that all by-catch discarded from a shrimp trawl dies as a result of the trauma of being caught, removed from the water and handled (Maclean, 1972; Seidel, 1975; Juhl & Drummond, 1977; Caddy, 1982; Saila, 1983; Howell & Langan, 1987). This assumption is implicit in listings of discarded by-catch (e.g. Saila, 1983; Gulland & Rothschild, 1984) and in discussions of the consequences of by-catch to other fisheries. Cushing (1984b), for example, in discussing whiting by-catch in the northern Ireland *Nephrops* fishery, assumed that the 40 million whiting discarded each year died. He calculated that, had they survived, a further 6096 tonnes of recruited fish could be added to the usual annual catch of 10 160 tonnes.

Few studies have been made of mortality of by-catch in shrimp trawls, but these indicate that a small though variable proportion of the by-catch survives being caught (e.g. Hyland, 1985; Wassenberg & Hill, 1989; Berghahn, 1990; Hill & Wassenberg, 1990). The survival of by-catch is dependent on many factors, both biological (e.g. species-specific differences in vulnerability to damage) and operational factors such as the duration of the tow and the length of time the by-catch is exposed on the deck of the trawler.

Of the many operational factors nominated as contributing to the probability of survival of by-catch discarded from trawls, duration of tow (De Veen, Huwae & Lavaleye, 1975; Neilson, Waiwood & Smith, 1989; Wassenberg & Hill, 1989; Van Beek, Van Leeuwin & Rijnsdorp, 1990), sorting time (Jean, 1963; Neilson *et al.*, 1989) and catch size (Neilson *et al.*, 1989) have been shown to be important. Jean (1963) has described the mortality of juvenile cod and plaice caught by northern New Brunswick groundfish trawlers. Jean measured the survival of fish following exposure on deck for periods of up to 45 min, after which time most cod and plaice were dead. Jean demonstrated that a large proportion of those fish might have survived if sorting times had been reduced to 15 min or less, especially at low temperatures.

Several studies have demonstrated that many species of teleost fishes are more prone to trawl-induced mortality than are cephalopods and crustaceans (e.g. Wassenberg & Hill, 1989, 1990). In their study of the survival of by-catch from shrimp trawls in Moreton Bay, Australia, Wassenberg & Hill (1989) found that, under normal conditions, about 20% of bony fishes placed in tanks after 20 min exposure on deck were alive 8 h later. In contrast, more than 90% of sand crabs, *Portunus pelagicus*, survived for at least 8 h after 20 min exposure on deck and 88% of *Alpheus stephensoni* and 70% of *A. distinguendus* survived for 8 h.

Wassenberg & Hill (1989) reported that, although gross damage to fishes was uncommon in their study, many of the crustaceans lost limbs as a result of trawling. More than 43% of sand crabs and *Alpheus* spp. had lost at least one limb during capture. This damage would probably lead to increased mortality of discarded crustaceans over longer periods of time (e.g. Scarratt, 1973; Kennelly, Watkins & Craig, 1990). In the study by Kennelly *et al.* (1990) of the survival of spanner crabs, *Ranina ranina*, discarded from a tangle-net fishery, loss of two or more limbs resulted in 100% mortality after 8 days.

Species-specific differences in post-trawl survival have been demonstrated in several studies (Jean, 1963; Hyland, 1985; Wassenberg & Hill, 1989, 1990; Hill & Wassenberg, 1990). It is apparent that some species of fin-fish are more hardy than others and survive capture and handling better than others. For example, in Moreton Bay, Australia, Hyland (1985) noted that river mulloway, *Johniops vogleri*, were usually dead when released from the codend, whereas yellowfin bream, *Acanthopagrus australis* swam actively when returned to the water. Hill & Wassenberg (1990) compared the mortality of 13 species of teleosts selected from the by-catch of a shrimp trawler in the Torres Strait fishery in northern Australia. Fishes were sorted from the catch in the usual way and left for 10 min on the deck, after which 30 of each species were selected and placed in tanks containing circulating sea water. Five of the species suffered 100% mortality after 12 h, while mortality rates in others ranged from 3% to 97%. As noted by Hill & Wassenberg (1990), a large proportion of the by-catch floated and these were assumed to be dead, even if still alive after 12 h. If predators did not eat floating discards before they revived, then mortality may be overestimated.

There is evidence that smaller individuals of a species are more vulnerable to trawl-induced mortality than larger fish (e.g. Jean, 1963; Neilson *et al.*, 1989). In the groundfish trawl fisheries studied by Neilson *et al.* (1989), halibut less than 57 cm long were 18 times more likely to die after trawling than those greater than 57 cm. This fact has important implications in those fisheries in which juveniles of commercially important species are caught as by-catch. In these fisheries, greater separation of such fishes from shrimps through changes in trawl design may prove the only way to reduce the effects of trawling short of not trawling at all. Regulations limiting the size of fishes allowed to be landed will not have the desired effect if a significant proportion of those fishes returned to the sea are dead or die soon after (Neilson *et al.*, 1989).

Most studies of the mortality of discarded by-catch have been based on relatively short-term observations—hours rather than days (e.g. Jean, 1963; Wassenberg & Hill, 1989; Berghahn, 1990; Hill & Wassenberg, 1990). These studies have provided clear evidence that most fish die within a few hours of capture. For example, almost all the smelt (*Osmerus eperlanus*) caught by shrimp trawlers in the north Wadden Sea die immediately (Berghahn, 1990). Although the majority of deaths occur quickly, the effects of some injuries (e.g. haemorrhaging and secondary infection of wounds) may take days or weeks to be fatal (Beamish, 1966; Neilson *et al.*, 1989; Berghahn, 1990). In the papers cited above, the effects may be considerable for some species and would lead to an under-estimation of mean survivorship of discarded by-catch (Neilson *et al.*, 1989).

In studies of by-catch mortality in Moreton Bay and in Torres Strait, Australia, whether the fishes floated or sank was important in determining subsequent survival (Wassenberg & Hill, 1989, 1990; Hill & Wassenberg, 1990). In the Torres Strait shrimp fishery, an estimated 29–59% of all discarded teleosts floated (Hill & Wassenberg, 1990). Floating fish were eaten by a wide range of predators, including birds, dolphins and sharks. The possession of a swim bladder, therefore, appears to be important in influencing the survival of discarded fin-fishes. When fishes are raised from the sea bed they are subjected to rapid depressurisation that often distends or ruptures their swim bladders and many die quickly after capture (e.g. Feathers & Knable, 1983). Other fishes, possessing a swim bladder, although alive when returned to the sea, are unable to leave the surface and are subject to intense predation (e.g. Hill & Wassenberg, 1990; Wassenberg & Hill, 1990).

Even if discarded individuals in the by-catch survive the trauma of capture and handling, their continued survival is by no means assured. A wide range of predators is known to feed on by-catch discarded from trawlers. Of these, birds are by far the most commonly observed predators or scavengers of discarded by-catch (e.g. Wahl & Heinemann, 1979; Watson, 1981; Furness & Cooper, 1982, Hudson & Furness, 1988; Ryan & Moloney, 1988; Blaber & Wassenberg, 1989; Vauk, Prauter & Hartwig, 1989; Berghahn, 1990; Hill & Wassenberg, 1990; Wassenberg & Hill, 1990). Other animals observed to feed on discards from shrimp trawlers include sharks (Cummins & Jones, 1973; Harris & Poiner, 1990), seals (Ryan & Moloney, 1988; Berghahn, 1990), sealions (Saila, 1983), dolphins (Wahl & Heinemann, 1979; Harris & Poiner, 1990; Wassenberg & Hill, 1990), crabs (Edwards, 1978; Wassenberg & Hill, 1987, Berghahn, 1990) and loggerhead turtles (Shoop & Ruckdeschel, 1982). Large predatory fishes such as scombrids also take their toll on discards (Hill & Wassenberg, 1990).

There have been few studies of the fate of live discards from shrimp trawlers. Wassenberg & Hill (1990) estimated that, when dolphins, terns and gulls were present, approximately 90% of fishes discarded in the Moreton Bay prawn fishery were eaten and dolphins alone could account for as much as 80% of the discarded catch. Hill & Wassenberg (1990) made similar observations in the Torres Strait shrimp fishery and concluded that dolphins and sharks were significant predators or scavengers of floating discards. The high rate of loss of fishes from baits set in mid-water also suggested that much of the sinking component of the discarded by-catch was also eaten, probably by sharks (Hill & Wassenberg, 1990).

Much emphasis is placed on the huge quantities of discards from shrimp fisheries, but a certain, if small, proportion of this by-catch probably survives. Initial rates of mortality of by-catch are determined by a complex interaction of factors including the biology of the species, duration of tow, times spent sorting and size of catch. The susceptibility of by-catch to mortality varies enormously among taxa, for example between crustaceans and teleost fishes and between fishes with and without functional swim bladders. Knowledge of the survival of species under different conditions could be used to promote changes in sorting practices and, ultimately, increased survival of discards, particularly if this were done in conjunction with the introduction of more selective trawls.

REDUCING BY-CATCH

While greater utilisation of by-catch is appropriate in some shrimp fisheries, there are many reasons for wishing to avoid, or minimise by-catch in others. Those reported and discussed in the literature include the following.

(1) To avoid killing commercially or recreationally important species, especially if the mortality has a significant effect on non-targeted populations (Roithmayr, 1965; Gutherz, Russell, Serra & Rohr, 1975; Seidel, 1975; Keiser, 1977a, b; Juhl & Drummond, 1977; Juneau & Pollard, 1981; Pellegrin, 1982; Rothschild & Brunenmeister, 1984; Sheridan *et al.*, 1984; Collins & Wenner, 1988).

(2) To avoid removing organisms from the food chain which may result in detrimental effects on populations of shrimp. An example is the removal of predators that would normally prey on predators of shrimp (Browder, 1981; Sheridan *et al.*, 1984).

(3) To avoid killing rare or protected animals, such as turtles (Shoop & Ruckdeschel, 1982; Oravetz & Grant, 1986; Henwood & Stuntz, 1987; Chan, Liew & Mazlan, 1988).

(4) To reduce the sorting time between trawls so that more tows can be done per trip. Fuel costs may also be reduced because of less drag from the weight of the by-catch in the trawl. This increased efficiency may allow longer tows to be done. Reduced amounts of by-catch in the trawls also produce a cleaner catch of uncrushed shrimps (High, Ellis & Lusz, 1969).

(5) To avoid the problem of rotting organic material on groundfish trawl grounds, which, when picked up in fish trawls, can contaminate the catch, making it unsuitable for human consumption or pet food (Seidel, 1975).

(6) To avoid criticism of the fishery due to the appearance of large numbers of small, floating, dead fishes (Seidel, 1975).

One method for reducing by-catch from shrimp trawlers is to confine trawling to areas and times known to produce relatively small amounts of by-catch (Caddy, 1982). In some cases, because of the inconvenience caused by by-catch clogging the trawl and increased sorting time, fishermen themselves restrict trawling to certain times. For example, High *et al.* (1969) reported that shrimp fishermen in the US Pacific northwest avoided trawling in the early mornings and late evenings because large quantities of small fish were taken at those times.

SELECTIVE TRAWL DESIGNS

A more direct approach to avoiding by-catch is to design fishing gear that allows by-catch, particularly turtles and fin-fishes, to escape. Such devices are usually known by the acronym 'TED' which can mean Trawl Efficiency Device, Trash Eradication Device, Trash Elimination Device or even Turtle Exclusion Device. In their simplest form, these are trawls that partition the catch using large-meshed panels. Organisms that do not pass through the panel are deflected and escape through openings in the trawl while the smaller and/or less mobile shrimps pass through to the codend.

Modifications to this basic principle enhance separation of the catch by using funnels to accelerate the catch toward these screens and by the use of rigid frames. The successful development of a TED depends on the application of a design appropriate to the fauna and fishing techniques used in a given fishery. TEDs designed to separate pandalid shrimps from groundfish in New England, USA (Averill, 1989) or Norway (Karlsen & Larsen, 1989; Valdermarsen, 1989) may not, for example, adequately evict turtles from trawls in the Gulf of Mexico.

The most high-profile application of TEDs is with reference to the incidental capture of turtles, particularly in the shrimp fisheries of the southeastern USA (Oravetz & Grant, 1986; Conner, 1987; Watson, 1989; Renaud *et al.*, 1990). Five species of turtle are captured by shrimp trawlers in the Gulf of Mexico and southern North Atlantic (Oravetz & Grant, 1986; Conner, 1987; Henwood & Stuntz, 1987; Watson, 1989). Loggerhead turtles (*Caretta caretta*) make up the majority of the catch (Henwood & Stuntz, 1987). TEDs were made mandatory in 1987 following the inclusion of marine turtles in the Endangered Species Act in 1978 (Conner, 1987). Of the many thousands of turtles caught by shrimp trawlers in the Gulf per annum, 20–38% died in the trawls (Henwod & Stuntz, 1987). The exact rates of mortality depended on a number of factors, most importantly the duration of the tow (Henwod & Stuntz, 1987; see also Poiner, Buckworth & Harris, 1990).

Brief descriptions of the development and application of TEDs in the US shrimp fisheries have been provided by Oravetz & Grant (1986), Conner (1987) and Watson (1989). These histories illustrate the many problems faced in gaining acceptance of these devices by the fishing industry. Although some designs can achieve the required reductions in catches of turtles, reducing the associated loss of shrimps to acceptable levels has proved problematic and fishermen have objected to the cost and arkwardness of the TEDs (Oravetz & Grant, 1986; Watson, 1989). Several designs have been approved as adequately excluding turtles from shrimp trawls (Christian & Harrington, 1987, 1988; Kendall, 1990; Renaud *et al.*, 1990). These designs fall into two categories; those that use a rigid grid immediately in front of the codend (Fig. 2) and so-called soft TEDs that use large-meshed screens, such as the

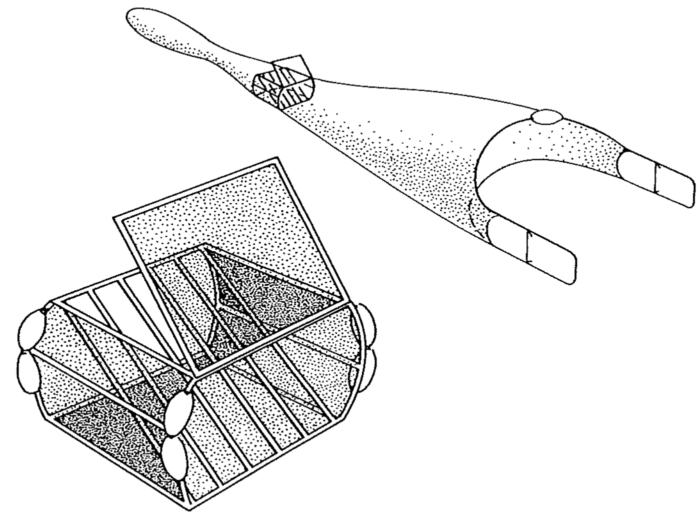

Fig 2.—Details of the NMFS designed TED, used to exclude turtles from shrimp trawls in the Gulf of Mexico shrimp fisheries. The TED itself is constructed of metal, the diagonal bars guide the turtles out through a flap at the top of the TED. Redrawn from Oravetz & Grant (1986).

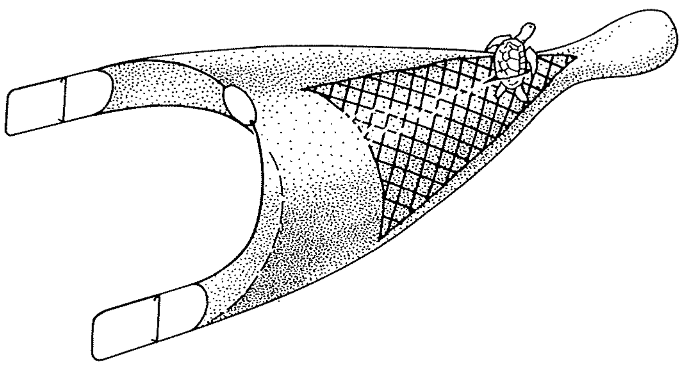

Fig 3.—Stylised representation of the Morrison soft TED as used by some commercial fishermen in the Gulf of Mexico. This design relies on a large-mesh screen to guide by-catch to an exit slit in the top of the trawl. Redrawn from Kendall (1990).

Morrison soft TED (Fig. 3). Although there have been few studies of the comparative merits of these designs (but see Collins & Wenner, 1988), much of the recent research has concentrated on soft TEDs because of their ease of use and good ability to exclude by-catch (e.g. Christian & Harrington, 1987, 1988; Kendall, 1990; but see Renaud *et al.*, 1990).

Shrimp trawling is thought to be a significant threat to the conservation of turtles in many regions of the world (Hillestad, Richardson, McVea & Watson, 1982; Chan *et al.*, 1988) and, unfortunately, turtles may be relatively abundant over shrimp trawling grounds. Although turtles are caught in many shrimp trawl fisheries, captures are sufficiently rare in some to be considered an unimportant source of mortality. In the northern prawn fishery of Australia, for example, turtles are caught in relatively small numbers (Poiner *et al.*, 1990). It is estimated that, in this fishery, although several thousand turtles are caught each year, only 6% of those caught drown in the trawls (Poiner *et al.*, 1990). Given the many other factors causing declines in populations of these turtles (e.g. loss of nesting habitat and indigenous harvesting), Poiner *et al.* (1990) concluded that shrimp trawling was not a significant source of mortality. As these authors pointed out, however, relatively little is known of the population dynamics of the species of turtles concerned and it is, therefore, difficult to assess the relative importance of mortality caused by shrimp trawling.

Outside the geographical range of turtles, TEDs have been used to reduce quantities of other by-catch, particularly fin-fish. Considerable research was done on the development of selective trawl designs in the late 1960s and early 1970s, particularly in Europe and the USA (see references in FAO, 1973). TEDs are now used, for example, in the trawl fisheries for pandalid shrimps in New England USA (Averill, 1989) and Norway (Karlsen & Larsen, 1989; Valdermarsen, 1989) to exclude groundfishes from shrimp trawls (see also Venderville, 1990). The design of trawls to separate shrimps from fin-fishes is made complex because the two groups are often of similar size. To separate the catch these designs rely heavily on the fact that many species of fishes tend to swim forward and upwards in the net and escape, whereas the less mobile shrimps remain in the lower parts of the trawl and go through the TED and into the codend. Soft TEDs, those that incorporate deflector panels and chutes made of netting of a larger mesh size, have been used with some success (e.g. High *et al.*, 1969; Christian & Harrington, 1987, 1988; Karlsen & Larsen, 1989; Valdermarsen, 1989; Kendall, 1990).

High *et al.* (1969) reported good results in an early study of selective trawl designs using a trawl with chutes, pockets and covers to exclude by-catch from shrimp fisheries in the US Pacific Northwest. In parallel tows with commercial boats using normal gear, the modified nets proved effective in dramatically reducing the by-catch of fishes and sea urchins in catches of pink shrimp. High *et al.* (1969) claimed that the use of their modified trawl reduced by-catch, usually 80% of total catch, to less than 1%. Reductions in catches of shrimps were thought to be offset by the ability to trawl at times and in areas otherwise not fishable because of excessive amounts of by-catch (High *et al.*, 1969).

Similarly, in the Gulf of Mexico, Seidel (1975) was able to reduce by-catch using trawls that included 'skylight' panels to allow fishes to escape. Comparative tows with standard and experimental trawls reduced catches of fish by 37 to 83.5%. Concomitant reductions in the catch of shrimps of up to 10% were compensated for by the longer time the trawls could be towed. In further research, Seidel (1981) achieved a 57% reduction in by-catch with an associated reduction in catch of shrimps of only 8%. Watson & McVea (1977) also experimented with separator panels and escape chutes in the Gulf of Mexico fishery and reported promising results. Flume tank observations were used to optimise the mesh-sizes and shapes of nets to maximise the passage of shrimps through separator panels. Field tests of these designs indicated that reductions of by-catch of 38 to 81% could be achieved, with concomitantly smaller reductions in shrimp catch of 6 to 62%.

Oravetz & Grant (1986) reported that TEDs were used successfully by Japanese fishermen in a joint venture with Indonesia, but no details of designs were given. The benefits of more efficient trawl designs include an ability to do fewer, longer trawls and cause less damage to shrimps by crushing. Further advantage was predicted because the chutes would allow the use of lighter webbing in net construction, thereby reducing costs of fuel (Seidel, 1975). Development of more efficient TEDs (those that have both good by-catch exclusion and shrimp retention characteristics) will no doubt continue as the perceived need to minimise by-catch increases. As noted by Kendall (1990), greater involvement of commercial fishermen will accelerate the development of more efficient TEDs.

Once the shrimps are separated from the by-catch, the fate of the ejected fishes and invertebrates differs among fisheries. Where by-catch is considered undesirable, separated organisms simply escape via opening in the trawl. The incidental mortality of excluded by-catch caused by the TED is little understood. There may be substantial sub-lethal damage to by-catch as it is buffeted through the various devices before being excluded. Assessing mortality caused by this effect would be extremely difficult and would need to be considered over extended periods (weeks, months) to allow for deaths caused by shock and infection to be documented.

In other fisheries, selective trawls are used in which by-catch is retained in a second codend, often with a larger mesh size (e.g. Chian, Chow & Chen, 1988). For example, in trawl fisheries for the Norway lobster *Nephrops norvegicus*, horizontal separator panels have been used to divide lobsters and fishes (e.g. Main & Sangster, 1982, 1985). Fishes such as haddock and whiting were shown to rise off the bottom as they tire and fall back into a codend fed from the upper half of the trawl. *Nephrops*, flatfishes and cod, in contrast, remain close to the bottom and enter a lower codend (Main & Sangster, 1982, 1985; Newland & Chapman, 1989).

Wassenberg & Hill (1989) and Berghahn (1990) have presented evidence suggesting that many species of by-catch do not die until many hours or days after being caught and discarded (see also Mortality of by-catch, p. 542). Mortality caused by the TED, and immediately evident, could be estimated by placing a codend over the escape chute. Of the many assumptions made in this sort of study perhaps the most important is that no additional mortality is caused by the secondary codend. If few fishes are killed by the TEDs themselves then the benefits of these devices would be further enhanced.

Several other approaches to avoidance of by-catch have been proposed. The use of electric fields to pre-sort catch was considered by the Watson (1976) and Seidel & Watson (1978) and relies on the differential responses of shrimps and fishes to electrical fields. The mouth of the trawl would be closed by a webbing panel (stopping entry of fishes) while the bottom panel of large mesh would allow entry of shrimps upwards (even during the day) in response to an electrical field under the net. Additionally, fishes would be frightened away by the electrical pulses. Sternin & Allsopp (1982) pointed out that the main limitation in using electrical stimuli in this fashion would be the great cost because of losses of energy in sea water. They suggested that other stimuli, such as light and air bubbles, might prove effective, but concluded that sound waves appeared to hold most promise as a practical, economical method of pre-sorting ahead of the trawl. This conclusion was based on the contrasting response of shrimps and fishes to sound and the smaller costs of generating sound compared with electrical pulses. While these more inventive approaches to avoiding by-catch may hold promise, we could find no evidence of their use in a commercial fishery.

In summary, many designs for avoiding by-catch have been suggested, all of which rely to some extent on the unwanted organisms passing through, or being deflected off, panels of different mesh sizes from that of the main net. Tests of such trawl designs have been promising, but even though by-catch is reduced, often dramatically, the catch of the target shrimp is often also reduced (although only slightly in some cases). Despite their potential, widespread application of TEDs to commercial shrimp trawl fisheries has remained limited to several regions (e.g. Norway and the US Gulf of Mexico).

IMPACTS OF TRAWLING ON ECOSYSTEMS

Although it is clear that shrimp trawling kills large numbers of incidentally caught fishes, it is not clear whether this mortality has measurable effects on adult stocks of those species. It has long been suspected that shrimp trawling has significant impacts on stocks, but, despite this general perception, there has been surprisingly little research (see also Gulland & Rothschild, 1984; Wassenberg & Hill, 1989). Trawling is considered to affect directly the stocks of species caught as by-catch and to have indirect effects, through changes in the abundance and species composition of benthic communities. These more general effects may be mediated through differential mortality of competitors, prey and predators, which can lead to changes in food-web dynamics (Gibbs, Collins & Collett, 1980; De Groot, 1984; Rothschild & Brunenmeister, 1984; Sheridan *et al.*, 1984; Wassenberg & Hill, 1987; Ryan & Moloney, 1988; Blaber & Wassenberg, 1989; Berghahn, 1990; Harris & Poiner, 1991). The physical impact of trawling may also change the nature of trawl grounds, making them more suited to a different suite of species (e.g. De Groot, 1984; Sainsbury, 1987, 1988; Hutchings, 1990). Not surprisingly, the more indirect effects of trawling on stocks of species caught as by-catch are even less well understood than the immediate and direct effects discussed in the previous section.

An example often referred to is the possible effect of the northern Gulf of Mexico shrimp fishery on commercial and recreational fisheries for fishes such as sciaenids and lutjanids (Roithmayr, 1965; Gutherz *et al.*, 1975; Juhl & Drummond, 1977; Juneau & Pollard, 1981; Pellegrin, 1982; Sheridan *et al.*, 1984; Collins & Wenner, 1988). Particular concern has been expressed about the potential impact of shrimp trawling on stocks of the red snapper (*Lutjanus campechanus*). Commercial and recreational landings of this species have declined and the expanding shrimp fishery has been nominated as a possible cause (Gutherz & Pellegrin, 1988). An estimated 4.8 million juvenile red snapper are caught by the US Gulf of Mexico shrimp fishery per year (Gutherz & Pellegrin, 1988), the majority of which are caught off the Texas coast. Gutherz & Pellegrin concluded that, although enormous numbers of juvenile red snapper were caught, the effect of this incidental capture on stocks of adults was unknown.

Rothschild & Brunenmeister (1984) concluded that the effects of shrimp trawling on fish stocks in the northern Gulf of Mexico might be large, simply by comparing quantities of discards with commercial catches of the same species. The quantity of by-catch estimated to have been discarded from the Texas shrimp fleet in the early 1970s was almost double the catch of the (substantial) groundfish fishery in that State. Although Rothschild & Brunenmeister did not cite any studies of the effects of shrimp trawling on stocks of groundfishes, they noted that landings from shrimp trawlers accounted for a large proportion of the total recorded landings of several important commercial species.

The only study we could locate which attempted to quantify directly the effects of trawling on groundfish stocks was that of Atkinson (1984). This study was prompted by the concern of commercial redfish (*Sebastes* sp) fishermen about mortality of discarded redfishes off Newfoundland. Catches from commercial trawlers were monitored for 5 years and total numbers and weights of fishes discarded in the fishery were estimated, based on monthly fish:shrimp ratios. These estimates of catch were compared with estimates of abundance and biomass of redfishes obtained from stratified random surveys. Atkinson (1984) estimated that the quantities of redfishes discarded annually ranged between 200–2000 tons, or 2–108 million fishes, but that these discards (even assuming 100% mortality) represented less than 3.4% of the standing population, or 2% of its biomass in the worst case.

The discards from trawl fisheries have been shown to influence the behaviour and even the numbers of predatory and scavenging species of several fisheries. Wassenberg & Hill (1987) showed that 33% of the diet of sand crabs, *Portunus pelagicus*, was made up of fishes discarded from shrimp trawlers. Wassenberg & Hill argued that discarded fishes maintained populations of sand crabs at larger numbers than would otherwise be the case. In the Gulf of Mexico, Shoop & Ruckdeschel (1982) speculated that populations of loggerhead turtles may be maintained at larger numbers than would be otherwise possible by the discards of shrimp trawlers. The fact that populations of turtles may be enhanced by trawler discards provides an insight into the complexities involved in understanding the dynamics of these fisheries.

An important effect of trawling, not often commented upon, is that it makes available large amounts of food to surface predators and scavengers, such as birds and dolphins, which would not otherwise have access to this resource (Hill & Wassenberg, 1990). Hudson & Furness (1988) suggested that several species of seabirds off Shetland may be able to sustain populations larger than normal because of scavenging behind fish trawlers. In Moreton Bay, eastern Australia, Blaber & Wassenberg (1989) compared the by-catch of shrimp trawlers with the regurgitated pellets of seabirds and suggested that the feeding habits and diets of two species of cormorant had almost certainly been modified to take advantage of fishes discarded from shrimp trawlers. Blaber & Wassenberg concluded that the populations of cormorants were artificially enlarged as a result of shrimp trawling. The effect on benthic communities of exporting the food resources taken by surface scavengers is unclear.

Wassenberg & Hill (1989) observed scavengers behind trawlers in Moreton Bay, Australia, and noted that small fishes (< 20 g) were eaten by birds, but not dolphins, while larger fishes (25–65 g) were eaten by both birds and dolphins. Hill & Wassenberg (1990) made similar observations in the Torres Strait shrimp fishery and concluded that dolphins and sharks were the most significant predators/scavengers of floating discards. Below the sea surface, by-catch suspended on lines in midwater were rapidly eaten by teleosts and sharks while that which sank to the bottom was observed to be eaten mainly by sharks (Hill & Wassenberg, 1990).

Changes in abundance and species composition of communities before and after the commencement of trawling have been taken to be evidence that trawling has significant effects on benthic community structure (e.g. Tiews, Sucondharmarn & Isarankura 1967; Pauly, 1979; Gibbs *et al.*, 1980; Tiews, 1983; Poiner & Harris, 1986; Sainsbury, 1987, 1988; Harris & Poiner, 1991). Studies of this kind are rarely possible because information prior to the commencement of trawling is usually not available. Poiner & Harris (1986) and Harris & Poiner (1991) have compared surveys of demersal fish communities in the southeastern Gulf of Carpentaria done in 1963–1965, before a major fishery for shrimp began, with those done 20 years later, in 1983–1986. Surveys done prior to the opening of the fishery were repeated as closely as possible to the original surveys by site, month and time of day. Catches were standardised as numbers of fishes per hectare swept and as total number of species per trawl. Poiner & Harris found significant decreases in total numbers of individual fish per hectare in 14 of 18 matched sites, but significant increases in the number of species of small fish per trawl in 16 of 18 sites. These changes were interpreted as being an effect of trawling in the intervening period.

Harris & Poiner (1991) repeated these surveys in 1985–86 at sites designed to replicate the original, pre-trawling, survey as closely as possible. As found in their first post-trawling survey, there had been significant changes in the abundance and species composition of assemblage of fishes caught in shrimp trawls. Although 63% of the species considered were caught in similar numbers in all surveys, total catches of fishes declined over the 20 years between surveys, as did catches of individual species, particularly scorpaenids and soleids (Harris & Poiner, 1991). Some taxa, such as carangids and clupeids were caught in greater numbers in the later surveys. Harris & Poiner (1991) interpreted this increase as being due to an increase in food made available through discarding from shrimp trawlers. As further evidence that trawling significantly changed the fish fauna in the Gulf of Carpentaria, Harris & Poiner (1991) cite the fact that species active during the day were caught in greater proportions in the latter survey.

In a variation of the before-and-after type of study cited above, Watts & Pellegrin (1982) compared composition and rates of catches of fin-fishes and shrimps before and after a 55-day closure of shrimp trawling grounds off Texas. Observers on commercial vessels immediately before and after the closure estimated by-catch by means of fish:shrimp ratios. Historical data collected 5 years before the closure by a research vessel using standard gear were compared with commercial catches after the closure. Watts &

Pellegrin noted that species composition of by-catch in shallow-water areas did not change, but that composition in offshore areas was much more varied in time and space. Although there was a significant increase in catches of shrimps following the closure, attributing this increase to the closure is difficult. Any such comparisons were confounded by differences in sampling method and place (89% of sampling was done in water < 10 fathoms deep before the closure, whereas after the closure only 34% of samples were taken in these depths). A further constraint to interpretation was imposed by the assumption that changes in ratios could describe changes in by-catch. Any changes in the ratios before to after sampling could be caused by either changes in catch rates of shrimps, fin-fishes or both.

Much of the evidence suggesting that trawling causes changes in benthic community structure comes from trawl fisheries for groundfishes (e.g. Tiews *et al.*, 1967; Pauly, 1979; De Groot, 1984; Sainsbury, 1987, 1988). An oft-cited study of the effect of trawling on epibenthic organisms is Sainsbury's (1987, 1988) comparison of catches of fishes from Japanese research cruises off northwestern Australia in the 1960's with similar data collected 11 years later, after the development of a large trawl fishery. Since the development of the fishery there have been dramatic changes in the species composition of the catch. During the 1960s, *Lethrinus*, *Lutjanus* and *Epinephelus* species constituted between 45 and 77% (by weight) of the catch and *Nemipterus* and *Saurida* species accounted for only 10%. The relative representation of species in samples taken 11 years later was reversed and the combined catch of *Lethrinus*, *Lutjanus* and *Epinephelus* species constituted only 15% of the total while catches of *Nemipterus* and *Saurida* had increased to 25%.

Sainsbury (1987, 1988) nominated three causes of the observed shift in the species composition of catches: (1) environmental change independent of the fishery, (2) direct but species-specific alteration of sizes of fish populations caused by fishing, (3) indirect effects caused by alteration of interspecific biological interactions, such as predator-prey relationships and altered habitat structure. While admitting that none of these possibilities could be dismissed entirely, Sainsbury favoured changes in habitat availability caused by trawling as the primary cause of the shift in species composition. This conclusion was based on comparative quantities of sponges taken in trawls during each of the above surveys. Catch rates of sponges and gorgonians had declined considerably since the establishment of the trawl fishery. In 1963, 14 of 20 trawls took more than 200 kg of sponges per h, while in 1979, only 3 of 40 trawls took sponges at that rate. Underwater photography showed that *Lutjanus* and *Lethrinus* species were commonly associated with sponges whereas *Nemipterus* and *Saurida* species preferred more open substratum. There is good evidence from other studies (e.g. Wenner, 1982) that the diversity and abundances of fishes are greater in association with sponge-coral habitats than with open sand.

Aside from these studies, little other empirical work has been done. Several studies have approached the problem more theoretically and have attempted to construct food webs that account for the flow of energy through these systems. Discarded by-catch which reaches the sea floor is presumably converted into trophic energy by organisms ranging from bottom scavengers, through detritus feeders (including penaeid shrimps) to microbes. Cushing (1984a) specifically considered the question of whether discarded fishes and

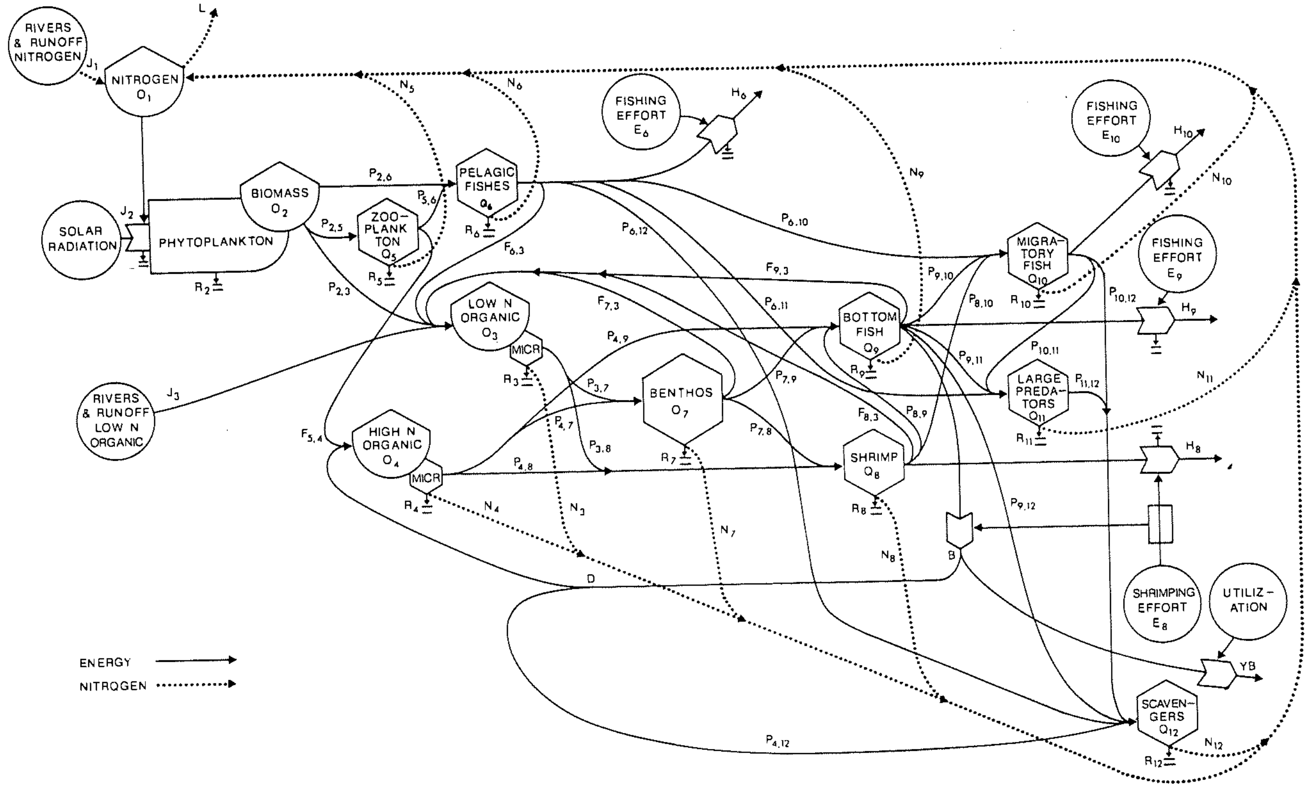

Fig 4.—Energy-flow diagram of the north-central Gulf of Mexico nearshore ecosystem (redrawn from Sheridan *et al.*, 1984).

discarded small shrimps might contribute significantly to productivity of the targeted shrimps in the fishery. From budgets of benthic production in the northern Gulf of Mexico, he concluded that discarded fishes from the shrimp fishery probably constituted only a very small proportion ($\ll 1\%$) of the total food available in the system. Nevertheless, he was cautious in accepting this conclusion because of the many assumptions incorporated into his model.

Sheridan *et al.* (1984) proposed two models for the northern Gulf of Mexico shrimp fishery that relate shrimps and by-catch. The first model was a population dynamics model relating shrimp and bottomfish numbers and the second, an ambitious energy flow model incorporating known data from the level of primary productivity through to large predators and scavengers. This second model contained a large number of parameters (Fig 4), some of which were only estimated or set arbitrarily (Sheridan *et al.*, 1984). These models are the only published attempts to describe the complexity of ecological interactions between shrimps and associated groundfish. Sheridan *et al.* (1984) were concerned primarily with the potential effects of reducing the quantities of discards on shrimp production in the Gulf of Mexico and less with determining the effects of mortality on populations of groundfishes.

While acknowledging that their models were largely speculative, Sheridan *et al.* (1984) suggested that "the discard practices most favourable to shrimp would increase shrimp harvests only 8% over the case with no discards", but that "since assimilation rates in the model were deliberately over-estimated, the actual benefit of discards to shrimp production probably is less". An important conclusion of this study was the necessity of measuring rates of predation throughout the system, something which has yet to be done.

The 'before-and-after' studies discussed above illustrate the difficulties in inferring causation from the description of pattern alone. Apart from confounding in time and space (lack of replication), such studies are weakened by the absence of control sites (as noted by many of the authors). Control sites, areas not subjected to a change in fishing intensity, are necessary in order to disentangle changes in the abundance of by-catch species that are independent of trawling. While there may be persuasive circumstantial evidence supporting the hypothesis that trawling has significantly altered benthic communities, much of this remains equivocal and in need of further study. Experimental closures, with adequate controls and replication, are required to demonstrate clearly that shrimp trawling significantly alters the stocks of by-catch species.

Attempts to model these complex systems offer an alternative approach to understanding the dynamics of fisheries. The great complexity of the ecosystems in which shrimp fisheries operate (e.g. Fig 4), however, makes the identification of important causal linkages between trawling and changing food web dynamics difficult. Models of this type, because of their great parameterisation and the scarcity of empirical data, are likely to have little predictive power. Even the description of the direct effects of trawling on populations of exploited species requires an understanding of the population dynamics of species which is rarely available. For example, the effects of catching large numbers of juvenile fishes by shrimp trawlers, of common concern, may be minimal if the age-specific mortality schedules of that species are such that this mortality is swamped by very large natural mortality.

CONCLUDING REMARKS

The quantities of fishes and invertebrates taken as incidental catch in shrimp fisheries are large and constitute a significant proportion of the world's total fisheries production (Allsopp, 1982; Saila, 1983). Although a proportion of that by-catch is used for human consumption or for industrial purposes, the majority is discarded at sea. Current estimates of by-catch for all but a very few fisheries are inadequate for anything but the most gross indication of the magnitude of the phenomenon (e.g. Keiser, 1977a, b; Saila, 1983). Reliable quantitative description of by-catch and its fate presents a major challenge to fisheries agencies. The by-catches of several large fisheries are relatively well described (e.g. the northern Gulf of Mexico and northern prawn fishery of Australia). For most other fisheries, however, even the most fundamental information, such as what and how much is caught is absent from the published literature. Such information is critical to the management of multispecies shrimp fisheries and the minimisation of conflicts over access to fisheries resources.

The first step in any investigation of the impact of shrimp trawling is a reliable description of the magnitude and composition of the by-catch. Few studies have ventured beyond this phase, possibly because of the many difficulties associated with estimation. Variability in quantity and composition of by-catch through time and space is usually large. Methods for assessing and/or quantifying the by-catch of a fishery are mostly imprecise, especially for large fisheries. Consequently, estimates of regional, country and world by-catch are poor.

Although many studies have demonstrated that large numbers of nontarget species are caught, few have been able to discover whether these catches have a measurable effect on the stocks of by-catch species. The estimates generated by most studies have been too crude to allow such an assessment. Although the effect of shrimp trawling on other resources may be similar whether by-catch is discarded or not, sampling methods and management options will differ depending on the proportion of by-catch landed. If a significant proportion of the by-catch is utilised then appropriate management options may differ from those for fisheries where most of it is discarded. It is important, therefore, to partition estimates of by-catch into discarded and retained components (Gulland & Garcia, 1984; Harris & Poiner, 1990).

The issue of wastage in dumping by-catch is a matter of concern in many shrimp trawl fisheries. 'Wastage' may be seen in several different ways, depending on the fishery, but chief among these are as follows.

(1) Loss of protein and/or product which might otherwise be utilised, either for human consumption or for industrial purposes.
(2) Loss of fish from other fisheries, both recreational and commercial.
(3) Disturbance of the ecology of a region, particularly the destruction of habitat used by other species, especially fishes.

Utilisation of by-catch is encouraged in some fisheries, but not in others. The fisheries in which utilisation may be encouraged are those in which other fisheries for by-catch species are insignificant or non-existent and/or where there is an unsatisfied local demand for protein. Avoidance of by-catch is seen to be desirable in many fisheries even though the effects of the by-catch in these fisheries have not necessarily been determined. The development of trawl designs that reduce by-catch is seen as an important area of future research.

Measuring rates and components of mortality caused by factors such as trawling or handling has rarely been attempted. Mortality is often assumed to be 100%, but the few studies done over short durations (hours) suggest very variable survival of species of fishes. Few studies have been published on whether differences in survival observed in the short term remain over the long-term (days, weeks).

Mortality caused by trawling of non-target organisms has rarely been described. Several 'before-and-after' studies have provided correlative information suggesting that shrimp trawling may have a significant effect on benthic communities. Relatively little modelling has been done, but existing models point toward relatively minor effects on stocks of commercially important species of by-catch. The paucity of data on these fisheries and the many parameters that have to be estimated means that models currently have little predictive power.

We suggest the following areas of study to be important for any shrimp trawl fishery where by-catch is perceived as an issue.

(1) To determine more accurately the quantities of by-catch utilised or discarded.
(2) To obtain accurate estimates of the effect of shrimp trawling on the standing stock of demersal fishes and on co-existing fisheries directed at those stocks and on the benthic communities that support them.
(3) To measure the survival of at least the more important species of by-catch, as caught by shrimp trawling under normal operating conditions. If realistic assessments of overall effects of trawling are to be made, then the longer-term effects of trawling on growth and survival must be considered. Experiments will quickly determine the influence of sorting time on the survival of by-catch.
(4) The continued development and application of TEDs with good exclusion of by-catch and retention of shrimps.

Seasonal variations, independent of shrimp trawling, in the abundance of species caught as by-catch offer options for management to reduce by-catch. Closures during times when fishes are most abundant or vulnerable to shrimp trawling may greatly reduce by-catch, with potentially minor impact on the shrimp fishery. This is especially so for those by-catch species that have an estuary-dependent phase in their life-history. Identification and protection of such nursery grounds would reduce by-catch. Closures are less attractive when shrimp trawling and patterns of abundance of by-catch species overlap to a large extent, as is the case of the red snapper in the Gulf of Mexico. It is likely that a combination of strategies, such as closures, greater use of TEDs and increased utilisation of by-catch will evolve as the solutions most likely to reduce the ecological and economic impact of by-catch. Incidental captures of species from other fisheries are now included in assessments of total allowable catches in several large trawl fisheries (e.g. the northwest Atlantic; Brown, Brennan & Palmer, 1979) and it is likely that this will spread to shrimp fisheries in other parts of the world.

Fisheries management is increasingly moving into an age in which the interactive, multispecies nature of fisheries, particularly trawl fisheries, is considered (e.g. references in May, 1984; Gulland, 1988). In this climate, the incidental catches of major trawl fisheries (including those for shrimp) will demand increasing attention. Much of the world's shrimp production comes from tropical regions where shrimp fisheries are embedded in highly interactive and diverse ecosystems that are little understood. Given the very large quantities of by-catch caught and the potential to affect other fisheries adversely, there is a clear need for more research in this field.

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APPENDIX B

The issue of by-catch in Australia's trawl fisheries.

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Kennelly, S.J.

THE ISSUE OF BY-CATCH IN AUSTRALIA'S TRAWL FISHERIES

Steven J. Kennelly

SUMMARY

The most commonly used definition of the term "by-catch" is "that part of the gross catch which is captured incidentally to the species towards which there is directed effort". Under such a definition, there is probably no fishery in Australia (nor the world) which does not have by-catch, making the scope, diversity and history of the issue enormous. In recent years, however, the majority of interest in by-catch has focussed on trawl fisheries because conventional demersal otter trawls are comparatively non-selective fishing gears and so catch large quantities of a wide range of untargeted species.

One form of by-catch that often escapes attention concerns those individuals of targeted species that are considered too small or unworthy to retain. If these discarded conspecifics are damaged or die as a result of capture and discarding, this by-catch may be detrimental to the target fishery itself and is thus an intra-fishery interaction problem. This problem not only occurs in fish trawl fisheries but for most types of fishing gear.

In general, the chief problems associated with trawl by-catch concern conflicts between trawl fisheries and other fisheries that target species which are discarded by trawlers (i.e. fishery-interaction problems). Research into this issue in Australia has been relatively scarce, with most work concentrating on attempts to describe and quantify the highly variable but very large quantities and diversities of trawl by-catches. These descriptive aspects of the issue are a pre-requisite to identifying, understanding and eventually managing any problems. There has been some research on estimating actual impacts of trawl by-catch on interacting fisheries via fishery-independent surveys of trawled and untrawled areas. Significant inroads also have been made in understanding the fate of discards as food for other organisms and effects that trawling may have on habitats and consequences for macrobenthic assemblages.

Unfortunately the situation in Australia has been slow to progress to the next stage of solving the perceived problems of trawl by-catch. Eighty eight years ago, Dannevig (1904) did the first observer-based survey of the by-catch of an Australian prawn fishery and it is surprising that, for most fisheries, researchers still need to obtain these quantitative descriptions of by-catches. After 88 years, we should be in a position to solve these problems and assess the effectiveness of various management alternatives. Sainsbury's (1991) work on the Northwest Shelf does this for a certain type of management strategy but the very small amount of work done on more selective trawl configurations and handling practices is unfortunate and obviously needs attention.

It is clearly necessary to describe and quantify by-catches in specific fisheries (in order to assess whether any problems exist) and the best way to do this is via on-board sampling of by-catches under normal commercial operations. But such work in itself is insufficient in solving the problems that arise when these by-catches are described. Once this preliminary descriptive work is done, it is necessary to test the effectiveness of alternative management strategies which may alleviate any problems that have been detected.

INTRODUCTION AND DEFINITION

This paper is a review of the by-catch issue in Australia's fisheries. The most commonly used definition of the term "by-catch" is Saila's (1983) "that part of the gross catch which is captured incidentally to the species towards which there is directed effort". Under such a definition, there is probably no fishery in Australia (nor the world) which does not have by-catch, making the scope, diversity and history of the issue enormous. In recent years, however, the majority of interest in this issue has focussed on trawl fisheries because conventional demersal otter trawls are comparatively non-selective fishing gears and so catch large quantities of a wide range of species. This review assesses the current status of knowledge of trawl by-catch in Australia by summarizing the available scientific literature and management alternatives. I attempt to do this in the light of the international situation and by highlighting areas where the Australian information is adequate or poor. In this way, priority areas for future research become apparent.

By-catch from non-trawl fisheries

To put the issue of trawl by-catch into some perspective, it is useful to mention briefly some of the types of by-catch that occur in other fisheries. A particularly important category of by-catch comprises those individuals of a target species which are not targeted by a fishing method but are nevertheless caught and discarded. Because different fishing gears are developed to catch particular species, and even particular sizes of particular species, they also usually catch individuals of the species that fall outside the targeted size (usually these discards are smaller). If such conspecifics are killed during capture and discarding, this eventually may prove detrimental to the fishery itself. Such a situation is not a fishery-interaction issue (as is the usual case with problems of trawl by-catch - see below) but an intra-fishery issue.

The by-catch of untargeted conspecifics occurs in all fisheries and their protection is the reason behind such management measures as mesh-size restrictions on nets and traps and minimum or maximum size limits on retained individuals. This type of by-catch also occurs in fish trawl fisheries where the by-catch often includes undersize conspecifics of the target species. Another example is the spanner crab fishery off eastern Australia where tangle-nets catch negligible quantities of other species but large numbers of undersize crabs, many of which are damaged during disentanglement and eventually die (Kennelly et al., 1990). These examples show that "by-catch" probably occurs in all fisheries - even those which catch only one species. Fish traps, long-lines, drop-lines, mud and sand crab pots, amateur fishing rods and almost every other type of fishing gear will catch organisms that are untargeted. A combination of the selective properties of the fishing gear, the skill of the fishers and the place and time of fishing determines how much, or little, of this by-catch is caught, discarded, damaged and/or killed.

Most fishing gears are designed to be selective in what they catch. Other, less selective gears have the potential to catch large quantities and a wide diversity of organisms and so cause interactions with other species, other fisheries and therefore other user groups. Oceanic drift netting is probably the most high-profile example of these non-selective fishing gears (Carr & Gianni, 1991) and world-wide lobbying in recent years has resulted in the widespread banning of this fishing gear. Its place as a high-profile, non-selective fishing method, however, is becoming occupied by otter-board demersal fish and prawn trawling (SEFA, 1992).

BY-CATCH FROM TRAWL FISHERIES

Introduction

In most countries and fisheries, some or all of the by-catch from trawling is considered as a "bonus from the sea" and is utilized as a source of protein for human or animal consumption (IDRC, 1982; Peterkin, 1982; Saila, 1983). Recently, however, more negative aspects of this by-catch have been emphasised as the mortality of some species is thought to reduce the subsequent stocks of fisheries which target such species (e.g. Ruello & Henry, 1977; Foldren, 1989; Cooper, 1990; Ohaus, 1990). These negative aspects may range from relatively simple effects (such as the direct mortality of juveniles due to trawling and discarding practices) through to more complex effects on community structure caused by habitat degradation, influences on species interactions and consequent cascading effects throughout the food web (see also Andrew & Pepperell, 1992). In the last few years, there has been an increased awareness of these problems of trawl by-catch, making this one of the most important and critical issues facing commercial and recreational fisheries throughout the world (SEFA, 1992).

In Australia, concern about the deleterious impacts of by-catch from prawn fishing began as early as the late nineteenth century when a Royal Commission examined the fisheries of NSW (Macleay et al., 1880). Conflict between amateur and professional fishermen over the reputed by-catch of the "sunken prawn net" led to the NSW Department of Fisheries doing the first recorded survey of by-catch in Australia (Dannevig, 1904). Little has changed in Australia during the past 100 years with the by-catch from trawling still of great concern to a broad cross-section of the community, particularly commercial fishers other than trawler operators (e.g. fish trappers, set and hand-liners, mesh netters, beach seiners), as well as recreational fishers, conservationists, environmentalists, fisheries managers, scientists and politicians from all levels of government. Of major concern are complaints regarding prawn and fish trawlers catching and discarding large numbers of undersize fish that, when larger, are targeted in other commercial and recreational fisheries. In particular, these claims are made with respect to prawn trawlers working in estuarine and oceanic locations thought to be nursery grounds for important fish species. In recent years, the challenge to manage interacting fisheries has led to demands for increased research into by-catch issues (e.g. Green et al., 1992), especially measurements of the magnitude and composition of by-catches and their spatial and temporal variabilities. Procurement of such information is an obvious prerequisite for the selection of appropriate strategies by fisheries managers and the determination of future directions for research into this issue.

The literature concerning trawl by-catch in Australia has grown markedly since the early 1970's and is diverse in the kinds of information derived and methods used. These papers can be separated into several categories, from studies that describe the abundances, diversity and/or utility of by-catches as marketable products, through studies of the fate of discarded organisms, experimental tests of impacts on epibenthic habitats and assemblages of fishes, to the development of modified gears and fishing practices designed to minimize by-catch.

Studies of trawl by-catch onboard commercial trawlers

1 - Describing by-catches

The first piece of information that is required to understand trawl by-catch concerns descriptions of its quantity and diversity. Whilst the most obvious and valid way to determine this information is for scientific "observers" to sort, identify, count, measure and weigh by-catches from normal commercial fishing operations, there have been only a few such studies completed in Australia. It is worth noting, however, that in comparison to the situation overseas, these few studies place Australia in a relatively sound position in describing trawl by-catch and involving industry in these issues (SEFA, 1992).

As mentioned earlier, the first study of by-catch from prawn nets in Australia was published 88 years ago by Dannevig (1904) who provided data on the numbers, species and marketability of by-catch from an observer-based survey of replicate prawn hauls done throughout Sydney Harbour by a commercial fisher under normal operations. He concluded that "all the most serious charges against the sunken prawn-net (that bushels upon bushels of young fish are being killed by the prawn nets and that the latter have been the ruin of the local fisheries) have either been based upon an absolute misconception or are otherwise greatly exaggerated .... many unfavourable observations that from time to time have been made with regard to the work in shallow water have been attached to the industry generally, and this is where considerable injustice has been done". Interestingly, in some cases these conclusions are consistent with those from modern-day observer programmes (see below) which show large spatial and temporal variabilities in the identities and quantities of species which comprise trawl by-catch.

Recent surveys of trawl by-catch onboard commercial vessels have been done in the Northern Prawn Fishery to examine (i) the potential utilization of by-catches (discussed below) and (ii) the incidental capture and mortality of sea turtles (Poiner et al., 1990). The subject of the latter study is a particularly controversial issue in American prawn fisheries where trawl nets used by these very large fleets now have to include authorized TEDs (Turtle Exclusion, Trash Elimination or Trawl Efficiency Devices). The results from Poiner et al. (1990) showed that 4114 (±1369) sea turtles were estimated to have been in the by-catch of the Northern Prawn Fishery during 1988, of which only 247 (±90) were estimated to have been drowned. The conclusion was that the mortality of sea turtles through prawn trawl by-catch in this fishery did not warrant concern.

The most recent observer programme to assess by-catches in Australia's trawl fisheries was done in NSW's oceanic and estuarine prawn fisheries in response to claims concerning large mortalities of juvenile fish (Kennelly et al., 1992). This project involved recording the weights, numbers and lengths of animals caught in trawls done during replicated, randomly-selected fishing trips censussed every month from several oceanic ports and estuaries which encompassed the geographical ranges of these fisheries. Monthly effort data obtained from commercial trawlers allowed an estimate to be made of the total numbers of days fished by individual fleets which could then be used to extrapolate total by-catches by fleets. After censusing over 3,500 tows during 3 years, this project provided reasonably precise estimates of total by-catches caught by various fleets in different places and times. Seasonal estimates of by-catches in the order of hundreds of thousands of juvenile snapper (Pagrus auratus), bream (Acanthopagrus australis) and mulloway (Argyrosomus hololepidotus) have been calculated but the data shows that these large by-catches only occurred in certain places at certain times and that these places and times varied between different years and different locations along the coast.

Whilst the quantification of by-catches is the first logical step in examining this issue and direct onboard quantification of by-catches is the best way to get this information, it is surprising that the existence of this issue for over 100 years in Australia has resulted in so few observer-based programmes. This is not just an Australian deficiency, as this form of by-catch characterisation is rare throughout the world. Clearly, many more such programmes should be done on a fishery-by-fishery basis before we can appreciate the real nature and scope of trawl by-catch in Australia.

2 - Assessing impacts on interacting fisheries

Whilst the first pre-requisite for understanding the fishery-interaction issue of by-catch involves its description and quantification, this does not determine the actual impacts that these by-catches have on other fisheries. Estimating cause and effect relationships between by-catches in trawl fisheries and stock sizes in other fisheries is a very difficult task and consequently very few estimates of such impacts have been made. One way to do this involves incorporating estimates of by-catch-induced mortalities from observer and survey programmes with life-history information of key species (Kennelly et al., 1992). Even if all the juvenile finfish discarded by prawn trawlers die (see below), this may mean very little to subsequent stocks of commercial and recreational fisheries for these species if most of these juveniles would have died of natural causes anyway (i.e. in the absence of trawling). Only by incorporating estimates of the natural mortalities of by-catch species, their ages at legal-size and estimates of trawl-induced mortality, can we attempt to estimate any impacts of prawn trawl by-catch on subsequent stocks for these species. Unfortunately, we have very few estimates of the natural mortalities of key fishes in Australia but estimates using this method for the by-catch of juvenile snapper (Pagrus auratus) in Botany Bay revealed that by-catches of 350,000 fish in one season may represent approx. 60,000 legal-size fish 3 years later (Kennelly et al., 1992).

In using such a non-experimental method to determine impacts of trawl by-catch, it is also necessary to have some understanding of the relative proportion of the available biomass that these by-catches represent. For example, estimates of by-catches of particular species in particular areas that are in the order of hundreds of thousands of fish may be negligible if the biomasses of these fish in these places are orders of magnitude larger. Unfortunately, there are few estimates of these biomasses for the relevant species.

Whilst this way of estimating impacts of trawl by-catch makes many assumptions, it can be useful in deriving first approximations of possible impacts when only simple observer data are available. This is often the case in trawl fisheries because the replicated spatial and temporal closures required in a more experimental approach for assessing impacts (e.g. Sainsbury, 1991 - see below) are usually difficult to implement, hard to enforce and very expensive in terms of lost revenue to the fishery.

Studies of trawl by-catch using fishery-independent surveys

1 - Describing by-catches

The most common way that fishery scientists have quantified trawl by-catch has been through research vessels or chartered commercial vessels doing surveys. Whilst the data generated from such work is not as representative as observations of normal fleet operations, it does supply useful information on the identities and quantities of by-catches from the same fishing grounds.

Several studies have been done in Queensland prawn fisheries which describe patterns in fish assemblages that are in by-catches. Stephenson et al. (1982 a,b) described the by-catch fauna in Moreton Bay and associations between these assemblages and the time of day, tide and location. Large variabilities were evident in these data and the authors concluded that most interactions appeared to be due to random variations rather than any particular co-variable. Watson & Goeden (1989), Cannon et al. (1987), Jones & Derbyshire (1988), Watson et al. (1990) and Dredge (1989 a,b) used trawl surveys to identify and quantify patterns in faunal assemblages off the coast of Queensland and the Great Barrier Reef. This research made use of the fact that, because of its relatively non-selective nature, demersal trawl gear can be used to sample the demersal assemblages of species on these offshore grounds. Discrete "nearshore", "mid-shelf" and "inter-reef" assemblages were identified in several of these papers. Gray et al. (1990) examined fluctuations in by-catches from a prawn-trawl survey in the Hawkesbury River, NSW over different years and across various salinity regimes. This paper showed differences in assemblages which correlated with position in the river and the salinity of different areas. Another study recently completed in NSW also made use of prawn-trawl gear as a means for estimating the relative abundances of demersal fauna in offshore grounds (Kennelly et al., 1993) and provided information on the optimal design for stratified, randomized surveys of these assemblages.

2 - Assessing impacts on interacting fisheries

The most common way researchers have attempted to assess impacts of trawl by-catch on interacting fisheries in Australia has been through fishery-independent surveys. Because standardized gears and sampling methodologies are used in such surveys, changes in by-catches and assemblages can be detected in areas and times that may be open or closed to trawling and so provide some evidence of cause and effect relationships.

The most thorough attempt to quantify such a relationship is the assessment of the impact of trawling on the epibenthic habitats and associated assemblages of fish in the Northwest Shelf fish trawl fishery and a nearby fish trap fishery (Sainsbury, 1987, 1988, 1991). Not only was this study one of the few to examine a causal relationship between trawl by-catch and an interacting fishery, it was also one of the few studies of trawl by-catch in Australia that examined a fish trawl fishery - most other studies have focussed on prawn trawling. The methods involved comparisons of historical records, trawl surveys before and after commercial trawling, in areas closed and open to commercial trawling and underwater video assessments of the impact of trawling on the epibenthic habitat. The results showed that species of tropical snappers (Lethrinus spp.) which were more common in areas with large epibenthic organisms such as sponges etc. were also (i) the target species of the fish trap fishery and (ii) in smaller abundances in areas where domestic and foreign fish trawlers operated. In these latter areas, the benthic habitat was modified such that there were far fewer epibenthic organisms and the fishes which dominated were threadfin bream (Nemipterus) and lizard fish (Saurida). It appeared that trawling modified the habitat and fish assemblages of these areas and thus affected the success of the trap fishery. This hypothesis was supported in a subsequent adaptive management experiment which compared assemblages in large trawled areas to large areas that were closed to trawling. Continued monitoring will provide a good empirical assessment of this particular trawl by-catch and fisheries interaction issue. The work done in this study is probably unique in the world and Sainsbury (1991) summarizes the reasons why it was possible in this particular fishery: the species involved had quite short life spans and hence short reaction times to changes in management; close management control was possible, facilitating the implementation of closures; the existing fishery was of low value whilst the alternate fishery was of high value; the fleet had alternate fishing options during closures; and there were large areas available for closures.

Another study which used survey data to assess possible impacts of trawl by-catch was done in the Gulf of Carpentaria prawn trawl fishery and involved comparing the results of stratified randomized surveys done before the start of commercial prawn trawling with data collected in similar ways after 20 years of trawling (Rainer & Munro, 1982; Rainer, 1984; Poiner & Harris, 1986; Harris & Poiner, 1991). The results showed increases in abundances of 12 taxa of fish, decreases in 18 taxa and in the overall diversity of assemblages. Whilst the authors attributed this to effects of a long period of prawn trawling in these areas, a lack of control (untrawled) sites precludes definitive conclusions.

Other, smaller-scale studies also have used survey data to assess impacts of trawl by-catch but have suffered from being correlative in their approach and lacking proper controls. Maclean (1972) described a study of the catch and by-catch of the Moreton Bay prawn fishery and found that large by-catches of winter whiting (Sillago maculata) did not appear to have any lasting effects on stock size. Blaber et al. (1990) found from random stratified surveys in the Gulf of Carpentaria that large by-catches of certain fish species in Albatross Bay could be attributed to a relatively light exploitation of fish populations in the area, despite the presence of a prawn fishery. Estimates of the total annual by-catch of these fish was thought to be less than 10% of the estimated standing stock of 93,000 tonnes. Hyland (1985) found from fishery-independent surveys that a large number of species may be affected by prawn beam-trawling in Moreton Bay. In particular, a species of sciaenid (Johnieops volgleri) was present in the by-catch in large numbers, did not appear to survive discarding well and its abundances had shown a steady decrease over time. In contrast, sea bream (Acanthopagrus australis) appeared to survive trawling quite well despite large by-catches by beam-trawlers and its abundances did not show long-term declines. In the Hawkesbury River in NSW, Gray et al. (1990) found no significant differences in quantities and compositions of by-catches from areas that were closed and those that were open to commercial trawling.

The conclusion from these studies that have attempted to quantify impacts of trawl by-catch using survey data is that such impacts vary in their nature and magnitude. Sainsbury's (1991) work on the Northwest Shelf suggests substantial impacts of fish trawl by-catch on the interacting fish trap fishery but other, less empirical studies are not as definitive in their conclusions. In several cases, no impacts were evident but this may have been a result of a lack of proper controls or statistical power rather than a lack of significant impact. Only rigorously-designed and executed experiments comparing replicated, trawled and untrawled areas before and after fishing offer the best chance of revealing cause and effect relationships where they exist.

Indirect effects of trawling on benthic assemblages

1 - Habitat degradation

A more subtle impact of trawling involves indirect effects that it may have on assemblages of species by influencing the structure of benthic habitats (Hutchings, 1990). Sainsbury's (1991) work (discussed above) is one of the few examples of an assessment of this sort of indirect impact and showed that by modifying the benthic habitat in areas through the removal of large epibenthic organisms, trawling affected the abundances and kinds of fish species which occupied those habitats.

In an earlier assessment of indirect effects, Gibbs et al. (1980) compared epibenthic assemblages (sampled using grabs) in trawled and untrawled areas before and after trawling in Botany Bay. The authors concluded that otter trawling caused no detectable alterations to the macrobenthic fauna but the large variabilities inherent in their data set may account for these non-significant results. As concluded by Hutchings (1990) in her review of the interaction between trawling and macrobenthic communities, there is almost a complete lack of information on this topic in Australia, making it a high priority area for future research.

2 - The fate of discards and consequences for food webs

An indirect effect of trawl by-catch involves any cascading effects throughout the food web that may occur as a consequence of catching, discarding and killing large quantities of a wide range of species. It is apparent that impacts on by-catch organisms should have follow-on impacts on those species with which they interact via predation, competition, mutualism, commensalism and/or parasitism etc. Consequences for the occurrence and expression of such interactions are obviously extremely difficult to comprehend, let alone quantify, and there exists very few examinations of such effects anywhere in the world. The work done in Australia (chiefly by Wassenberg and Hill, CSIRO), however, constitutes one of the first attempts to unravel some of these complexities.

Studies that quantify trawl by-catch often assume that all discards die as a result of the trauma associated with capture, removal from the water and handling but there exist very few studies that have quantified such mortalities. Through a varied series of quite elegant experiments in Moreton Bay and Torres Strait, Wassenberg & Hill (1989, 1990, 1993), Hill & Wassenberg (1990) and Harris & Poiner (1991), quantified rates of mortality of various types of discarded by-catch and the proportions that were eaten by surface, midwater and benthic scavengers. The methods used included experiments comparing various exposure times on deck, holding discards in sea water tanks for long periods, tethering baits on the surface, midwater and on the bottom, analyses of gut contents, *in situ* videos and floatation trials. The results showed that the survival of discards was quite low, although such factors as the time spent sorting, whether trawling occurred during the day or night, air temperatures and the duration of tows were all thought to affect survival. Crustaceans (crabs, bugs etc.) had a higher survival rate than fish, with over 70% surviving up to 7 days after trawling. Only 1 species of fish (Pseudorhombus jenynsii) had a survival that was greater than 30%. Most of the mortality of discards occurred within the first 3 days after trawling implying that long-term experiments (over several days) are required to assess this mortality adequately. When discarded, by-catch either floats on the surface or sinks and nearly half the fish studied floated, whilst most crustaceans sank. Floating discards were eaten by birds, sharks and dolphins, but birds tended to avoid large discards. The behaviour of birds and dolphins suggested that they had learnt to follow trawlers - an observation that was supported by their behaviour in areas closed to trawling. Those discards that sank did so quite rapidly, spending only 5 to 10 minutes in the water column when they were susceptible to mid-water scavengers like sharks. Most of the discarded material that reached the bottom was dead fish, whilst most discards reaching the bottom alive were crustaceans. Once on the bottom, discarded material tended to be eaten by other fish, sharks and crabs but there was no evidence of material being eaten by prawns, the trawlers' target species. Of particular interest in this work was the suggestion that the success of the sand crab (Portunus pelagicus) fishery in Moreton Bay may owe something to the supply of large quantities of discarded trawl by-catch to these benthic scavengers (Wassenberg & Hill, 1987). Similarly, Blaber & Wassenberg (1989) note that the 3 major species of sea-birds in Moreton Bay primarily depend on food from trawler discards, with the pied cormorant possibly consuming 13.7% of the total fish by-catch.

Two other papers suggested another indirect interaction of trawl by-catch that receives very little attention. Significant rates of predation by small fishes on prawns (Brewer et al., 1991; Salini et al., 1990) may be reduced by the by-catch and subsequent mortality of these fish by prawn trawlers. If such an interaction were sufficiently large, by-catch from prawn trawlers may actually enhance the size of the target stock.

The conclusions from this work is that trawling results in the movement of large amounts of food from the bottom of the sea to the surface and that this affects the feeding behaviour and eventually the abundances of surface, mid-water and benthic scavengers. Despite a lack of human utilization of trawler discards in Australia (discussed below), it is obvious that other organisms in the sea do use this material. Throughout the world, research on the subtle impacts that trawl by-catch may have on the food web is very much in its infancy. More work along the lines described above needs to be done before we can fully appreciate the scope of such interactions.

Utilization of trawl by-catch

Much of the international literature on the by-catch of prawn fisheries has emphasised the waste of dumping large quantities of edible protein at sea, especially in or near the waters of developing countries where protein is in short supply (IDRC, 1982; Saila, 1983; Gulland & Rothschild, 1984). Despite this large wastage, substantial utilization of by-catch does occur in many of the world's trawl fisheries (e.g. Grantham, 1980; Peterkin, 1982; see references in Andrew & Pepperell, 1992). A combination of economic factors and limited storage facilities on vessels inhibit greater use of by-catch in many fisheries because the target prawn and fish species are far more valuable than the larger quantities of small fish and invertebrates in by-catches (e.g. Silas et al., 1984; Chong et al. 1987). Further, factors such as the varied species composition of by-catches and the toxicity of some species precludes the development of fish meal industries where consistent oil content and protein composition are required (see also IDRC, 1982). Despite such problems, increased use of by-catch is predicted to be an important area of research and development in the future, especially in waters near developing nations (see also Andrew & Pepperell, 1992).

In Australia, quite substantial profits already come from the by-catch of some fisheries. In the trawl fishery for oceanic eastern king prawns (Penaeus plebejus) in NSW, large quantities of octopus (Octopus spp.), squid (Loligo spp.), trawl whiting (Sillago spp.) and balmain bugs (Ibacus spp.) are landed each year and large domestic markets have been developed (Kennelly et al., 1992). Whilst such by-catch is usually considered "acceptable" in terms of inter-fishery conflicts because the capture and discard of such species do not directly affect other commercial and recreational fisheries, these species are still subject to the same problems of over-fishing that can face any exploited stock.

The Northern Territory Department of Primary Industry and Fisheries recently completed a study which focussed on potential products and markets from the by-catch of the Northern Prawn Fishery (Pender & Willing, 1989, 1990; Willing & Pender, 1989; Ramm et al., 1990; Pender et al., 1992a,b). These papers described a 3 year programme which assessed the distributions, abundances, size compositions and potential utilization of by-catch species. They identified that only certain valuable species were currently retained for domestic markets (bugs, squids, snappers, emperors, large mackerels, large cods and sharks), with the rest of the by-catch discarded at sea. Some 43 species of fish, sharks, crustaceans and molluscs were identified as having commercial potential, however, with an estimated catch of 15,300 tonnes during 1988. Clearly, more diverse markets for such products need to be developed. Haysom (1985) mentioned two quite unusual markets for trawl by-catch species in the Queensland prawn fishery where sea snakes are landed for sale in the snakeskin fashion market and dried red-and-gold pipehorse are sold in the Orient as an aphrodisiac.

Compared to the situation overseas, there is a lack of literature dealing with the use of trawl by-catch in Australia. Despite this, the conclusions from the above studies note that the potential for economic use of Australia's trawl by-catch is large, diverse and, with the exception of only a few cases, unrealized. This is clearly one aspect of the trawl by-catch issue in Australia which should attract the future attention of researchers, managers, wholesalers and exporters.

Management alternatives to solve the trawl by-catch issue

So far I have concentrated on the work that has been done to quantify, describe, characterize and understand the issue of trawl by-catch in Australia. Unfortunately, whilst the above summaries suggest that we have at least some appreciation of the issues and problems, there have been very few studies that have examined ways to solve the problems. Fisheries managers have several choices available that can alleviate problems of trawl by-catch. One of these involves using by-catch for consumption by developing new markets for these species (described above). Unfortunately this solution will not solve fishery-interaction issues where the by-catch and mortality of juvenile fishes are seen as causing significant impacts on subsequent sizes of exploitable stocks. Publication of results showing by-catches numbering in the hundreds of thousands of juvenile fish per year per fleet leads to strong protests from other commercial and recreational fisheries. These reactions occur despite a lack of information concerning post-trawl mortalities of these discards, their natural mortalities, their overall biomasses and therefore the actual impacts of these by-catches. The involvement of trawl fishing industries in developing ways to minimize any deleterious effects of their by-catch is an important step in resolving these conflicts. Fisheries managers and industry have a variety of tools which may be used to address such fishery interaction issues and these can be broadly categorized as involving closures to trawling or more selective trawl gears and fishing practices.

The use of closures to trawling to alleviate by-catch problems is considered by trawl fishers to be a harsh management strategy because it involves reducing the harvest of the fishery's target species in those places and/or times of closures. However, it is clearly the most effective means for stopping any by-catch problems because ceasing trawling ensures absolutely no by-catch, habitat degradation nor unnatural impacts from the fishing method in those places and times that are closed. A problem is that trawling effort may increase in those areas and times outside particular closures, effectively negating some or all of the desired effects of the management strategy. Sainsbury's (1991) work in the Northwest Shelf Fishery examined the effectiveness of large spatial closures and showed that impacts of trawl by-catch on epibenthic habitats and associated assemblages of fish do not occur in areas where trawling is stopped. As summarized earlier and discussed by Sainsbury (1991), however, the conditions that permitted such large-scale closures were unique to this region and may not be applicable elsewhere, particularly in regions where prawn and fish trawl fisheries are extremely valuable and where alternative fisheries do not exist or are themselves under excessive fishing pressure.

The chief problem with closures as a generalist solution to problems of trawl by-catch lies in being able to identify where and when such closures should be implemented without closing off so much of the target fishery that it becomes uneconomic. As noted earlier, very few data sets exist which describe the by-catch of trawlers operating under normal conditions and these few studies document quite significant variabilities in the timing and location of large by-catches of juveniles of important species (e.g. Dannevig, 1904; Kennelly et al., 1992; Pender et al., 1992b). Such variabilities preclude the establishment of fixed seasonal or localized spatial closures, implying that more flexible closures may be necessary. To advise managers on the most effective times and locations of such closures, however, onboard observers would need to collect data on a regular basis, over the full spatial range of the fishery. Of course, such large and expensive programmes would be unnecessary if managers could rely upon industry for such information. This is unlikely, however, as such information could be seen as leading to restrictions of the fishers own operations in order to protect untargeted species that are of minimal interest to them.

Another suite of management strategies that may alleviate the trawl by-catch issue involves research, development and implementation of more selective gears and fishing practices which are designed to minimize the by-catch and mortality of unwanted organisms. Unfortunately, development of these methods in Australia is very much in its infancy as compared to the substantial amount of work done overseas (e.g. Seidel, 1975; Wardell, 1983, 1989; Watson, 1989; Kendall, 1990; Isaksen et al., 1992).

Sumpton et al. (1989) described comparisons in the Queensland prawn fishery of catches and by-catches from prawn trawls made of mono- and multifilament netting. Whilst the multifilament nets caught more small prawns and less sand crabs than the monofilament nets, there were no other significant differences in by-catches. In the Northern Fish Trawl Fishery, Mounsey & Ramm (1991) described the development of the Julie Anne semi-demersal fish trawl which was found to catch 43% of the by-catch and only 3% of the epibenthos caught in a conventional trawl. This modified trawl involved raising the footrope of the trawl off the bottom and raising the headrope of the trawl.

Andrew et al. (1991) described an experiment which assessed the effects of long sweeps in herding fish into prawn trawls. It was found that these wires which stretch from otter boards to the nets herded red spot whiting (Sillago bassensis) and sand flathead (Platycephalus caeruleopunctatus) but not king prawns (Penaeus plebejus), balmain bugs (Ibacus spp.) or other species. Another experiment by Andrew et al. (1993) showed that the Morrison soft TED, as developed and used in some American fisheries, significantly reduced the amount of by-catch in the NSW king prawn fishery by excluding most organisms from codends that were larger than the mesh-size of the TED panel. This type of TED is also used by certain estuarine prawn trawl fisheries in NSW to exclude unwanted jellyfish from catches (Kennelly et al., 1992). Most organisms that are larger than the mesh-size used in the TED panel are effectively excluded, however these sorts of panels do not exclude organisms that are smaller or the same size as the target species. As one of the most common target organisms in Australia's trawl fisheries are prawns, and the fishery interaction issue of by-catch concerns juvenile fish that are of a similar or smaller size, simple TED panels are an insufficient solution to this issue.

In one of the few Australian attempts to modify trawl gear to assist in this regard, Kennelly et al. (1992) and Broadhurst & Kennelly (submitted ms.) described a stratified, randomized, manipulative field experiment which compared the prawn-retention and mulloway-exclusion characteristics of conventional codends with two designs that incorporated square-mesh panels in the codends. These designs took advantage of the different behaviours of prawns and fish when caught in a prawn trawl by providing the swimming juvenile fish avenues of escapement before reaching the base of the codend. The results showed that square-mesh panels in codends retained most of the prawns targeted (Metapenaeus macleayi) whilst excluding significant numbers of juvenile mulloway (Argyrosomus hololepidotus). This gear modification showed great potential and further refinements of the designs should enhance prawn retention and exclude even larger numbers of small fish (see also work done overseas by Robertson, 1983; Isaksen & Valdermarsen, 1986; Suuronen, 1990; Walsh et al., 1992).

At an International Conference on By-catch in the Shrimp Industry (SEFA, 1992) a plethora of different modifications to prawn trawls and fishing practices that reduced by-catches were presented. These included the Nordmore grid, TEDs, fish-eyes, short trawl nets, square-mesh panels, sorting machines, short tows, etc. Whilst many of these designs were shown to be effective in their respective fisheries, one of the conclusions from this conference was that the type of modification appropriate for any given fishery depended on the prawns that are being targeted, the type of by-catch that is to be excluded, the nature of the trawling grounds and the fishing practices and vessels employed in the fishery. No one modification was found which would work universally, but the types of modifications that may be appropriate in any particular fishery are well-known and documented in the international literature (see references in SEFA, 1992).

The answer, of course, is to do the relevant research on gears and fishing practices on a fishery-by-fishery basis, within the objective of retaining target species whilst excluding unwanted by-catch. Research along these lines should also examine the effects of any trawl modifications on the survival of the excluded by-catch so that effects of damage incurred by escaping fish, for example as they pass through panels, are minimized. Whilst this latter problem has only recently begun to attract the attention of gear technologists overseas and has been shown in some cases to be negligible (e.g. DeAlteris & Castro, 1992), it is of obvious importance in any future work on trawl modifications.

It is important to have industry actively involved in any study seeking to develop and implement modifications to trawl gears and fishing practices that reduce by-catches. This involvement has two advantages: (i) industry are seen to be a driving force in addressing potential problems that other fisheries and the public may see as deriving from the by-catch of large numbers of juvenile fish; and (ii) scientists and managers can fully utilize industry's unique practical knowledge of the relevant gear technology as it applies to their fisheries.

CONCLUSIONS

In general, the chief problems associated with trawl by-catch concern conflicts between trawl fisheries and other fisheries that target species discarded from trawling (i.e. fishery-interaction problems). Research into this issue in Australia has been relatively scarce and has concentrated on attempts to describe and quantify the highly variable but very large quantities and diversities of trawl by-catches. These descriptive aspects of the issue are a pre-requisite to understanding and eventually managing these problems. There also has been some work on estimating actual impacts of trawl by-catch on interacting fisheries and significant inroads have been made in understanding the fate of discards as food for other organisms and effects of trawling on habitats and consequences for macrobenthic assemblages.

Unfortunately, however, the situation in Australia has been slow to progress to the next stage of solving the perceived problems. Eighty eight years ago, Dannevig (1904) did the first observer-based survey of the by-catch of an Australian prawn fishery and it is surprising that, for most fisheries, researchers still need to obtain such quantitative descriptions of by-catches. After 88 years, we should be in a position to solve these problems and assess the effectiveness of various management alternatives. Sainsbury's work on the Northwest Shelf does this for a certain type of management strategy but the very small amount of work done on more selective trawl configurations and handling practices is unfortunate and obviously needs attention.

It is clearly necessary to describe and quantify by-catches in specific fisheries (in order to assess whether any problems exist) and the best way to do this is via on-board samping of by-catches under normal commercial operations. But such work in itself is insufficient in solving the problems that arise when these by-catches are described. Once this preliminary descriptive work is done, it is necessary to test the effectiveness of alternative management strategies which may alleviate any problems that have been detected.

I am sure that Dannevig would be surprised at the lack of advances in the field of by-catch in Australia over the past 88 years. With the high priority and high profile currently being given to this issue in Australia and throughout the world, however, I am confident that the next 10 years will see substantial advances in not only understanding the complexities involved but also in solving some of the perceived problems.

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APPENDIX C

The effect of shrimp trawling by-catch on other commercial and recreational fisheries - an Australian perspective.

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The Effect of Shrimp Trawling ByCatch On Other Commercial and Recreational Fisheries - An Australian Perspective

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ABSTRACT

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As shrimp and fish trawling accounts for the majority of commercial fisheries production in New South Wales, Australia, the effect of their by-catch on the stocks of component species is fundamental to many of our fisheries assessment and management priorities. In recent years, the assessment of the impact of by-catch has become particularly important as conflicts with other commercial and recreational fisheries have escalated. A major current research initiative is an assessment of the by-catch of oceanic and estuarine shrimp trawling and the impact that this has on other commercial and recreational fisheries.

There are several major components to our research. The first involves quantifying the by-catch of shrimp trawlers via the regular collection of data by onboard "observers" throughout NSW. This involves recording the weights, counts and lengths of animals caught in trawls, in addition to operational data (location, date, time of day/night, trawl duration, gear-type, etc.). All trawls from replicated, randomly-selected fishing traps are censussed every month from several oceanic ports and estuaries in NSW, encompassing the geographical ranges of these fisheries.

Monthly effort data obtained from commercial shrimp trawlers enable us to derive estimates of the total numbers of days fished by individual fleets. These are used in combination with catch rates from the observer programs to estimate total by-catches by fleets in different places and times. Estimates of growth rates and natural mortalities can then be used to determine the expected consequences that such impacts may have on fish stocks in subsequent years.

Experimental assessments of alternative gear-types with the potential to reduce by-catch have also been completed. This work examined effects of long sweeps on trawls, assessments of the potential effectiveness of TEDs (Trash Elimination Devices) and square-mesh codends.

Data from the first part of our 3 year project concerning the above components are presented for two of the key commercial and recreational finfishes which are caught as by-catch by shrimp trawlers in NSW: snapper (Pagrus auratus F: Sparidae) and mulloway (Argyrosomus holoepidotus F: Sciaenidae). These are data summarize (i) the large quantities of these species that are caught by shrimp trawlers in various parts of NSW, at various times and (ii) potential ways of minimizing these impacts via temporal and geographic closures and gear modifications such as TEDs and square-mesh codends.

INTRODUCTION

For many years, by-catch from shrimp trawling (defined here as that part of the trawled fauna that is not shrimp) has been known to be large in both its quantity and diversity (Slavin, 1982; Gulland & Rothschild, 1984). In most countries and fisheries, some or all of this by-catch is considered as a "bonus from the sea" and it is utilized as a source of protein for human or animal consumption (IDRC, 1982; Saila, 1983). Recently, however, more negative aspects of shrimp trawl by-catch have been emphasized as the mortality of by-caught fish is thought to reduce the subsequent stocks of fisheries which target such species (Gordon, 1988; Foldren, 1989; Cooper, 1990; Ohaus, 1990). These negative aspects may range from relatively simple effects (such as the direct mortality of juveniles due to trawling and discarding practices) through to more complex effects on community structure such as habitat degradation, influences on species interactions and their consequent cascading effects throughout the food web (for a recent review see Andrew & Pepperell, 1992). In the last few years, there has been an increased awareness of such problems of shrimp trawl by-catch, making this one of the most important and critical issues facing commercial and recreational fisheries throughout the world.

In New South Wales, Australia, demersal trawling for shrimp and fish accounts for the majority of the production (in weight and value) of commercial fisheries (approx. $A45m per annum). Over the past 5 years throughout Australia, the by-catch from these activities has become of increasing concern to a broad cross-section of the community, particularly commercial fishers other than trawlers (e.g. fish trappers, set and hand-liners, mesh netters, beach seiners), recreational fishers, conservationists, environmentalists, fisheries managers, scientists and politicians from all levels of government. Of major concern in NSW have been complaints regarding shrimp and fish trawlers catching and discarding large numbers of undersize fish that, when larger, are targeted in other commercial and recreational fisheries. In particular, these observations are made with respect to shrimp trawlers working in estuarine and oceanic locations thought to be nursery grounds for several important finfish species.

Five years ago we recognized this increasing conflict and discovered that, despite a great deal of anecdotal and observational information, there existed virtually no data on the identities, quantities, timing or locations of the by-catches of estuarine and oceanic shrimp trawlers (but see Gray et al., 1990). As a first step in providing management recommendations concerning this issue, we therefore began to identify and quantify spatial and temporal differences in the by-catch from these trawlers. This was done through intensive observer programs which determined average catch rates (and associated variances) by trawlers per day/night of fishing. From these catch rates and estimates of effort by whole fleets (available as total trawler days/nights), we were able to extrapolate estimates of the total catches by fleets for different regions and times.

Using these estimates, we could measure the impact of estuarine and oceanic shrimp trawling on by-caught species in these places and times. Of course, in isolation, such information does not equate to a quantification of the effect that such impacts have on subsequent stocks of the commercial and recreational fisheries for these species. This can only be done by (i) having some knowledge of the mortality of these discarded animals, and (ii) incorporating estimates of natural mortalities and growth rates of each species from the sizes at capture by shrimp trawlers to post-legal sizes. Whilst we have few estimates of these parameters for many of the key finfish in NSW, some are available for the species of interest in this paper.

In addition to these descriptive phases of our project, we also executed a series of independent surveys of the relative distributions and abundances of shrimps and by-catch species. These provided additional estimates of the impacts of shrimp trawling and short-term assessments of any increases and/or decreases in the relative abundances of the sampled species. This was done via stratified, randomized surveys on the main oceanic shrimp trawling grounds (using our 26m research vessel - see Kennelly et al., in press) and in estuarine grounds using chartered commercial vessels. We forego a discussion of these surveys here as they are published elsewhere. Instead we wish to (i) concentrate on the results from our observer programs by describing the by-catch from various shrimp trawl fisheries and (ii) detail some of our experiments and comparisons that address ways of dealing with some of the problems identified in the observer programs (via the consideration of temporal and geographical closures and various gear modifications).

In this project, over 230 species have been recorded as by-catch in the estuarine and oceanic observer programs. 103 species are considered commercially and/or recreationally valuable. For the sake of brevity, and in order to illustrate the types of information we are generating, we present data for only two of the most important commercial and recreational species in NSW, the common snapper (*Pagrus auratus* F: Sparidae) and the mulloway (*Argyrosomus hololepidotus* F: Sciaenidae).

MATERIALS AND METHODS

Estuarine and oceanic observer programs

Fig. 1 shows the north coast of NSW, encompassing the range of the major shrimp trawl fisheries in the state. These fisheries mainly target two species, the eastern king prawn (*Penaeus plebejus*) at night and the eastern school prawn (*Metapenaeus macleayi*) during the day or night. Estuarine shrimp trawling occurs in 5 estuaries in NSW, mainly during the summer period. Oceanic shrimp trawling occurs out of 11 ports along the coast in all seasons.

In each month that shrimp trawling has occurred since late 1989, we have attempted to place scientific observers on board 4 randomly-selected boats during a typical day's (or night's) trawling in each of 4 estuaries (Botany Bay, Sydney Harbour, the Hawkesbury and Clarence Rivers). Similarly, in each season, we aimed to have observers on 12 randomly-selected vessels doing a typical day's (or night's) trawling out of 4 oceanic ports (Port Stephens, Coffs Harbour, the Clarence River and Ballina). During these trips, the catch and by-catch from each tow were placed on the sorting tray and then sorted by the crew and our observer, separating the various species. All the commercially and recreationally-important species were counted and measured. Other non-commercial species were identified and in estuaries they were counted. Because of the quantities of catch and by-catch caught in oceanic waters, we randomly subsampled the catch and took detailed measurements and weights on a known fraction of the total. For each tow, we also recorded the time, location, depth and duration of the tow, as well as the gear configuration used. Because boat-trips were randomly sampled each month (in estuaries) and each season (on oceanic grounds), average catch rates and variances were calculated per month/season from replicate boat-trips rather than replicate tows. Whilst the latter method would have provided greater replication (and smaller variances), one cannot assume that individual tows were independent - in fact, usual fishing practices indicate the opposite. Further, estimates of effort by fleets (used below in extrapolating by-catch rates to whole fleets) are only available in units of boat-trips.

As mentioned in the Introduction, the catch rates per trip (and associated variances) for each port/estuary for each month/season can be extrapolated to estimate catches by whole fleets for each location in each month/season using the total numbers of boat-trips done by the fleet (using rules for the derivation of standard errors of combination estimates, e.g. Myers and Shelton, 1980). These estimates of trawling effort are available in NSW via reports that fishers are legally required to submit on a monthly basis. Whilst such effort data may be inaccurate due to incorrect completion of forms by fishers, they are the best available. Here we assumed that these data were precise to within 10% of the true figure (i.e. the co-efficient of variation was assumed to be 10%).

Examinations of ways to minimize impacts of by-catch

Temporal and geographic closures

An examination of the average catch rates of snapper and mulloway from the estuarine and oceanic observer programs provided details of the locations and times that produced large by-catches of these species. This information is presented separately for each estuary and oceanic port, for each month/season of sampling. If the patterns in this data prove to be consistent in subsequent years of our observer programs, then they may indicate where and when spatial and temporal closures could be implemented if management wishes to minimize impacts of shrimp trawling on snapper and mulloway, regardless of the relative catches of shrimp. Of course, relating these places and times to the corresponding catches of shrimp would permit an estimate of the possible effects such closures may have on the shrimp fisheries. We have decided to leave this latter comparison for later publications which will incorporate results from an ancillary project which is developing yield per recruit models for the shrimp species involved.

Comparisons of alternative gears

Three different gear modifications were examined for their potential to reduce by-catch. The first involved an examination of the effects of different lengths of sweeps on the by-catch of oceanic shrimp trawlers (see Andrew et. al., 1992). The second involved assessing the utility of soft TEDs (Trash Elimination Devices - similar to the Morrison Soft TED - Kendall, 1990) in reducing by-catch on oceanic shrimp grounds (Andrew et al., -

submitted manuscript). As these experiments are published elsewhere, we do not discuss them here.

Some assessment of the utility of soft TEDs in estuaries was possible by comparing catch rates by trawlers in one of the estuaries sampled during the observer program - Botany Bay, where large numbers of juvenile snapper are sometimes caught as by-catch (described below). Fortuitously, approximately half the fleet in this estuary use TEDs to exclude unwanted jellyfish which often occur in the bay and hinder the effectiveness of the trawls. The other half of the fleet choose not to use TEDs. A comparison of the data obtained from our random sampling of these two groups of vessels (with and without TEDs) over the past few seasons gave us some information on the potential for TEDs to reduce the impact of shrimp trawling on these juvenile snapper.

A third gear modification that we investigated aimed to reduce the by-catch of juvenile mulloway in the Hawkesbury River (which is shown below to be large at certain times of the year). This experiment involved a comparison of 3 designs of codend. The control codend (the conventional one used in this fishery) was hung such that the 40mm meshes were diamond-shaped. The second codend had the netting hung such that the whole codend was comprised of square-shaped meshes. The third codend was a combination of these, with the basal half of the codend hung with diamond-shaped meshes and the upper half hung with square-shaped meshes. This latter configuration was designed to retain shrimps in the back of the codend, whilst allowing juvenile mulloway to escape from the anterior, square-shaped openings where water flows out of the codend (see also Briggs, 1992). Over a period of 10 days in the fall (the time of the year when juvenile mulloway are caught in large numbers), 30 replicate tows, each of 30 minutes duration, were done using each of these codends. In this experiment, the order and location of 3 replicate tows of each codend (a total of 9 tows per day) were randomized throughout each day.

RESULTS

Estuarine and oceanic observer programs

Fig. 2 summarizes the catch rates of snapper and mulloway by oceanic shrimp trawlers operating out of the 4 sampled ports for the first 6 seasons of our 3 year sampling program. The greatest catch rates of snapper from these trawlers occurred offshore from the Clarence River in summer and fall. Catch rates of snapper off other ports was negligible, as were the catch rates of mulloway off all ports (note the order-of-magnitude difference in the scales of the vertical axes on the two graphs).

Fig. 3 summarizes the catch rates of snapper and mulloway by estuarine shrimp trawlers operating in the 4 sampled estuaries for the first 19 months of our 3 year sampling program. The Clarence River, Sydney Harbour and Botany Bay are closed to trawling during the winter. As seen in Fig. 3, the greatest catch rates of snapper by estuarine trawlers occurred in Botany Bay, with smaller catch rates occurring in Sydney Harbour. For mulloway, by far the greatest catch rates occurred in the Hawkesbury River, with smaller catch rates recorded in the Clarence River.

Fig. 4 focusses on the largest catch rates identified from the observer programs. It shows estimates of the total by-catch of snapper from oceanic trawling off Ballina, the Clarence and Coffs Harbour and in the Botany Bay and Sydney Harbour estuaries, and that of mulloway in the Clarence and Hawkesbury Rivers. This is done for those periods that were (i) included in the observer programs and (ii) had estimates available for total trawling effort that could be used in extrapolations (a time lag in the collection and processing of these latter data precludes similar extrapolations for more recent periods).

The results show that quite large numbers of snapper were caught by oceanic shrimp trawlers off the Clarence in the fall and winter of 1990 and also in Botany Bay during the 1989-90 season. Whilst negligible by-catches of mulloway were estimated for oceanic shrimp trawling, quite large numbers were caught by that part of the Hawkesbury River fleet that was sampled during the 1990 calendar year (estimated to be approx. 50% of the shrimp trawl fleet in that river). Smaller total catches were estimated for the Clarence River in the 1989-90 season.

Comparisons of snapper by-caught in Botany Bay by shrimp trawlers with and without TEDs

Fig. 5 shows the size-structures of snapper by-caught by shrimp trawlers in Botany Bay that used/didn't use TEDs to exclude jellyfish. The results showed that larger snapper tended to be excluded from the by-catch when TEDs were used.

Experimental assessment of effects of square-mesh codends on catches of shrimp and mulloway in the Hawkesbury River

Fig. 6 shows the average catches of shrimps and mulloway (per 30 min tow) in the various types of codend that were tested. On average, the codend made entirely of square-shaped mesh caught 47.8% of the weight of shrimps that the conventional codend caught, whilst the average by-catch of mulloway was reduced by 95.2%. The codend made of both diamond-shaped and square-shaped mesh showed an average catch of shrimps that was 83.9% of that caught in the conventional codend, whilst the by-catch of mulloway was reduced by 54.3%.

DISCUSSION

The catch rates of snapper and mulloway that were derived from our estuarine and oceanic observer programs illustrate the utility of this type of data in isolating where and when large by-catches from shrimp trawling occurs for these species (Figs. 2 & 3). The data presented here only represent the first half of our full sampling program, but if the trends depicted in the figures are consistent throughout the second half, we would feel confident in recommending to fisheries managers the kinds of geographic and temporal closures to shrimp trawling that may be appropriate to minimize impacts on these species (should such management tools be used). For example, if the trends seen in Fig. 2 continue over the next 18 months, then oceanic trawling off the Clarence River may be considered a problem area for snapper during summer, fall and winter and would warrant a close examination of our tow-by-tow location data. This would help to determine if certain regions in this location are the chief sources of this snapper by-catch. Similarly, shrimp trawling effort in Botany Bay may have to be reduced if the large by-catches of snapper that occur during the shrimp trawling season (Fig. 3) prove to be consistent and represent a significant contribution to the total mortality of juvenile snapper. Further, some spatial and temporal closures may be required in the Hawkesbury River to minimize the by-catch of mulloway that occurs there outside summer. Again, more detailed analyses of the information on the locations of individual tows obtained during the observer programs will assist in isolating problem areas. At the end of our project later this year, and after analyses of the complete data sets, we should have a robust picture of the consistencies of spatial and temporal fluctuations in the by-catches of key species. If such patterns are not consistent in different years, yet the problem is considered serious enough to warrant management, flexible closures may have to be implemented which would be based on the levels of by-catch detected in ongoing monitoring programs.

Another vital piece of information that our observer programs provided was the identification of a very large and diverse assemblage of species that are by-caught by shrimp trawling in NSW. As mentioned in the Introduction, more than 230 species have been recorded as by-catch during our observer programs, 103 of which are considered to be commercially and/or recreationally valuable. Only two of the more important species were discussed in this paper as examples, but after complete analysis of all our data, we will be able to generate similar information for all species.

The potential recommendations of spatial and temporal closures discussed above may not be the appropriate management tools for all, or indeed any, of the species, places or times examined. For example, the information provided in Figs. 5 & 6 (discussed below) suggest the potential utility of gear modifications in minimizing negative aspects of shrimp trawl by-catch. Nevertheless, we stress that observer programs such as those described above, permit one to be confident of determining where, when and what species are involved in potential impacts.

Fig. 4 shows the estimated total by-catches of snapper and mulloway for those locations and times for which extrapolations were possible. The estimates suggest that quite large numbers of snapper may have been caught and discarded by oceanic shrimp trawlers off the Clarence during certain periods (the median estimate is in the order of 300,000 fish) and in Botany Bay during the shrimp trawling season in 1989-90 (median estimate of around 350,000 fish). For mulloway, smaller numbers were involved, with negligible by-catches occurring during oceanic shrimp trawling operations, but a median estimate of around 100,000 fish by-caught by that subset of the Hawkesbury River fleet that was sampled during the 1990 calendar year. Whilst we have presented no data on the fate of these discarded fish, field observations indicated that only a very small percentage survived trawling operations (as found in other studies, e.g. Wassenberg & Hill, 1989). Some of the small snapper and mulloway discussed in this paper were dead when the codends were retrieved, caused either by drowning, squashing or being stung by venomous by-catch in the codends. Once emptied from the codend, more fish died as the catch was usually sorted out of water and, once discarded (alive or dead) many fish were eaten by flocks of birds that usually aggregated around most shrimp trawlers surveyed (see also Wassenberg & Hill, 1990). We also know from aquaculture research that it is not uncommon for even the most carefully-handled juvenile snapper and mulloway to die 2-3 weeks after any form of handling (Bell, pers. comm.). Nevertheless, even if all the juvenile snapper and mulloway that were by-caught by shrimp trawlers died, this may mean very little to subsequent stocks of commercial and recreational fisheries for these species if most of these juveniles would have died of natural causes anyway (i.e. in the absence of shrimp trawling). Only by incorporating estimates of the natural mortalities of these species, their ages at legal size and our estimates of mortality due to shrimp trawling, can we begin to estimate any causal effects that shrimp trawl by-catch may have on fisheries for these species.

The only estimates of natural mortality we have for the 2 species discussed here are estimates for the same species of snapper in New Zealand (M = 0.46 per year - Vooren & Coombs, 1977) and the same species of mulloway in South Africa (M = 0.70 - estimated from Smale's, 1985, catch curve). Snapper in NSW are thought to reach legal-size at about 3 years old (unpublished data), whilst mulloway are thought to reach legal size at about 2 years old (Wallace & Schleyer, 1979). Using these pieces of information in combination with the median of our extrapolated estimates of total catches provided in Fig. 4, we can derive the following estimates as examples of the kinds of effects that shrimp trawling may have on subsequent stocks of these species:

The by-catch of snapper by oceanic shrimp trawlers off the Clarence in fall and winter 1990 may reduce the total number of snapper available to other fisheries 3 years later by about 71,000 fish. The by-catch of snapper by estuarine shrimp trawlers in Botany Bay during the 1989-90 season may reduce the total number of snapper available to other fisheries 3 years later by about 60,000 fish. The by-catch of mulloway by the sampled subset of estuarine shrimp trawlers in the Hawkesbury River during 1990 may reduce the total number of mulloway available to other fisheries 2 years later by about 11,000 fish, and the by-catch of mulloway by estuarine shrimp trawlers in the Clarence River during the 1989-90 season may reduce the total number of mulloway available to other fisheries 2 years later by about 4,000 fish. In the absence of reliable estimates of natural mortality at age, such figures will, of course, be questionable, but these calculations do illustrate the necessity to take account of natural mortality and rates of growth when interpreting very large by-catches of juvenile fish by shrimp trawlers in terms of consequences for other fisheries. More complete estimates of such effects will become available once the data from all 3 years of our observer programs are analyzed and incorporated with estimates of trawling effort. Despite this, however, final calculations of effects of such by-catches on other fisheries will always be subject to errors proportional to the reliability of estimates of natural mortalities at age for individual species. We anticipate that the length-frequency data gathered during this project will provide us with at least preliminary estimates of these mortalities.

Despite these uncertainties, it would be unwise not to explore ways of minimizing these potential effects of by-catch. One suite of management alternatives involves the above-mentioned geographic and temporal closures of shrimp trawling operations. Another group of possibilities involve gear modifications designed to reduce by-catch, whilst maintaining catches of shrimps. Fig. 5 suggests that the relative by-catch of larger snapper was reduced by those trawlers in Botany Bay that used TEDs to exclude jellyfish. Whilst this comparison was not a proper experimental evaluation of this gear-type, it does suggest that TEDs hold some potential for minimizing impacts of shrimp trawling on this species. We anticipate exploring this potential further by doing formal experimental trials.

In this paper we described an example of a formal experimental gear trial via our assessment of the utility of square-mesh codends. The results from this experiment (Fig. 6) showed that square mesh panels in codends have great potential for reducing the by-catch of juvenile fish, particularly the relatively fusiform mulloway, without large declines in catch rates of shrimps. The recommendation from this experiment would be to refine these codends such that they further reduce by-catches of mulloway, whilst maintaining catches of shrimps. Such work could then lead to the implementation of such gears by managers in those places and at those times of the year where the by-catch of such fish is considered to be a problem.

Whether fisheries managers adopt all or any of the alternative strategies discussed in this paper (e.g. closures and/or gear modifications) will depend on the degree to which effects of by-catch are considered important. This decision must take into account not only the sorts of impacts on other fisheries that have been discussed here, but also the very important economic considerations associated with maintaining catches of shrimps in these valuable fisheries.

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Fig. 1. Map showing the location of the 4 oceanic ports and 4 estuaries that were sampled in the observer programs. Depth contours are 20, 60, 100 and 200m.

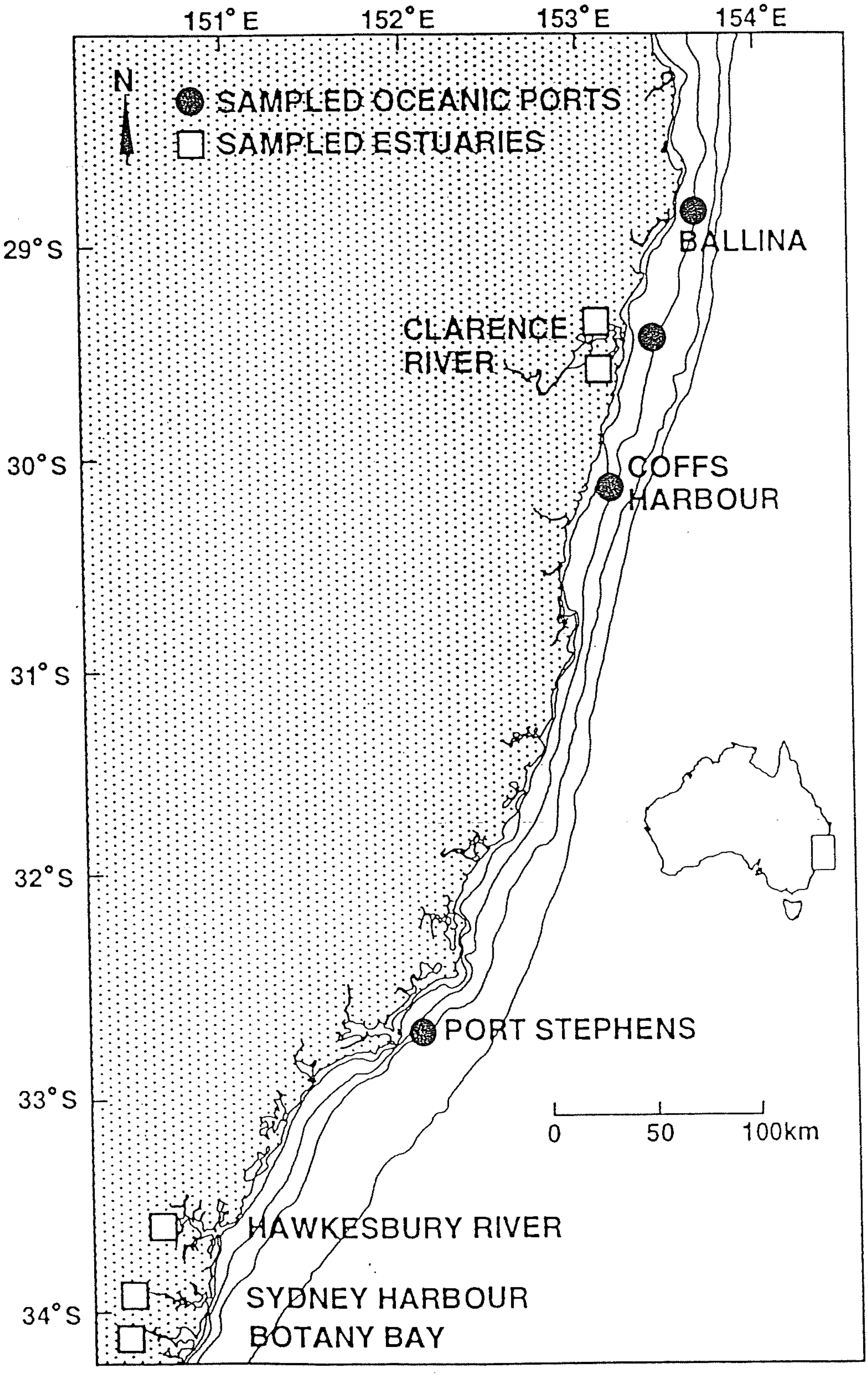


Fig. 3. Mean by-catches of snapper and mulloway estimated from estuarine shrimp trawling in the Clarence and Hawkesbury Rivers, Sydney Harbour and Botany Bay in each month.

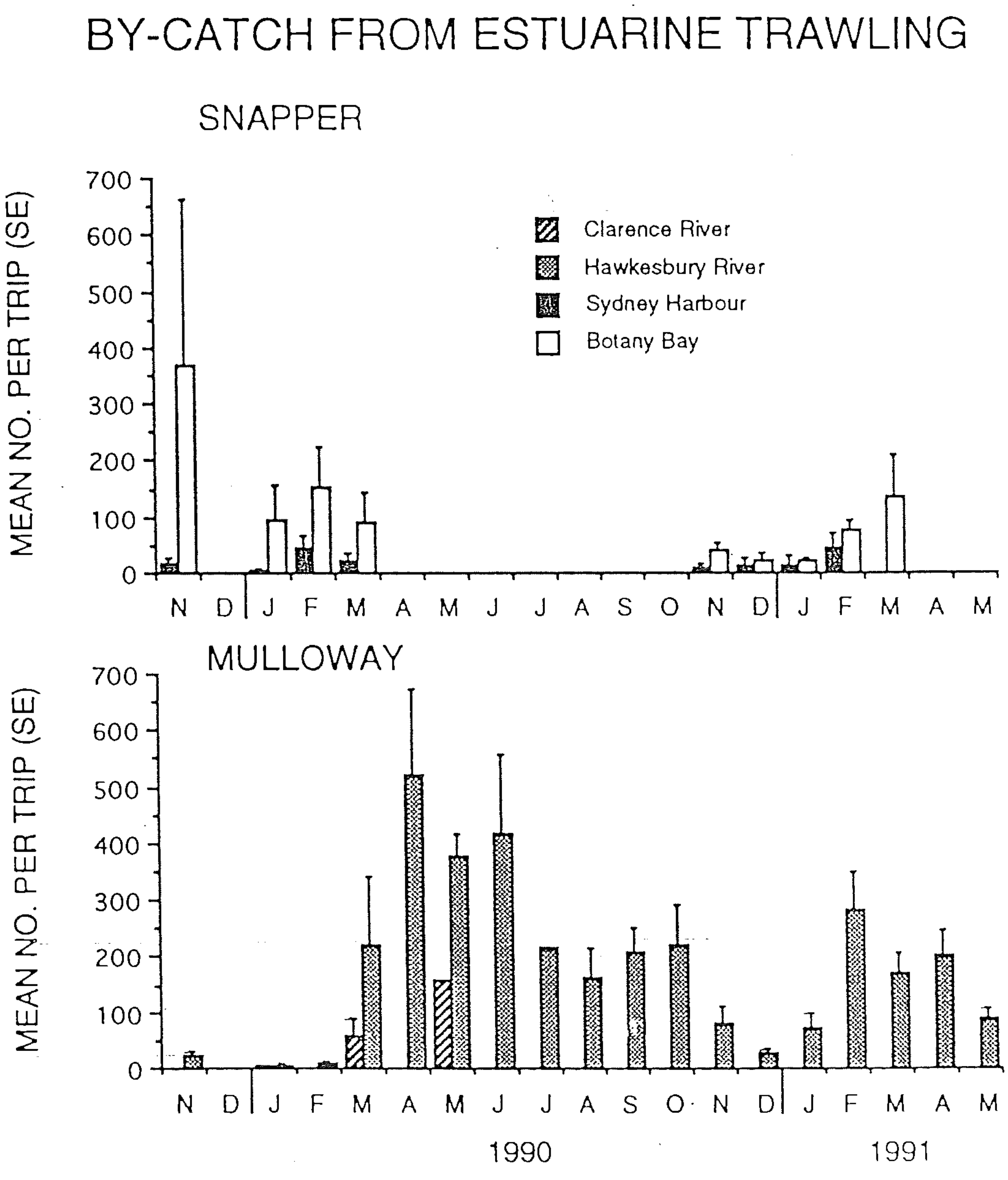


Fig. 2. Mean by-catches of snapper and mulloway estimated from oceanic shrimp trawling off Ballina, the Clarence River, Coffs Harbour and Port Stephens in each season.

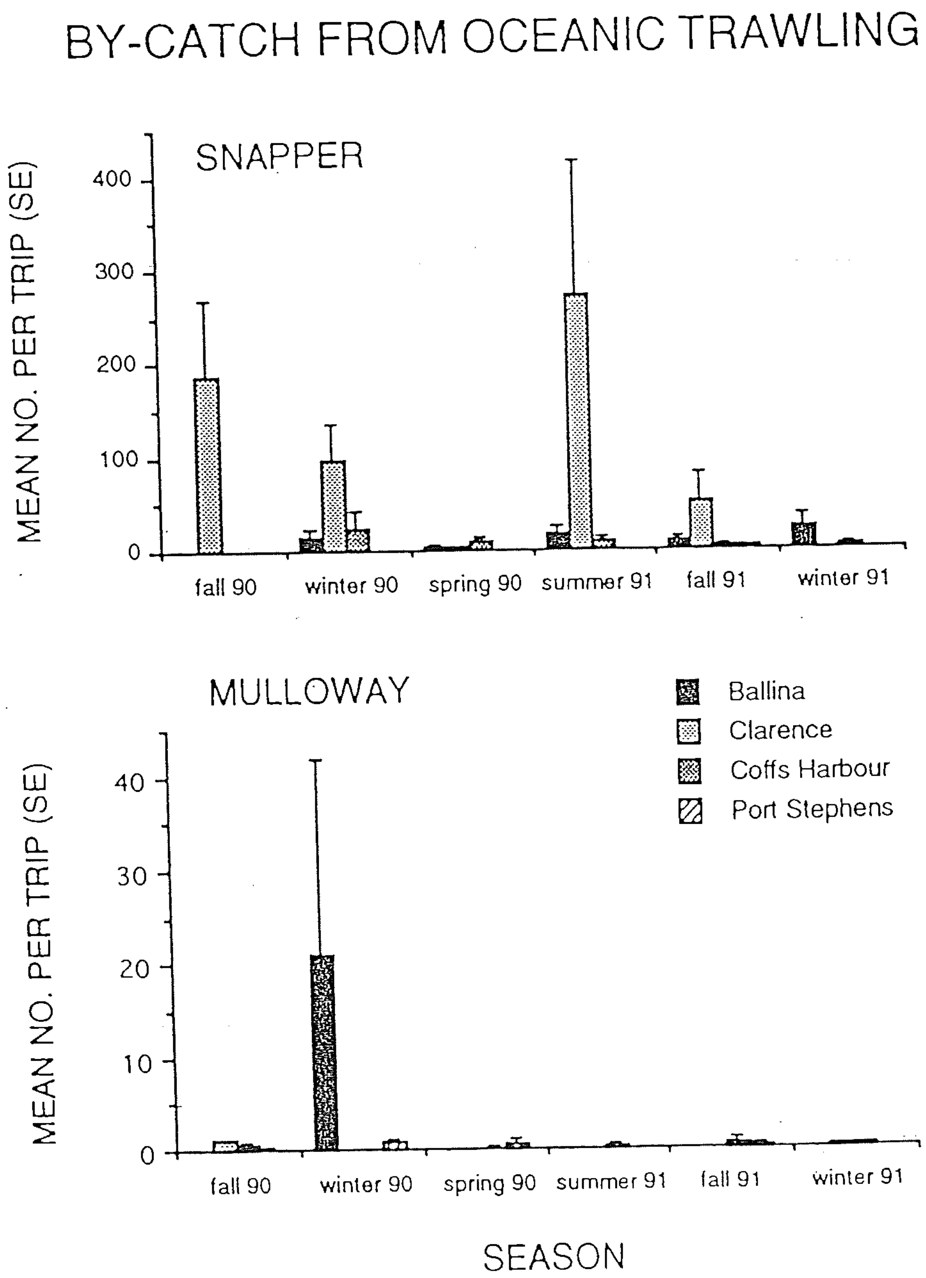


Fig. 5. The relative size-structures of populations of snapper caught by trawlers with and without TEDs in Botany Bay.

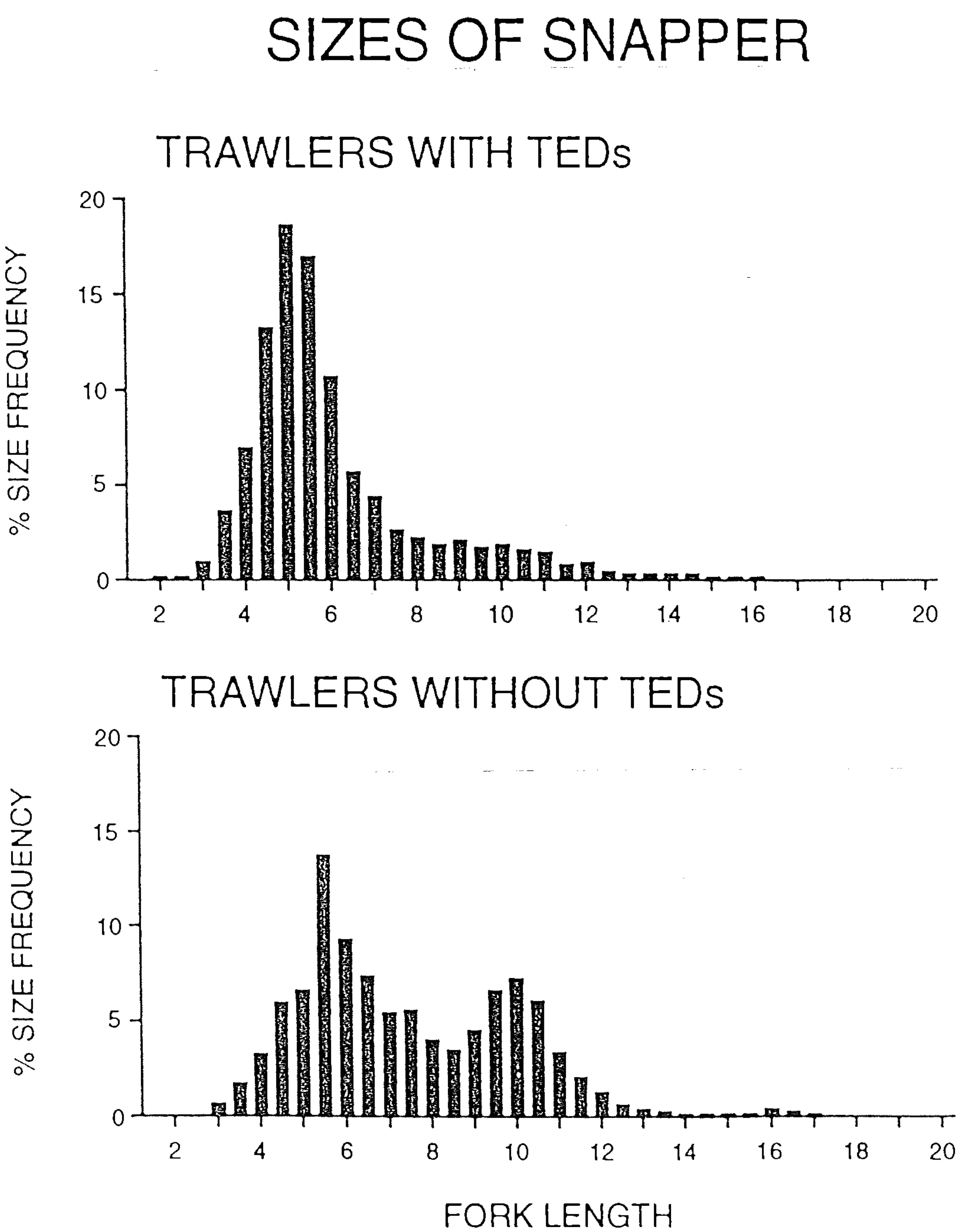


Fig. 4. Estimated total by-catches of snapper and mulloway from oceanic and estuarine shrimp trawling, calculated from mean catch rates and effort data on whole fleets.

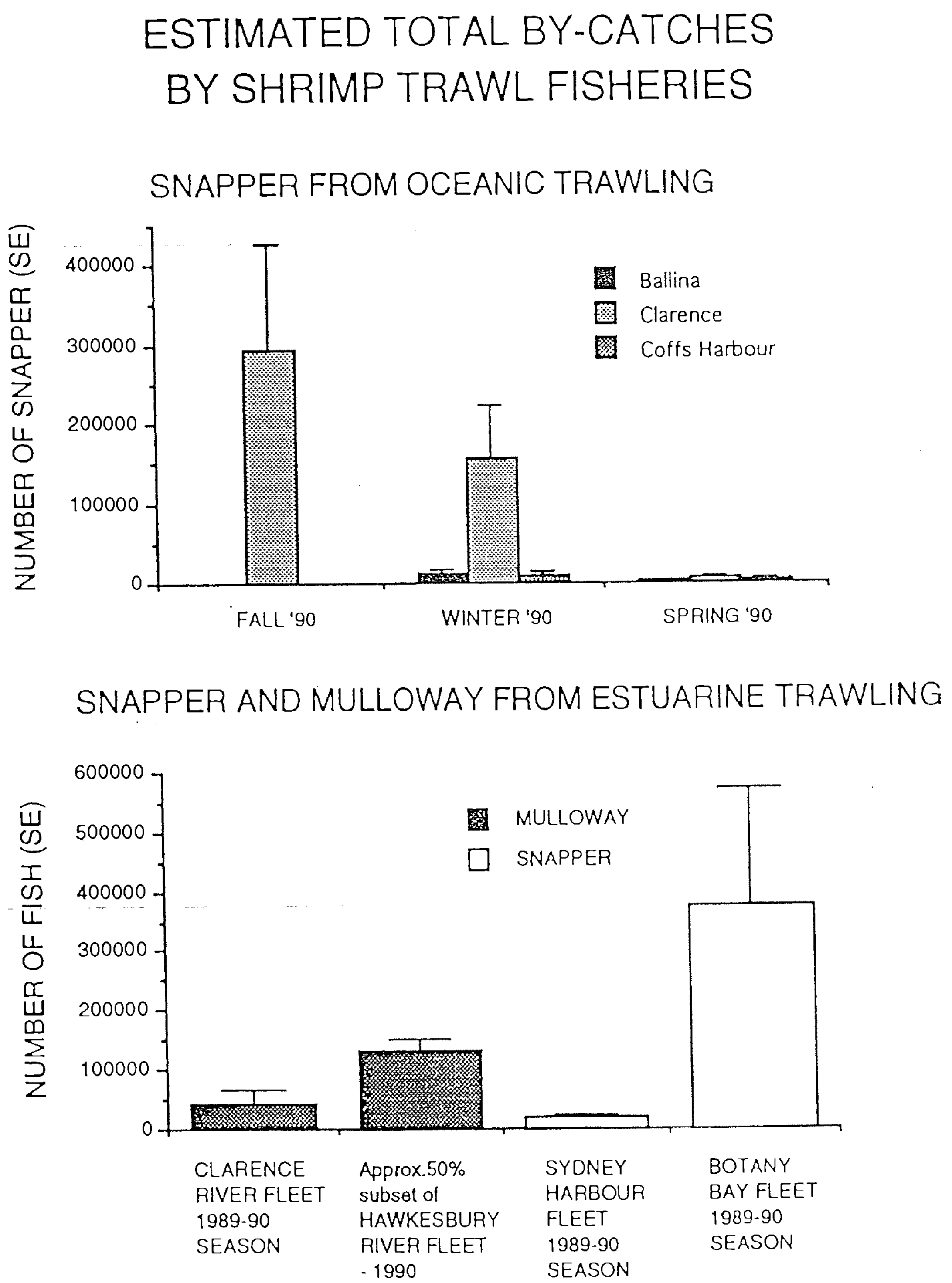
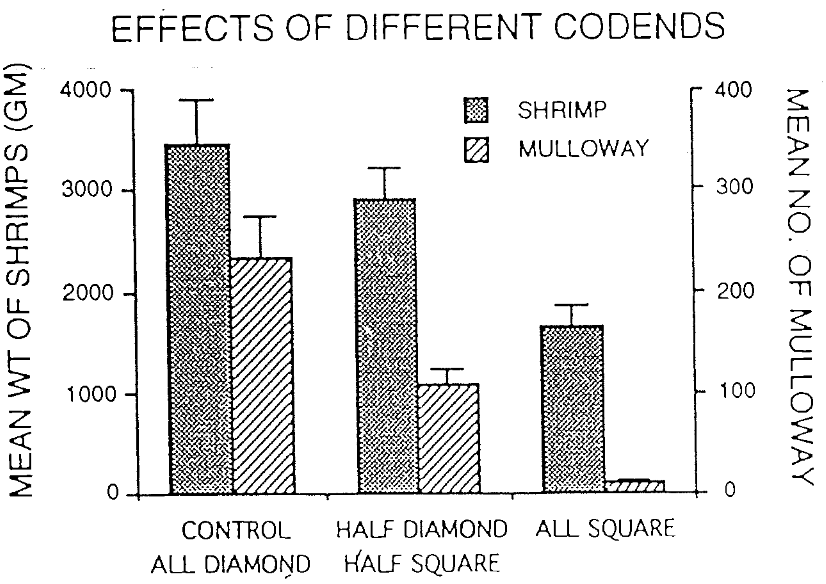


Fig. 6. Mean catch rates (per 30 min tow) of shrimps and mulloway in trawls with different codend configurations (n = 30).



APPENDIX D

Variance and cost-benefit analyses to determine optimal duration of tows and levels of replication for sampling relative abundances of species using demersal trawling.

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Variance and cost–benefit analyses to determine optimal duration of tows and levels of replication for sampling relative abundances of species using demersal trawling

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ABSTRACT

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The effects on catch per unit effort (CPUE) of trawlable species due to the duration of tows and temporal and spatial heterogeneity were examined using demersal trawling in the prawn grounds off the east coast of New South Wales, Australia. Standard trawls in a triple-rig configuration were used in a nested experimental design to compare catch rates in tows of various durations, during the day and night, in shallow and deep fishing grounds. Significant effects from all these factors were detected, but the kinds and degrees of these effects differed among variables. To determine the degree of spatial and short-term temporal variability in CPUE, a pilot survey was completed where replicate tows were done at various locations on replicate days (school prawn grounds) and nights (king prawn grounds). Cost–benefit analyses determined optimal CPUE estimates of species given (i) the time available to survey a location during any sample period, and (ii) the sizes of variances among tows and days/nights. The consequences of this replication on the sizes of standard errors in subsequent sampling were estimated. A uniform and optimal methodology was developed which is currently being used in surveys of the New South Wales prawn trawl grounds.

INTRODUCTION

In the research and management of marine fisheries, direct sampling of individuals (by in situ counting) is usually impossible. Estimates of abundance are frequently derived, therefore, from catch per unit of effort data (CPUE) which use the quantity of individuals caught with a known fishing effort as an index of abundance for that place and time. In most cases, these

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CPUE estimates are obtained from commercial catch records of individual fishing vessels and fleets. Unfortunately, the catchability of species can vary among gear-types and so affect the usefulness and accuracy of such data for representing trends in total abundances (Collie and Sissenwine, 1983). As indices of abundance, CPUE data are more useful, therefore, if they are treated as relative indices and compared with each other in appropriate surveys (Clark, 1979; Sissenwine et al., 1983). The methods used in such surveys would ideally be uniform, unbiased, optimal with respect to the quantity and diversity of catch obtained and sufficiently replicated in space and time to account for patchiness in distributions (Byrne et al., 1981; Collie and Sissenwine, 1983; Kennelly, 1989). As a consequence, there have been many studies in the fisheries literature which have examined the reliability and accuracy of methods used to sample abundances of species via the collection of CPUE data (e.g. Kjelson and Colby, 1977; Collie and Sissenwine, 1983; Miller, 1983; Neilsen, 1983; Sissenwine et al., 1983).

Previous studies have examined the usefulness of benthic trawling for sampling relative abundances of prawns and other species (e.g. Taylor, 1953; Jones, 1956; Roessler, 1965; Clark, 1974, 1979; Byrne et al., 1981; Doubleday and Rivard, 1981; Nielsen, 1983; Francis, 1984). Several conclusions can be derived from this literature in terms of the criteria that should be considered in designing a sampling regime for surveying the relative abundances of trawlable species. Apart from the obvious requirements that fishing gear, sorting and sampling techniques are standard and consistent for each replicate, two other characteristics of the survey must be determined a priori: (i) the optimal duration for tows; and (ii) the replication of tows throughout space and time (i.e. the formal design of the survey).

The duration of tows may directly affect the quantity, diversity and size composition of trawled species and consequently has been the focus of many previous papers (e.g. Cardador, 1983; Carothers and Chittendon, 1985; Sobajima et al., 1985; Godo et al., 1990). These experiments usually compare catch rates of replicate tows over a range of durations.

Spatial and temporal heterogeneity in the distributions and abundances of species directly influences estimates of average CPUE and therefore any derived inferences about relative abundances (Sissenwine, 1984; Kennelly, 1989). To account for such variability, it is necessary to replicate sampling in a way that provides the most reliable and representative estimates, within the logistic constraints of limited time and/or money. The choice of optimal numbers of replicates in any stratified, randomized survey of relative abundances can be calculated easily using cost–benefit and variance analyses of data from pilot surveys (Winer, 1971; Saila et al., 1976; Snedecor and Cochran, 1980; Underwood, 1981). These techniques have been used successfully in many habitats, from deserts and terrestrial plains (Robinette et al., 1974; Caughley et al., 1976) to kelp forests (Kennelly and Underwood, 1984, 1985) and coral reefs (Fowler, 1987). Cost–benefit analyses have also been applied to surveys of commercial fisheries, e.g. ocean shrimp (Abramson, 1968), age composition of Pacific herring (Schweigert and Sibert, 1983; see also discussions by Smith, 1984, and Schweigert, 1984), and spanner crabs (Kennelly, 1989). Leaman (1981) discussed cost–benefit techniques in the assessment of groundfish stocks and noted two problems in such applications: (i) the large and contagious distributions of species mean that expensive preliminary sampling must often be large-scale; and (ii) the decisions of the allocation of sampling effort can be difficult and complex where many species are involved in a given survey.

The ocean prawn-trawl fishery of New South Wales encompasses two fisheries. The first involves demersal trawling for eastern king prawns (*Penaeus plebejus*) in offshore waters (40–200 m depth), mainly during the night. The second targets eastern school prawns (*Metapenaeus macleayi*) in nearshore waters (10–30 m depth), mainly during the day. The by-catch component of each fishery comprises many species of untargetted, commercially and/or recreationally important fish and crustaceans and large quantities of non-commercial species.

In order to design a sampling regime for a survey of the relative abundances of demersal trawl species off the coast of New South Wales, we firstly determined the optimal duration of tows by examining the catches in tows of different durations. This was done across the range of conditions which are covered by the fisheries (day and night fishing in deep and shallow grounds). We also present cost–benefit and variance analyses on data from large-scale pilot surveys of the distributions and abundances of the assemblage of species caught by prawn trawling in both nearshore (school prawn grounds) and deeper areas (king prawn grounds). These estimate optimal levels of spatial and temporal replication which may be used in subsequent surveys on these assemblages.

MATERIALS AND METHODS

This study was done on the prawn grounds off the coast of New South Wales using the Fisheries Research Vessel 'Kapala' (see Fig. 1). To obtain CPUE data on those species caught by demersal prawn trawling, we used standard commercial fishing gear that is commonly used in eastern Australian fisheries (see Fig. 2). All trawls were 'Florida Flyers' with a headline length of 22 m. The trawls were connected to wooden otter boards (2.4 m × 1.1 m) with upper and lower bridles. For another description of the gear used see Fig. 2 in Andrew et al. (1991). This configuration was towed at a ground speed of 2.4–3.2 knots for one of three tow durations (see below). The vessel travelled in randomly-selected directions at 5 knots for 5 min between tows to provide independence of replicate tows during a day or night's sampling.

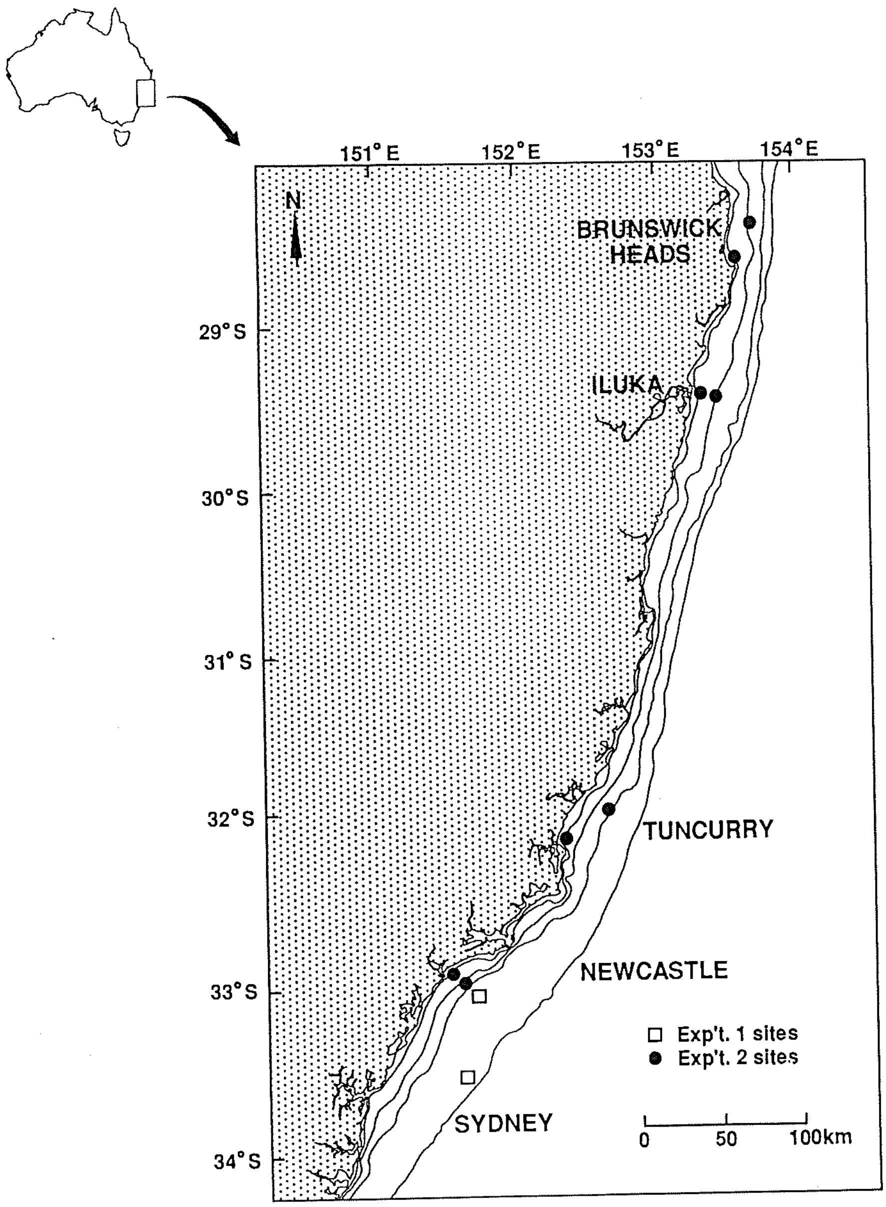

Fig. 1. Locations sampled in Experiments 1 and 2. Depth contours are 20, 60, 100 and 200 m.

When retrieved, the catches from the three codends were combined onto the sorting table for sampling. From each tow, the total weights and numbers of commercial fish and crustacean species were recorded. In addition, for each

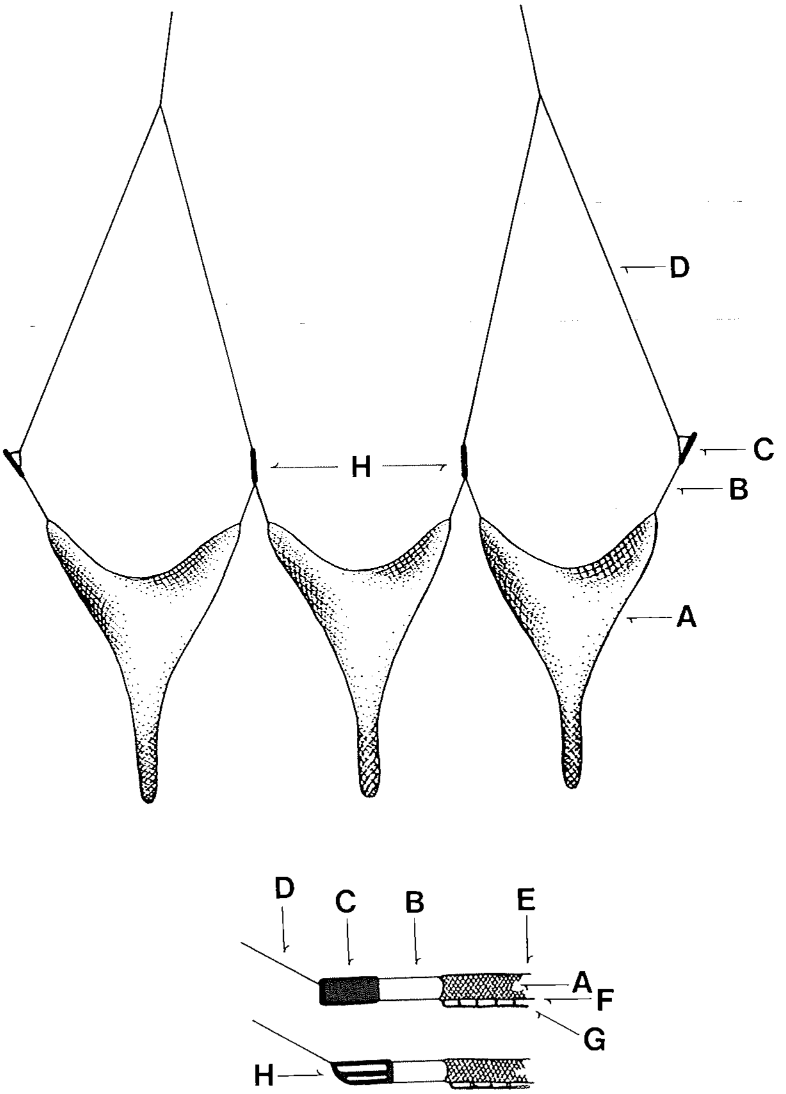

Fig. 2. Configuration of the triple-rigged trawl gear used. Insert shows details of otter boards and bridles: (A) net; (B) bridles; (C) otter boards; (D) wire warp; (E) headrope; (F) foot-rope; (G) groudchain; (H) sleds.

tow, we recorded the combined weight of by-catch, the number of species of finfish, crustaceans, molluscs, and the total number of species.

Experiment 1. Effects on CPUE due to tow duration, day/night sampling and depth

During a 3-week period in March 1990, four replicate tows of 15, 30 or 45 min duration were done during the day and night in deep water (155–175 m off Sydney) and in shallow water (45–55 m off Newcastle) (see Fig. 1).

Each set of data was tested for homogeneity of variances (Cochran's test), transformed if necessary (using square root and natural logarithms) and analysed in the relevant 2- or 3-factor fully orthogonal ANOVA (see Table 1). Student–Newman–Keuls (SNK) multiple comparisons were used to isolate significant differences among treatments in the ANOVAS.

Experiment 2 (pilot survey). Effects on CPUE of sampling on replicate days/nights and between replicate tows

Four replicate tows were completed on each of three replicate days/nights at each of two sites off the north coast (Brunswick Heads and Iluka) and mid-coast (Tuncurry and Newcastle) of New South Wales (see Fig. 1). These sites were selected as representative of the fishing grounds in the two main areas of the fishery off the north coast and mid-coast. All sampling was done in school prawn grounds (9–27 m depth) during the day and king prawn grounds (46–100 m depth) during the night. Tows of 30 min duration were used because this was chosen as the optimal time after completing Experiment 1.

To determine optimal numbers of days/nights and tows for sampling assemblages at any location and sampling period, cost–benefit analyses were done for 33 sets of data from school prawn grounds and 27 sets of data from king prawn grounds (scarce species, i.e. less than an average of one individual per tow, were excluded). The standard cost–benefit procedure was followed for each ground separately (e.g. Winer, 1971; Snedecor and Cochran, 1980; Underwood, 1981). In these analyses, the product of two sums is minimized (see below) to determine the optimal numbers of days/nights and tows in these analyses with two levels of replication (replicate days/nights done at any location and replicate tows during each day/night). These sums are the total cost of each sampling period and the variance of the estimated mean of each sampling period.

The restricting cost in this study was the amount of ship-time available to do the sampling. The total time available to sample one location during a sample period was 30 h. The time required to sample one tow was 1 h and the time taken to do a day/night's work (minus the time spent sampling) was 6 h. This latter cost includes travel to the sample site, preparations for sampling, storing gear after sampling and travel back to port.

The variance for estimated means in any such experimental design may be determined from the appropriate mean squares in the analysis of variance, by methods discussed in Winer (1971) and Underwood (1981). For the present study, the variance of the means on each day/night in each location is estimated by dividing the mean square representing day/night by the number of readings in each mean. These considerations lead to the following formulae.

The estimated variance of the means from a sampling period at a location is

$$\text{Variance} = (\sigma_e^2 + n_e \cdot \sigma_d^2)/n_e \cdot n_d \qquad (1)$$

where n_e is the number of replicate tows per day/night, n_d is the number of replicate days/nights, σ_e^2 is the estimated variance among replicate tows and σ_d^2 is the estimated variance among days/nights in each sample period and location.

$$\text{Cost of each sampling period at a location} = n_d \cdot n_e \cdot C_e + n_d \cdot C_s \qquad (2)$$

where n_d and n_e are as before, C_s is the cost per day/night (6 h here) and C_e is the cost per replicate tow (1 h here).

The product of eqns. (1) and (2) is minimized (by differentiation) to calculate the optimal number of replicate tows per day/night per sample period and location. Using these optimal numbers of replicate tows, the optimal numbers of days/nights to be sampled in any sample period and location is calculated from the cost equation (eqn. (1) above).

RESULTS

Experiment 1. Effects of tow duration, day/night sampling and depth

Fourteen sets of data were sufficient to warrant analysis in this experiment. These were the numbers of: 1, species of fish; 2, king prawns; 3, blue-swimmer crabs (*Portunus pelagicus*); 4, spider crabs (F: Majidae); 5, mantis shrimps (*Stomatopoda*); 6, snapper (*Pagrus auratus*); 7, tiger flathead (*Neoplatycephalus richardsoni*); 8, spiky flathead (*Ratabulus diversidens*); and the weights of: 9, all prawns; 10, all by-catch; 11, all crustacean by-catch; 12, shovelnose lobsters (*Ibacus* spp.); 13, red spot whiting (*Sillago bassensis*); 14, sand flathead (*Platycephalus caeruleopunctatus*). Of these variables, those presented in Table 1 had homogeneous variances or had variances which could be stabilized. Those variables which showed significant effects due to day/night or tow duration in SNK tests are presented in Fig. 3. Significantly more species of fish were caught during the night than during the day (Table 1(a); SNK tests of means in Fig. 3(a)). There were also significantly more species of fish caught in 45 min tows than in shorter tows at the shallow site at night and fewer species caught in 15 min tows than in longer tows at the deep site at night and the shallow site during the day. Despite a significant effect of the duration of tows in the ANOVA of the weights of all miscellaneous crusta-

TABLE 1

Summaries of analyses of variance[1] to determine effects on CPUE of various trawled species due to fishing at different depths, during the day and night and for different tow durations

(a) Treatment	d.f.	No. of species of fish	Weight of crustaceans
Shallow vs. deep (S)	1	ns	ns
Day vs. night (D)	1	**	ns
S×D	1	ns	ns
Tow duration (T)	2	**	*
S×T	2	ns	ns
D×T	2	ns	ns
S×D×T	2	ns	ns
Residual	36		

(b) Shallow site	df	No. of king prawns, *Penaeus plebejus*	Weight of shovelnose lobsters, *Ibacus* spp.	No. of blue-swimmer crabs, *Portunus pelagicus*	No. of snapper, *Pagrus auratus*	Weight of sand flathead, *Platycephalus caeruleopunctatus*
Day vs. night	1	**	ns	**	ns	ns
Tow duration	2	ns	ns	ns	ns	ns
D×T	2	ns	ns	ns	ns	ns
Residual	18					

Deep site	df	No. of tiger flathead, *Neoplatycephalus richardsoni*	No. of spiky flathead, *Ratabulus diversidens*
Day vs. night	1	ns	ns
Tow duration	2	**	*
D×T	2	ns	ns
Residual	18		

[1]To stabilize variances the weights of miscellaneous crustaceans, shovelnose lobsters and the numbers of blue-swimmer crabs, snapper and tiger flathead were transformed using sqr$(x+1)$, and the numbers of king prawns were transformed using $\ln(x+1)$.
ns=Non-significant ($P>0.05$); *significant ($P<0.05$); **significant ($P<0.01$).

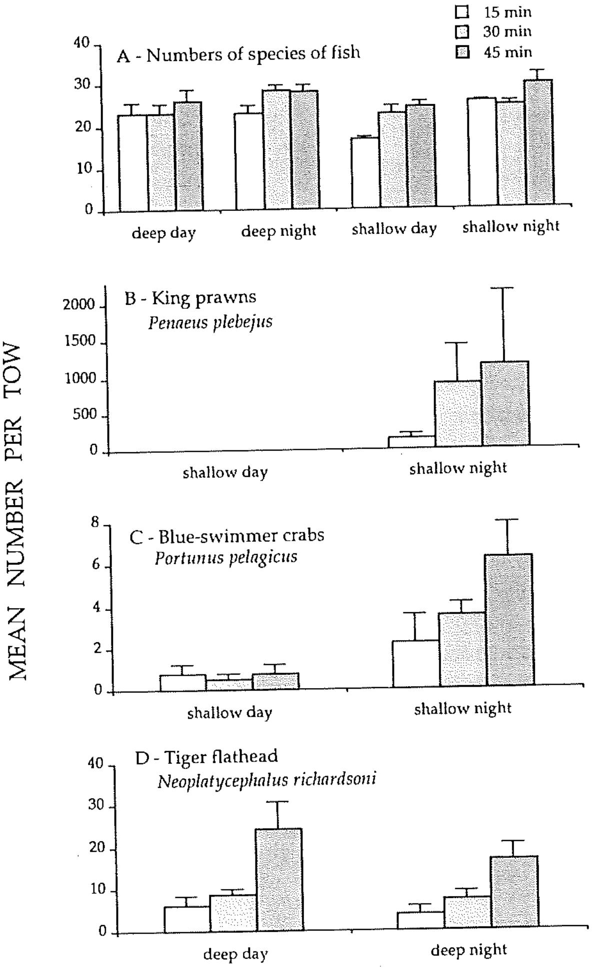

Fig. 3. Differences in the catches of those sets of data which showed statistically significant effects due to different trawl durations, in deep and shallow areas, during the day and night (mean ± SE, $n = 4$).

ceans caught (Table 1 (a)), there were no significant differences in SNK tests among means. All other variables occurred only at either the shallow or the deep site and were analysed accordingly (Table 1 (b)). In the shallow ground, there were significantly more king prawns and blue-swimmer crabs caught during the night than during the day, but despite a trend for catches to increase with increasing tow duration, these were not statistically significant (Figs. 3(b) and 3(c)). At the deep site, the numbers of tiger flathead and spiky flathead were similar during the day and night (Table 1 (b)). Significantly more tiger flathead were caught in 45 min tows than in tows of shorter duration (Fig. 3(d)). Despite a significant effect of the duration of tows for

TABLE 2

Summaries of cost–benefit analyses of data from the pilot survey

Set of data	Mean in pilot survey	Variance due to replicate trawls	Variance due to replicate days/nights	Optimal no. of trawls	Optimal no. of days/nights	Estimated SE using optimal replication (% of mean)	Estimated SE using selected replication (% of mean)
School prawn grounds							
Total no. of species	29.7	19.4	8.4	4	3	7.1	7.1
No. of fish species	22.9	16.8	3.7	6	3	6.4	7.1
No. of crustacean species	4.3	1.3	0.5	4	3	12.4	12.4
No. of cephalopod species	2.5	0.6	0	13	2	7.4	9.6
Stout whiting (*Sillago robusta*)	317	87321.7	187864.3	2	4	75.9	83.4
Red spot whiting (*Sillago bassensis*)	58.6	11546.9	1551.8	7	3	55.7	65.6
Sand flathead (*Platycephalus caeruleopunctatus*)	42.7	1728.2	501.5	5	3	39.4	41.3
Teraglin (*Atractoscion aequidens*)	10.2	262.2	55.8	6	3	56.5	62.4
Tailor (*Pomatomus saltator*)	8.2	364.4	121.1	5	3	97.9	102.4
Jewfish (*Argyrosomus hololepidotus*)	2.9	148	2	22	1	102.5	125.2
Snapper (*Pagrus auratus*)	2.4	72.4	1.7	16	2	74.3	108
Red gurnard (*Chelidonichthys kumu*)	13.1	163.7	1.5	26	1	21.3	28.7
Hairtail (*Trichiurus lepturus*)	1.3	7.4	1.8	5	3	81.6	86.1
Shovelnose ray (*Aptychotrema rostrata*)	3	9.1	2.3	5	3	38.7	40.8
Bottle squid (*Loliolus noctiluca*)	56.3	1337.3	367.7	5	3	27.1	27.2
Broad squid (*Loligo chinensis*)	6.2	73.8	0.4	33	1	30.0	40.5
2-spot crab (*Ovalipes australiensis*)	20.7	134.1	134.4	3	4	32.3	36.1
3-spot crab (*Portunus sanguinolentus*)	19.1	134.2	120.2	3	4	33.6	37.5
Blue-swimmer crab (*Portunus pelagicus*)	2.9	4	18.2	2	4	77.6	87.3
Stingaree (*Urolophus* spp.)	19.1	244.4	148	4	3	43.7	43.7
Stingrays (*Dasyatis* spp.)	3.1	132.6	62.2	4	3	179.6	179.6
Numbfish (*Hypnos monopterygium*)	2.2	7.2	4.2	4	3	64.6	64.6
Boxfish (*Anoplocapros inermis*)	10.2	89.3	98.8	3	4	55.6	62.3
Soles (F: Soleidae)	1.9	17.1	1.6	9	2	67.7	71.8

King prawn grounds							
Total no. of species	34.7	13.3	9.3	3	4	5.3	5.9
No. of fish species	24.5	11.1	1.9	6	3	4.5	5.1
No. of crustacean species	7	1.9	0.1	11	2	5.4	6.3
No. of cephalopod species	3.2	0.6	0.9	2	4	17.2	18.5
King prawns (*Penaeus plebejus*)	98	4240.2	682.9	7	3	21.1	24.6
Racek prawns (*Parapenaeus australiensis*)	21.8	2170.7	269.1	7	3	63.7	75.5
Shovelnose lobsters (*Ibacus* spp.)	6.2	10.6	5.7	4	3	26.9	26.9
Slender squid (*Loligo* sp.)	34	408.5	389.9	3	4	33.7	37.7
Cuttlefish (*Sepia* sp.)	15.9	117.6	41.4	5	3	29.2	30.5
Arrow squid (*Nototodarus gouldi*)	5.1	52.1	43.8	3	4	77	85.7
Octopus sp.	2.5	2.8	0.8	5	3	27	28.4
Saw shark (*Pristiophorus* sp.)	1.8	8.8	0.4	11	2	44.9	53.6
Gummy shark (*Mustelus antarcticus*)	1.2	1.8	0.5	5	3	46.4	48.7
Redfish (*Centroberyx affinis*)	4.1	123.6	4.1	14	2	62.1	83.3
Spiky flathead (*Ratabulus diversidens*)	3.2	15.5	6	4	3	57.3	57.3
Red gurnard (*Chelidonichthys kumu*)	1.9	3	2.4	3	4	48.7	54.1
Total weight of by-catch	91	599.1	139.6	5	3	10.2	10.8
Total weight of fish	62.2	536	174.4	5	3	15.6	16.3
Total weight of crustaceans	3.5	21.4	0.6	15	2	28.7	40.1
Stingaree (*Urolophus* spp.)	28.2	458.2	194.2	4	3	36	36
Longfin gurnard (*Lepidotrigla calodactyla*)	16.8	58.6	18	5	3	18.7	19.6
Cocky gurnard (*Lepidotrigla mulhalli*)	3.6	5.5	1.4	5	3	25.2	26.5
Orange-swimmer crab (F: Portunidae)	1.4	1.4	0.5	4	3	37.2	37.2

spiky flathead in the ANOVA (Table 1), there were no consistent differences among means in the SNK tests.

Experiment 2. Cost–benefit analyses of the pilot survey to determine optimal numbers of days/nights and tows per day/night

The optimal numbers of replicate tows and numbers of days/nights to be sampled at any location in school prawn grounds and king prawn grounds are summarized respectively in Table 2. Having determined the appropriate numbers of replicate days/nights and tows per day/night, the standard error for the mean of data in any sample period may be estimated as the square root of the variance calculated from the variance equation (eqn. (2) above). The anticipated sizes of standard errors for sampling a location during one sample period are given for the optimal replication for each set of data and the selected replication for subsequent surveys (4 tows on each of 3 days/nights). Table 3 contains those variables for which there were no significant differences among days/nights. For these data, the variance due to day/night was either zero or negative, making cost–benefit analyses superfluous (see Winer, 1971).

TABLE 3

Sets of data which showed no significant differences among replicate days/nights in the pilot survey

Set of data	Mean in pilot survey
School prawn grounds	
Total weight of by-catch	106.2
Total weight of fish	78.4
Pt. Jackson shark (*Heterodontus portusjacksoni*)	30.8
Stingray (*Dasyatis* sp.)	1.4
School prawns (*Metapenaeus macleayi*)	87.9
King prawns (*Penaeus plebejus*)	15.3
Banjo ray (*Trygonorhina fasciata*)	2.3
Large tooth flounder (*Pseudorhombus arsius*)	2.3
Smooth flounder (*Pseudorhombus tenuirastrum*)	1.2
King prawn grounds	
Red spot whiting (*Sillago bassensis*)	79.7
Tiger flathead (*Neoplatycephalus richardsoni*)	28.7
Smooth flounder (*Pseudorhombus tenuirastrum*)	3.4
Spiky dogfish (*Squalus megalops*)	2.5

DISCUSSION

In Experiment 1, several species were present only at the shallow site (king prawns, shovelnose lobsters, blue-swimmer crabs, snapper, sand flathead) or only at the deep site (tiger flathead, spiky flathead). Whilst it is easiest to interpret such differences as being due to depth, the lack of replication of sites in deep and shallow water precludes such a conclusion for reasons of pseudoreplication (see Hurlbert, 1984). Nevertheless, clear differences in the abundances of species did occur at the two sites, implying that future surveys in such grounds should include replication among sites at different depths.

Diel sampling showed clear differences in CPUE for certain sets of data. In shallow and deep sites, the numbers of species of fish were greater during the night than during the day, implying that the diversity of these assemblages is greater at night when more species seem to be active and amenable to capture by trawling. King prawns were only caught at night at the shallow site, confirming the well-known nocturnal emergence of this species (Coles, 1979) and many other penaeid prawns (Allen, 1966; Greening and Livingston, 1982; Bauer, 1985). More blue-swimmer crabs were caught at night, confirming their tendency for nocturnal emergence (Wassenberg and Hill, 1987; Sumpton and Smith, 1990). Nocturnal habits of these kinds of macro-invertebrates have been suggested to be in response either to competitive interactions with similar, though diurnal, species or to predatory interactions with diurnally-feeding fishes (Coles, 1979; Greening and Livingston, 1982). Unfortunately, no evidence is available which differentiates such causes. Whatever the underlying causes for such differences, subsequent sampling programmes should account for such habits and sample during the day and/or night, depending on the species or groups of species of interest (see also Greening and Livingston, 1982).

The duration of tows was found to be important in estimating the CPUEs of two sets of data. Of particular relevance to a survey of the assemblages of fishes caught in these grounds was that the numbers of species of fish caught was greater for tows of longer duration (see also Carothers and Chittendon, 1985; Sobajima et al., 1985). The only individual species which showed a statistically-significant effect due to the duration of tows were the numbers of tiger flathead, which were caught in greater numbers at the deep site in 45 min tows. This may have been due to this species swimming faster or getting exhausted later than other species, thus avoiding the trawl for longer. The lack of significant differences due to the duration of tows for most species in this experiment probably reflects the variability of catches among replicates of any given tow duration, at any depth, during any day/night. Such spatial and temporal heterogeneity masked most effects that may have occurred by towing for 15, 30 or 45 min.

In deciding the optimal duration of tows for subsequent surveys, several factors were considered in addition to the results shown in Table 1 and Fig. 3. During this experiment, we found that 15 min was too short to allow for inherent variation in tow-to-tow behaviour (see Wathne, 1977). Further, 45 min was too long for enough replicates to be completed during a given sampling period if any logistic problems were encountered. Thirty minute tows were accepted as the optimal duration of tows for subsequent sampling because, although this required only a small compromise in terms of sampling the numbers of species of fish and the numbers of tiger flathead (Fig. 3), it meant that several replicated and standard tows could be completed within a given place and sampling period.

The cost–benefit analyses of data from the pilot survey (Experiment 2) showed that to best sample the diversity of the assemblage of species present (as measured by the total numbers of species caught) on school prawn grounds at any location and sampling period requires four replicate tows on each of three replicate days (Table 2). This sampling regime yields an estimated standard error of 7.1% of the mean for one such census. In contrast, to sample the diversity of the assemblage on king prawn grounds at any location and sample period in the most cost-effective way requires three replicate tows on each of four replicate nights. These results indicate that night-to-night variability in species richness is slightly greater in king prawn grounds, and/or that tow-to-tow variability in species richness is slightly greater in school prawn grounds.

To sample other categories of data optimally requires different levels of replication (see results for other variables in Table 2). For example, the best samples of the numbers of king prawns on king prawn grounds require seven tows on each of three nights, supplying an estimated standard error of 21.1% of the mean. This indicates that the numbers of king prawns vary among individual tows more than they vary among replicate nights (as compared to the numbers of species). If we were concerned only with estimating relative abundances of king prawns in king prawn grounds, these levels of replication would be used in subsequent surveys. For another species, bottle squid (*Loliolus noctiluca*) on school prawn grounds, one would ideally use five replicate tows on each of three days, supplying an estimated standard error of 27.1% of the mean. Other levels of replication are provided in Table 2 for use in trawl surveys which wish to target on particular species and groups of data.

Several sets of data showed no significant differences in catches among replicate days/nights (Table 3). For these variables, one may conclude that it is not necessary to sample on replicate days/nights, but to devote sampling effort to maximize the replication of tows on one day/night. This conclusion should be treated with caution, however, as it is possible that the small variances due to day/night were caused by the limited scope of this pilot survey. It would be prudent, therefore, to maintain replication across days/nights in any subsequent survey.

The field experiments described in this paper led to the development of a standardized methodology to survey relative abundances of trawled species in the New South Wales offshore prawn trawl fishery. The selection of subsequent levels of replication took into account: (i) the levels of replication given in Tables 2 and 3; (ii) the prerequisite that levels of replication be uniform at all locations, during all sample periods, in both school prawn grounds and king prawn grounds; and (iii) logistic constraints other than the time available for towing at each location and time. These included the availability of the research vessel throughout different seasons and years, and the time available for the crew to sleep when doing consecutive day/night work. The levels of replication we decided to use were four replicate tows on each of three nights at each location during each sampling period. Of course, this decision causes a problem in that, for many species in Table 2, these levels of replication are sub-optimal (see also Leaman, 1981). The consequences of this replication on the precision of estimates for all variables are presented in Table 2. Whilst using this replication increases the standard errors for many sets of data compared to that using optimal levels, there were only slight decreases in precision for most variables; e.g. the numbers of king prawns in king prawn grounds using four tows on each of three nights gives a precision of 24.6%, whilst using the optimal levels of seven tows on each of three nights gives 21.1%. We intend to complete quarterly censuses of the prawn trawl grounds off the New South Wales coast for several years. Such repetitive sampling should decrease standard errors to allow powerful comparisons of means for most species.

The results presented permitted the development of sampling regimes for trawlable species caught in the New South Wales fishing grounds that are optimal with respect to duration of tows and the spatial and temporal heterogeneity of the various species, given logistic constraints of limited ship-time. Studies such as these are obvious prerequisites for the proper design of sampling regimes which are required to estimate relative distributions and abundances in the most cost-effective and reliable way.

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APPENDIX E

The effects of trawl configuration on the size and composition of catches using benthic prawn nets off the coast of New South Wales, Australia.

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The effects of trawl configuration on the size and composition of catches using benthic prawn trawls off the coast of New South Wales, Australia

N. L. Andrew, K. J. Graham, S. J. Kennelly, and M. K. Broadhurst

Andrew, N. L., Graham, K. J., Kennelly, S. J., and Broadhurst, M. K. 1991. The effects of trawl configuration on the size and composition of catches using benthic prawn trawls off the coast of New South Wales, Australia. – ICES J. mar Sci., 48: 201–209

The catch per swept area and size selectivities of several configurations of prawn trawls were assessed during night-time trials. Catches using triple rigged prawn trawls were compared to single trawls with and without sweeps of 40 and 140 m length in a nested sampling design. Sweeps were found to herd Australian red spot whiting and sand flathead but not prawns and shovelnose lobsters. Single trawls with long sweeps caught significantly larger red spot whiting and sand flathead than any other trawl configuration. Triple gear caught more smaller red spot whiting than other configurations but this effect was not evident for sand flathead. The results are discussed in terms of the likely behaviour of the herded species and implications for the management of fisheries for prawns and herded species of finfish.

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Introduction

Of the many factors that influence the catches of bottom trawls (e.g. trawl geometry, Wathne, 1977; Sissenwine and Bowman, 1978; Carrothers, 1981; Wardle, 1983; DeAlteris *et al.*, 1989), the effects of sweeps (long wires between otter boards and trawls) are perhaps the least understood. Although sweeps are often used to enhance trawl efficiency in demersal finfish fisheries there is relatively little in the published literature on the subject. Long sweeps were apparently first used in the early 1920s in the French trawl fisheries (see references in Hickling, 1931; Bagenal, 1958) and their use soon spread to other European fisheries. Catches of demersal fishes such as cod, hake, and haddock were shown to be significantly greater using the Vigneron–Dahl modification of the otter trawl, as sweeps were then known (Hickling, 1931; Bowman, 1932; Margetts, 1949; Bagenal, 1958).

Several studies have demonstrated that catches from trawls increase with increasing length of sweep (e.g. Foster *et al.*, 1981; Mathai *et al.*, 1984; DeAlteris *et al.*, 1989; Engås and Godo, 1989) and that size compositions of catches also change with the length of sweeps (Engås and Godo, 1989; but see Bowman, 1932). Recent studies have also demonstrated that there are species-specific differences in the herding responses of fish to approaching trawls (e.g. Main and Sangster, 1981a, b; Wardle, 1983; Glass and Wardle, 1989). Given the widespread usage of bottom trawls in stock assessment research, there is a clear need to understand better the catchability and vulnerability of fish and invertebrates to sweeps attached to bottom trawls.

Off the coast of New South Wales, Australia, there is an economically important fishery for the eastern king prawn (*Penaeus plebejus*). Because *P. plebejus* burrows during the day (Racek, 1959), the fishery operates at night. The offshore trawl fishery began in the late 1940s with trawlers towing a single trawl (Racek, 1959), but most are now triple-rigged. The change to multi-rig trawling, with its inherent increase in swept area, has led to an increase in the incidental catch of species other than prawns. Principally, these are demersal fishes and invertebrates such as shovelnose lobsters. This by-catch has become an increasingly important source of income for fishermen and, in some instances, by-catch species such as red spot whiting (*Sillago bassensis*) are targeted.

The results presented here are part of a larger study of the by-catch of prawn trawl fisheries in New South Wales. In this paper the relative efficiencies of several trawl configurations as used (or proposed) by the commercial fleet are compared, with special reference to the catch rates of fish and crustacea in triple-rigged trawls and single trawls with and without long sweeps.

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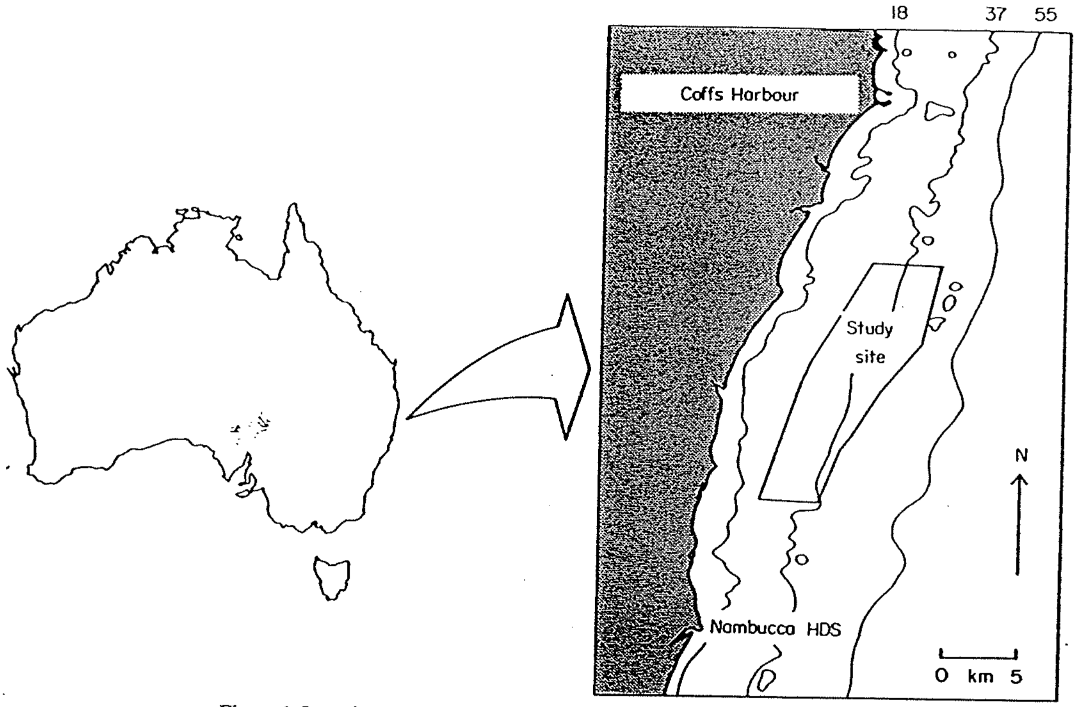


Figure 1. Location map of the study site (depth contours are in metres).

Methods

The study was done using FRV "Kapala" (25 m, 460 hp) on an established prawn-trawl ground south of Coffs Harbour between 5 and 12 December 1989 (Fig. 1). All tows were done at night, between 2025 and 0405 h and each was 30 min long. The grounds trawled varied in depth between 35 and 48 m. The target towing speed was 2.8 knots (range 2.4–3.2). To ensure independence among replicate tows, the vessel steamed in randomly selected directions at 5.0 knots for 5 min between tows. Distances towed were determined by satellite navigator and radar.

Because only one vessel was available for this experiment and it was impracticable to change between single configurations and triple gear between tows, only one configuration was used per night. The order in which they were used was randomized among nights. A total of seven nights was available for the cruise, resulting in three configurations being used on each of two nights. The trawl configurations compared were: single trawl with 7 m bridles, single trawl with 40 m bridles, and triple-rigged trawls (Fig. 2). The availability, through good weather, of the seventh night allowed us to trial a single trawl with very long (140 m) sweeps (Fig. 2). Because this configuration was used on one night only, the results were excluded from statistical analyses but are presented graphically for comparative purposes.

All trawls were "Florida Flyers" with a headline length of 22 m. This design is used commonly in eastern Australian prawn trawl fisheries. The trawls were connected to wooden otter boards (2.4 x 1.1 m) with upper and lower bridles (Fig. 2). During trawling the lower bridle made contact with the seabed and therefore acted like a sweep wire. The trawls were designed with similar and contrasting dimensions so that catch-rate comparisons could be made (Table 1).

In order to calculate the area of seabed swept by the trawls, the wingspread of each trawl configuration was measured with an acoustic trawl instrumentation system for a range of ground speeds between 2.4 and 3.4 knots. The acoustic device could not measure doorspread, so the area swept on each tow was calculated from the wingspread (from the regression of spread against boat speed for each trawl configuration) and distance travelled. In calculating swept area for the triple gear it was assumed that the starboard and port trawls behaved identically (total wingspread = (port wingspread x 2) + centre wingspread). Raw catch data were converted to catch per hectare based on these calculations. Any differences in catch rates were then interpreted as being caused by the herding effects of the lower bridles and sweeps.

Several commercially important species of fish were caught in sufficient quantities to enable comparisons to be made between trawl configurations. Those species chosen were Australian red spot whiting (*Sillago bassensis*) and sand flathead (*Platycephalus caeruleopunctatus*). Australian whiting (Family Sillaginidae) are small schooling fish that are abundant over inshore trawl grounds in

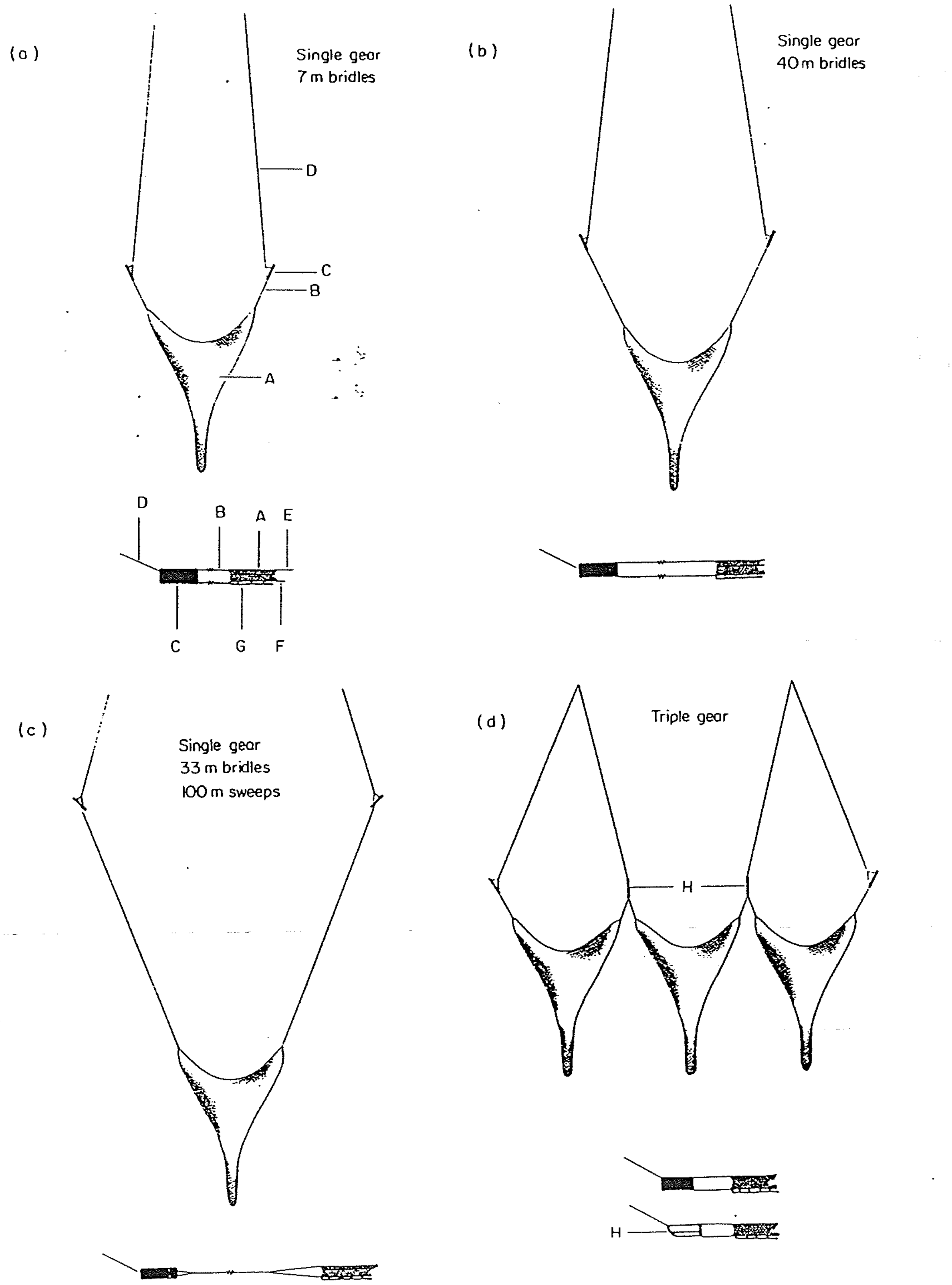


Figure 2. Configurations of: (a) single trawl, (b) single trawl with 40 m sweeps, (c) single trawl with 140 m sweeps, and (d) triple prawn trawl. Inserts show details of otter boards and bridles: (A) net, (B) bridles, (C) otter boards, (D) wire warp, (E) headrope, (F) footrope, (G) groundchain, (H) sleds.

Table 1. Dimensions of the trawl configurations used during the experiment. All lengths and distances are in metres.

Configuration	Headline length	Bridle+ sweep lengths	Door spread
Single	22	2×7	36
Single	22	2×40	102
Single	22	2×40+2×100	302
Triple	3×22	2×12+10	100

southeastern Australia. Several species of crustacean were also caught in sufficient numbers to compare catch rates, namely shovelnose lobsters or bugs (Scyllaridae: *Ibacus* spp., a genus restricted to the Indo Pacific) and two species of penaeid prawn. The majority of prawns caught were eastern king prawns (*Penaeus plebejus*), although brown tiger prawns (*P. esculentus*) were caught occasionally. These species of prawn were combined for analysis. In addition, the combined weight of by-catch was compared between trawl configurations and nights. The lengths of individual fish of the above species were measured from all tows and combined to provide length–frequency distributions for each configuration. Catches of prawns and shovelnose lobsters were too small to give valid size-frequency distributions for these species.

Differences in catch per hectare were compared between nights and trawl configurations for each of the above variables, the null hypothesis being that there were no differences in catch due to differences in trawl configurations. Data were analysed using analysis of variance. The experimental design used was hierarchical with two factors: Trawl Configuration (fixed factor with three levels: triple gear, single trawl without sweeps, and single trawl with 40 m bridles) and Night (nested within Trawl Configuration, with two levels).

Six replicate tows were done on each night except one, during which only four were completed. For analysis, the mean of the cell for this latter night replaced the two missing values and two degrees of freedom were subtracted from the residual to correct for the consequent loss of power (Winer, 1971). Where tests were non-significant at $p<0.25$, that factor was pooled with the residual (Winer, 1971). Cochran's test (Snedecor and Cochran, 1980) was used to test for heterogeneity of variance prior to analysis. In all cases, untransformed data could be analysed. Means were separated following significant F-tests using the S.N.K. procedure (Snedecor and Cochran, 1980).

Results

Operational and trawl parameters

There were no significant differences between nights in the depths trawled (single factor analysis of variance, $F_{(6,33)}=1.10$, $p>0.35$). The results of the experiment were not therefore confounded by depth. Triple gear swept a significantly greater area of the seabed than either single trawls without sweeps or with 40 m bridles (Fig. 3a, Table 2, S.N.K. tests). There was no difference in swept area between single trawls with and without 40 m bridles (S.N.K. tests, Fig. 3a). The mean area swept by the trawl with 140 m sweeps, although slightly less than the other single trawl configurations (Fig. 3a), differed by less than 0.5 ha. There were no significant differences between nights in the area swept by the same trawl configuration (Table 2).

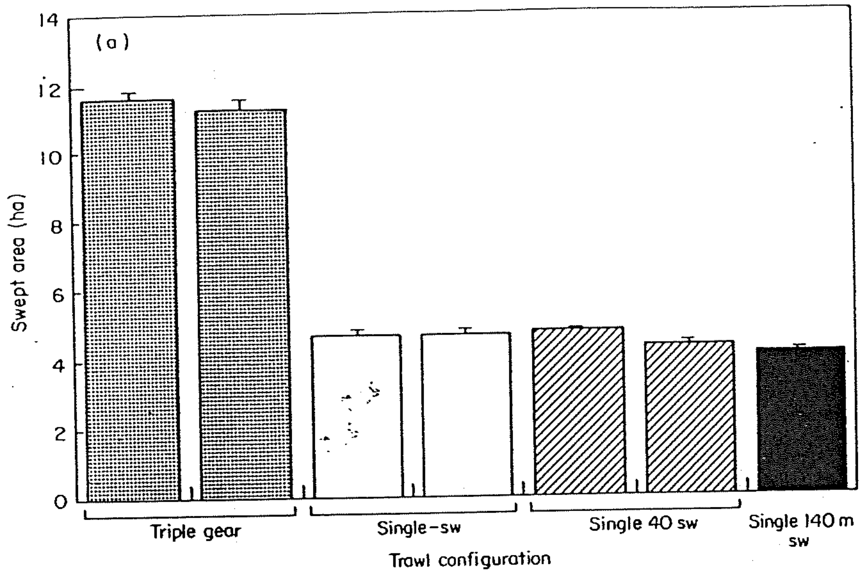
There was a significant negative linear relationship between boat speed and wingspread (Fig. 3b) for all trawl configurations, indicating that the sheering effect of the doors increased as the drag component of the trawl decreased. Australian fishermen operate prawn trawls with an unusually wide wingspread (around 70–75% of headline length is usual for Florida Flyer nets in Australia). The single trawls with 7 m bridles and 40 m sweeps were slightly over-spread at about 80% of their headline length. The single trawl with 140 m sweeps and bridles and trawls in the triple gear configuration showed spreads of 65–70% of headline length.

Direct observations of the trawls by scuba divers in trials prior to the start of this experiment indicated that all trawl configurations, including the single trawl with 40 m sweeps, were working correctly on the seabed. Abrasion marks on the otter boards and ground-chains of the trawls in all configurations also showed that good contact with the seabed was maintained.

Catch per hectare among configurations

There were no significant differences in catches (per hectare swept) of red spot whiting and sand flathead between the triple gear, single trawl with no sweeps, and single trawl with 40 m bridles (Table 2, Fig. 4a, b), nor between nights in catches of red spot whiting and sand flathead (Table 2). On average, more than twice the amount of red spot whiting and sand flathead was caught by trawls attached to 140 m sweeps than by any other configuration (Fig. 4a, b). Red spot whiting made up 76% of the total whiting catch, the remainder was stout whiting (*Sillago robusta*). Patterns in the catches of stout whiting were similar to those for red spot whiting. There were no significant differences between trawl configurations in the total weight of by-catch (Table 2, Fig. 4c). The mean amount of by-catch caught per hectare was greatest using trawls with 140 m sweeps (Fig. 4c).

There were no significant differences in catches of prawns and shovelnose lobsters between triple gear, single trawls with no sweeps, and single trawls with 40 m bridles (Table 3, Fig. 5), nor between nights in catches using the same configurations (Table 3). In contrast to the fish



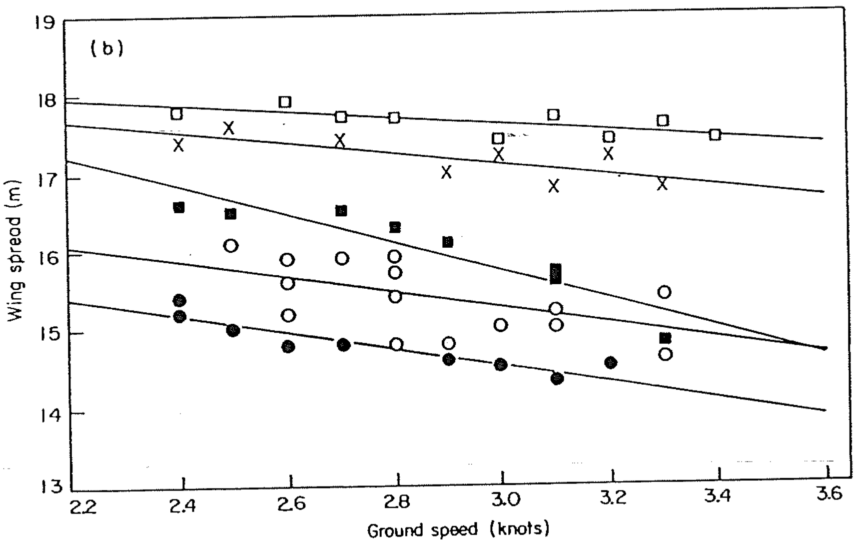


Figure 3. (a) Mean area swept (±s.e.) by each trawl configuration. Duplicate histograms refer to two replicate nights. (b) Wingspread as a function of ground speed. □ = no sweeps, $y=19.0-0.5x$ ($r^2=0.63$, $p<0.05$ with 10 d.f.); × = 40 m sweeps, $y=19.3-0.7x$ ($r^2=0.31$, $p<0.05$ with 7 d.f.); ■ = single gear with 40 m bridles and 100 m sweeps, $y=21.2-1.8x$ ($r^2=0.86$, $p<0.05$ with 7 d.f.); ○ = centre net triple gear, $y=17.8-1.1x$ ($r^2=0.87$, $p<0.05$ with 10 d.f.); ● = port net triple gear, $y=18.3-1.0x$ ($r^2=0.31$, $p<0.05$ with 15 d.f.).

Table 2. Analysis of variance tables for differences in swept area, catch per hectare of red spot whiting, sand flathead, and total by-catch. **Indicates significant at $p<0.01$, n.s. indicates non-significant at $p<0.05$, pld indicates factor non-significant at $p<0.25$, and sum of squares pooled with residual. Degrees of freedom for the F-test for factor Configuration when $\text{Night}_{(\text{Con})}$ pooled = (2,31).

		Swept area			Red spot whiting			Sand flathead			Total by-catch		
Source	d.f.	MS	F	prob	MS	F	prob	MS	F	prob	MS	F	prob
Configuration	2,3	183.5	528.8	**	13.62	0.91	n.s.	5.58	2.33	n.s.	157.1	5.27	n.s.
$\text{Night}_{(\text{Con})}$	3,28	0.35	1.6	n.s.	15.92	1.07	pld	2.39	2.39	n.s.	29.82	1.65	n.s.
Residual	28	0.22			14.93	1.00			18.04				

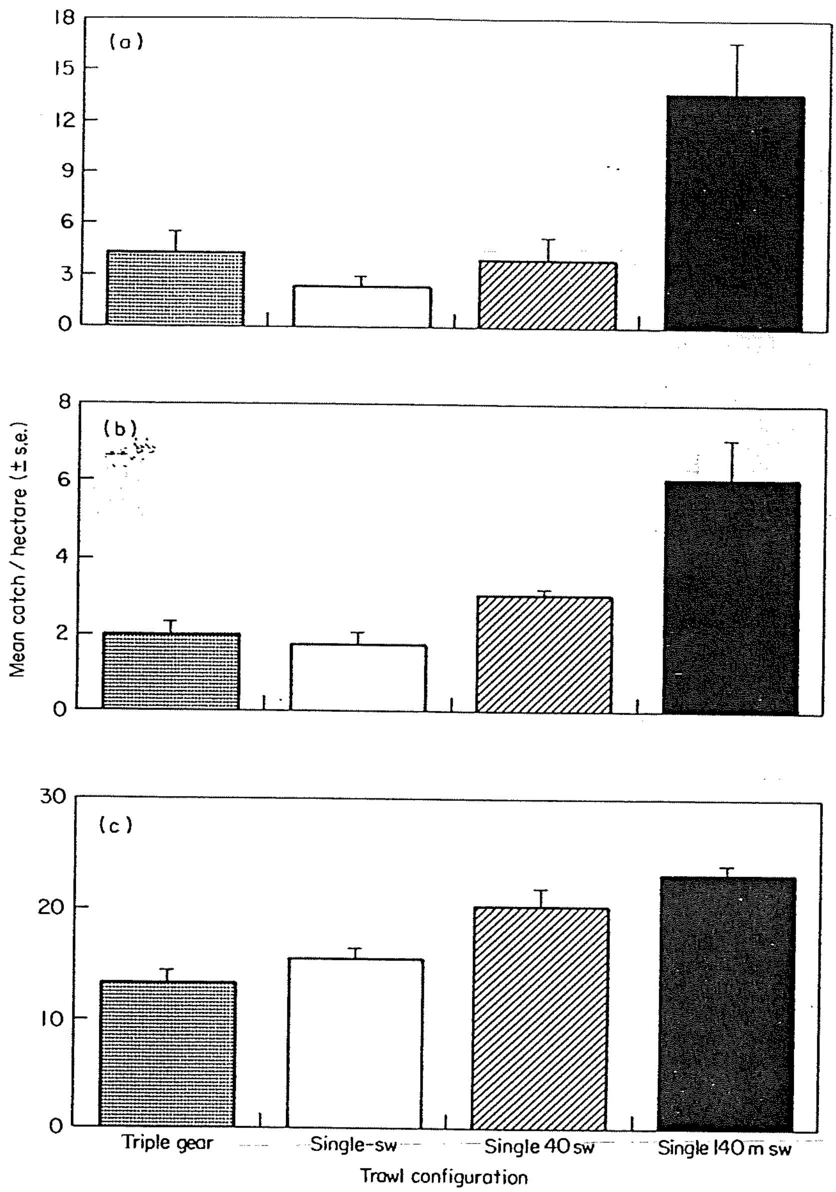


Figure 4. The mean catch per hectare (±s.e.) of (a) red spot whiting, (b) sand flathead, and (c) total weight of by-catch using the four different trawl configurations.

Table 3. Analysis of variance table for differences in catch per hectare of prawns and shovelnose lobsters. n.s. indicates non-significant at $p<0.05$.

Source	d.f.	Prawns MS	Prawns F	Prawns prob	Shovelnose lobsters MS	Shovelnose lobsters F	Shovelnose lobsters prob
Configuration	2,3	0.017	0.72	n.s.	0.21	1.29	n.s.
$Night_{(Con)}$	3,28	0.023	2.88	n.s.	0.16	1.87	n.s.
Residual	28	0.008			0.09		

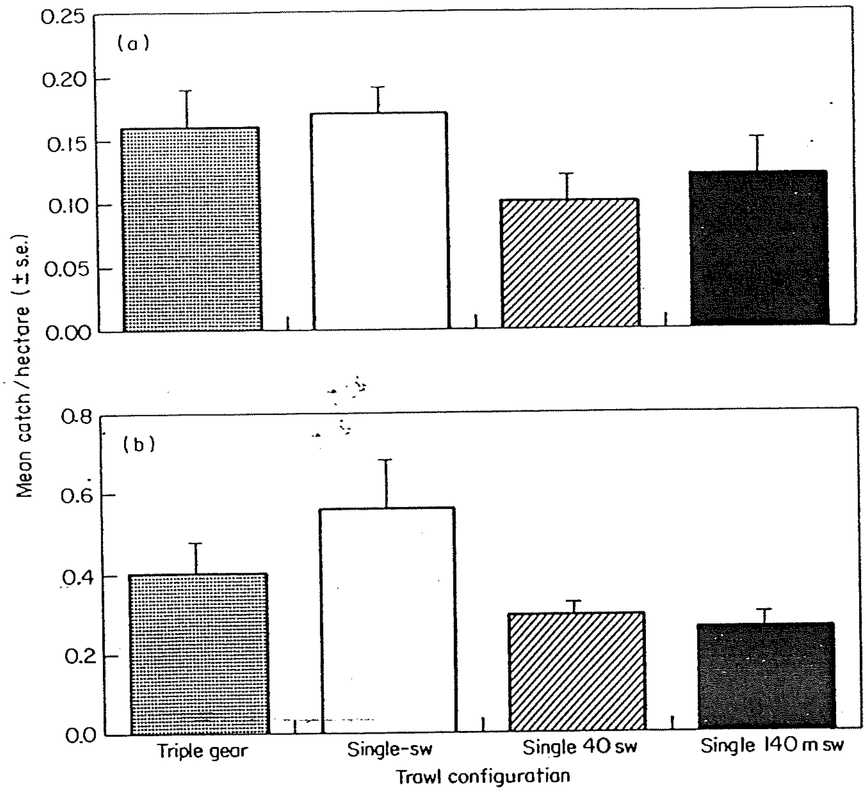


Figure 5. The mean catch per hectare (±s.e.) of (a) prawns and (b) shovelnose lobsters using the four different trawl configurations.

Table 4. Mean sizes (cm ± 95% C.I.) of red spot whiting and sand flathead caught in different trawl configurations off Coffs Harbour in December 1989. Sample sizes are indicated in parentheses.

	Red spot whiting	Sand flathead
Single, no sweeps	17.3±0.16 (787)	32.5±0.55 (309)
Single, 40 m sweeps	17.4±0.16 (389)	31.9±0.49 (243)
Single, 140 m sweeps	17.9±0.16 (355)	33.5±0.54 (265)
Triple gear	16.6±0.08 (1027)	32.4±0.37 (559)

mentioned above, trawls with 140 m sweeps did not, on average, catch more prawns or shovelnose lobsters per hectare than triple gear or either single trawl configurations without sweeps or with 40 m bridles (Fig. 5).

Single trawls with 140 m sweeps caught significantly larger red spot whiting than did any other configuration (Table 4), but there was no significant difference in the sizes of red spot whiting caught with either of the other single trawl configurations (Table 4). Triple gear caught significantly smaller red spot whiting than any other trawl configuration (Table 4). The length–frequency distributions of sand flathead were similar for all configurations except the single trawl with long sweeps which caught significantly larger fish (Table 4).

Discussion

The results presented here provide no evidence that the fishing efficiency (per area swept) of triple prawn gear is different to that of single trawls without sweeps or with 40 m sweeps. This result may be ascribed to a number of causes, including the relative lack of statistical power of the F-tests used to compare catches (see Table 2) and differences in trawl geometry (e.g. angle of attack of the bridles) among configurations. The problem of low statistical power was circumvented for red spot whiting because the effects of night could be pooled with the residual variance, thereby increasing the degrees of freedom for the F-test to (2, 31). Even with this comparatively powerful test there was no evidence of differences between the three configurations compared in the analysis.

The 80% spread of the single trawl with 40 m bridles indicated that the sweeps were working at a slightly wider angle than the other configurations. This may be expected to lessen the herding effect of the sweeps as less time would be available for fish to be herded into the catching zone (see also Wardle, 1983; Engås and Godo, 1986, 1989; Engås and West, 1987; Newland and Chapman, 1989). We conclude that the difference in spread between this configuration and others had little effect on the results.

The exclusion of the single night using 140 m sweeps from statistical analyses weakens any inferences that can be made concerning the effects of very long (140 m) sweeps on catch rates. Several properties of the data suggest, however, that these results may be interpreted as being due to the effects of long sweeps. For all five variables analysed (four species and total weight of by-catch) there were no significant differences between replicate nights. This result leads to the inference that if 140 m sweeps had been used on a second night then the results would have been similar to those gained on the first night. If this assumption is accepted, then several interpretations of the relative fishing efficiencies of the alternate trawl configurations can be discussed.

The results presented here support those from previous studies in that the use of very long sweeps attached to bottom trawls enhanced the catches of some species of fish (e.g. Hickling, 1931; Bowman, 1932; Margetts, 1949; Bagenal, 1958; Engås and Godo, 1989). In the present study, catches of Australian red spot whiting (*Sillago bassensis*) and sand flathead (*Platycephalus caeruleopunctatus*) in trawls with very long sweeps were, on average, more than double those of single trawls without long sweeps and triple gear. The lack of increase in catches of slow-moving benthic invertebrates such as prawns and shovelnose lobsters in trawls with long sweeps is also in accord with previous studies (e.g. Mathai *et al.*, 1984; Main and Sangster, 1985; Newland and Chapman, 1989) and suggest that these species are limited in their response to approaching trawls. Newland and Chapman (1989) have demonstrated that, in trawl fisheries for the Norwegian lobster *Nephrops norvegicus*, as many as 50% of individuals do not respond to the gear until touched by it.

It is significant that red spot whiting and sand flathead were herded by sweeps, despite the fact that the experiment was done at night. Most studies of the reactions of fish and invertebrates to different trawl configurations, including the effects of long sweeps, have been done during daylight, when the potential for herding is greatest (e.g. Blaxter *et al.*, 1964; Main and Sangster, 1981a, b; Wardle, 1983; Engås and Godo, 1989; Glass and Wardle 1989; Wardle, 1989). Several studies on the reactions of fish to towed gear have demonstrated that fish lose their ability to respond to approaching trawls under very low light conditions (e.g. Blaxter *et al.*, 1964; Glass and Wardle 1989; Wardle, 1989). Wardle (1989) concluded that many fish can not see at light levels less than about 10^{-6} lux, and that, importantly, other senses such as hearing are not capable of perceiving the approaching trawl. Bagenal (1958), however, has provided some evidence that sweeps are still effective at night, though less than during daylight.

Although the results presented here indicate that some fish are herded by long sweeps at night, it should be noted that in the present study (and that of Bagenal, 1958) no estimates of light intensity were made. Similarly, we do not know whether bioluminescence (Wardle, 1983) enhanced the visibility of the trawls. It is conceivable, therefore, that fish may have been able to see the oncoming trawl in these studies, at least when close to it. In the experiment reported here tows were done during the 7 days leading up to a full moon, and weather conditions ranged from clear skies to heavy rain.

If senses other than vision are used then it is most likely that sound is used by fish to maintain position relative to the approaching trawl (Bagenal, 1958; Wardle, 1983). Several papers have discussed the sensitivity of fish to vibrations caused by trawls and it is generally considered that fish have a limited capacity to locate the sources of sound (e.g. Chapman, 1964; Wardle, 1983). It is possible that the otter boards in trawls with very long sweeps may be at a sufficient distance to allow fish to locate the source of the disturbance and react accordingly. In schooling species such as red spot whiting it is also conceivable that the flight reactions of individuals on the periphery of a school, as they are touched by the boards or sweeps, cause a directed response throughout the school.

The size-selectivity of long sweeps reported by Engås and Godo (1989) was also found in this study. More large red spot whiting were caught using a single trawl with long sweeps than with other configurations. Engås and Godo (1989) reported that, while catches of cod and haddock increased with increasing sweep length, the proportion of small fish in these catches declined. These authors attributed this selectivity to the possibility that small fish were less likely to be herded than larger fish. In the present study more small red spot whiting were caught in triple prawn gear than in single trawls with and without sweeps. This result suggests that the presence of three trawls reduced the probability that smaller whiting avoided capture by swimming out of the catching zone. Triple gear did not appear to have the same effect on sand flathead.

The results presented here suggest that long sweeps attached to bottom prawn trawls increase the catch rates of herdable fish such as Australian red spot whiting and sand flathead, even at night. No increase in catch rate was evident for invertebrates such as prawns and shovelnose lobsters. Species-specific differences in vulnerability to capture by trawls using long sweeps have clear implications for fisheries management. Assessments of the abundance and species composition of stocks using trawls with different lengths of sweeps will not be comparable unless the relationship between catch rate and sweep length is known (see also Engås and West, 1987; Engås and Godo, 1989; Mahon and Smith, 1989). If it is the goal of fisheries managers to minimize incidental catches of fish species in prawn trawl fisheries, or to increase the catch of selected fish species, then the use of long sweeps should be carefully regulated.

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APPENDIX F

An application of the Morrison Soft TED to the offshore prawn fishery in NSW, Australia.

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Andrew, N.L., S.J. Kennelly and M.K. Broadhurst.

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An application of the Morrison soft TED to the offshore prawn fishery in New South Wales, Australia

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ABSTRACT

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The effects of the Morrison soft TED on bycatch from the offshore prawn fishery in New South Wales are described. Use of the TED did not significantly reduce catches of prawns (*Penaeus plebejus*) and invertebrate bycatch. The TED reduced the capture of discarded finfish and invertebrates, including species of commercial importance, by 32%. There was no evidence of size-selectivity of catch of prawns or eastern bluespot flathead (*Platycephalus caeruleopunctatus*), an important commercial finfish. Use of the TED reduced income earned by an estimated 4%. It is concluded that the Morrison soft TED has great potential to reduce bycatch in this fishery, but further research is needed to understand the performance of the TED under a range of conditions normally found in the fishery.

INTRODUCTION

The bycatch of shrimp (=prawn) trawl fisheries has been of increasing concern in recent years (Juneau and Pollard, 1981; Pellegrin, 1982; Rothschild and Brunenmeister, 1984; Sheridan et al., 1984; Collins and Wenner, 1988; see Andrew and Pepperell, 1992 for review). Several devices have been designed to reduce bycatch, particularly in Europe and the USA (FAO, 1973; Averill, 1989; Karlsen and Larsen, 1989; Valdermarsen, 1989; Kendall, 1990). Such devices are referred to as TEDs (Trawl Efficiency Devices, Trash Eradication Devices, Trash Elimination Devices or even Turtle Exclusion Devices). Although TEDs have been successful in reducing bycatch in many instances, smaller catches of target species and operational problems in using trawls fitted with TEDs has limited application to commercial fisheries (Andrew and Pepperell, 1992).

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In their simplest form, TEDs partition the catch using large-meshed panels. Organisms that do not pass through the panel are deflected and escape through openings in the trawl while the smaller and/or less mobile shrimps pass through to the codend. The most publicized application of TEDs has been to reduce the capture of turtles, particularly in the shrimp fisheries of the south-eastern USA (Oravetz and Grant, 1986; Conner, 1987; Watson, 1989; Renaud et al., 1990). Outside the geographical range of turtles, TEDs have been used to reduce quantities of other bycatch, particularly finfish (e.g. Matsuoka and Kan, 1991).

The design of trawls to separate shrimps from finfish is complex because the two groups are often of similar size. Separation of finfish from shrimp largely relies on the fact that many species of fish swim forward and up in the trawl and escape, whereas the less mobile shrimps remain in the lower parts of the trawl and go through the TED and into the codend. Soft TEDs, incorporating deflector panels and chutes made of netting of a larger mesh size, have been used with some success to separate shrimps and finfish (e.g. High et al., 1969; Christian and Harrington, 1987; Karlsen and Larsen, 1989; Valdermarsen, 1989; Kendall, 1990).

The Morrison soft TED has been used successfully to exclude turtles from shrimp trawls in the Gulf of Mexico and, in addition to turtles, reduced catches of other species of bycatch, particularly fish (Christian and Harrington, 1987; Kendall, 1990). The ease of installation and handling of this TED further enhances its potential for widespread acceptance by professional fishermen (Kendall, 1990).

The aim of this study was to test the Morrison soft TED under commercial conditions in the offshore fishery for eastern king prawns (*Penaeus plebejus*) off New South Wales, Australia. As with most prawn fisheries, no TEDs are used in the offshore fishery. Preliminary experiments on a research vessel (K. Graham and N. Andrew, unpublished data, 1991) indicated that the Morrison soft TED had great potential to reduce bycatch on these grounds. In this study, we report the results of an experiment in which the Morrison TED was used on commercial fishing vessels. Of particular interest was the commercial cost of reductions in catches of prawns and valuable bycatch.

MATERIALS AND METHODS

The experiment was done using three prawn trawlers ('Simon Barjona', 'Fleetwing' and 'Living Waters') on commercial grounds east of Yamba and Iluka, New South Wales (153° 22′S, 29° 26′E) between the 2nd and 11th of October 1991. All trawlers towed three Florida Flyer trawls (mesh size, 50 mm) in a standard triple gear configuration (see Andrew et al., 1991 for details). The size and cut of trawls differed among the vessels. 'Simon Barjona' and 'Fleetwing' were fitted with two-panel Florida flyers, each with headline lengths of 17 m. 'Living Waters' was fitted with four-panel Florida flyers, each having a headline length of 14.5 m.

Because of difficulties in installing the TED into the four-panel trawls on the 'Living Waters', the results from this vessel were not analysed statistically. The effects of the TED in this trawl were similar to those in the two-panel trawls but, for all variables, differences between the two codends were negligible. Although the sewing instructions given by Christian et al. (1988) were followed as closely as possible, it was clear there was too much net in the TED, reinforcing the importance of having the TED stretched tightly within the trawl.

The TEDs were cut from 4 mm braided polyethelene woven into 197 mm stretched mesh. On each vessel, the TED was sewn into one of the outside trawls according to the installation instructions provided by Christian et al. (1988). In the 'Simon Barjona' and 'Fleetwing', the TEDs measured 36.5 meshes across the leading edge. A 20 mesh opening was cut in the trawl with the TED immediately in front of the codend to allow the escape of selected species (Fig. 1). We assumed the two outside trawls behaved identically in terms of fishing power. Underwater observations of a Morrison TED sewn into a Florida Flyer trawl indicated that the TED did not alter the geometry of the trawl when it was fishing (K. Graham and N. Andrew, personal observation, 1991).

Four tows, each of 90 min duration, were carried out per night between 18:00 h and 02:30 h. The experiment was done over six nights; two nights each on 'Fleetwing' and 'Living Waters' and four on 'Simon Barjona'. The location of each tow was determined by the skipper of the vessel. After each

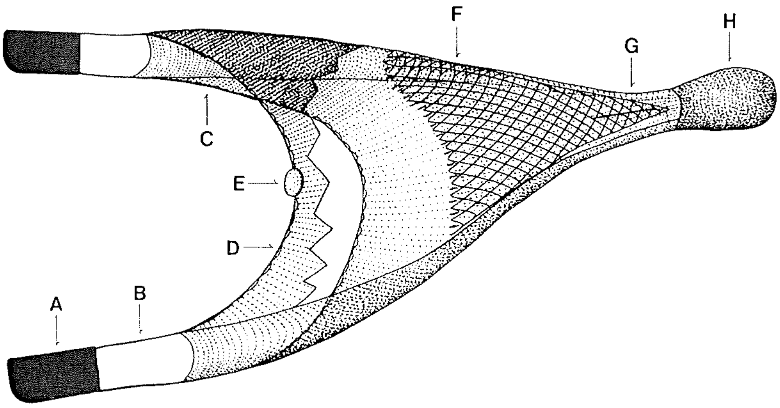

Fig. 1. Stylized diagram of a Morrison soft TED as sown into a prawn trawl. A, otter board; B, bridle; C, foot rope; D, head rope; E, float; F, Morrison TED; G, escape opening; H, codend. (Redrawn from Kendall, 1990).

tow, the codends were emptied onto separate sorting areas. Prawns and other important species of commercial size were removed and set aside. The remaining bycatch, including under-size individuals of commercial species, was then sorted.

Data collected from each codend were the weights and sizes of *P. plebejus* (to the nearest mm carapace length), the weight of the bycatch of species of no commercial value (discarded by the fisherman), the numbers, weights and sizes (to the nearest 5 mm) of commercial species rejected by fishermen because individuals were smaller than the minimum legal size or too small to be worth retaining, and the numbers and weights of retained commercial species (see below). The sizes of retained by catch could not be estimated because this interrupted the working routines of the fishermen too much. The dollar value of the catch from each codend was also calculated as the sum of products of catch (kg) × price per kg for each species. Unit prices used were those paid by the Maclean Fishermans Co-operative, New South Wales, for the week ending 3 October 1991.

In addition to prawns, several species of bycatch were caught in sufficient quantities to enable statistical comparisons to be made between the control trawl and that equipped with the TED. The species chosen were Australian red spot whiting (*Sillago bassensis*) and eastern blue spot flathead (*Platycephalus caeruleopunctatus*). Invertebrates were also caught in sufficient numbers to compare rates of catch, but, in all cases, species were combined to the generic or family level. The largest catches of commercial invertebrates were slipper lobsters or bugs (Scyllaridae: *Ibacus* spp.) and octopus (Octopoda: *Octopus* spp.). Other taxa, principally loliginid squids and portunid crabs, were also caught and included in estimates of the total catch of invertebrates. The prawns caught were predominantly *P. plebejus*, but small numbers of brown tiger prawns (*Penaeus esculentus*) were caught. These two species were combined for analysis.

The effect of the TED on catch and income derived was estimated by calculating the ratio of TED catch: control catch for each tow. Because estimates of catch came from codends within the same trawl configuration, they were not independent estimates of catches and could not, therefore, be compared in the normal two-sample case. The ratios were transformed to natural logarithms to reduce the influence of very large ratios which occurred when the TED codend had a very large catch or, more usually, when the Control net caught very little. The mean ratio was calculated for each variable using all tows pooled across night and vessel.

An estimate of variance about these means was gained from the residual mean square of single factor analyses of variance of differences among nights. 95% confidence intervals were constructed using these variances and based on the 18 degrees of freedom available from the analysis of variance. The expectation under the null hypothesis of no effect is that the mean ratio equals zero, deviations from zero indicate that the TED has a significant effect on catch rates. In several instances, nothing was caught in the control net (division by zero) and the ratio was set to zero. When the TED net caught nothing, the ln (ratio) was set to −1. The effect of these substitutions was to make tests of difference more conservative.

RESULTS

The Morrison soft TED significantly reduced catches of discarded bycatch (trash) (Fig. 2). Catches of discards were, on average, 32% smaller than in

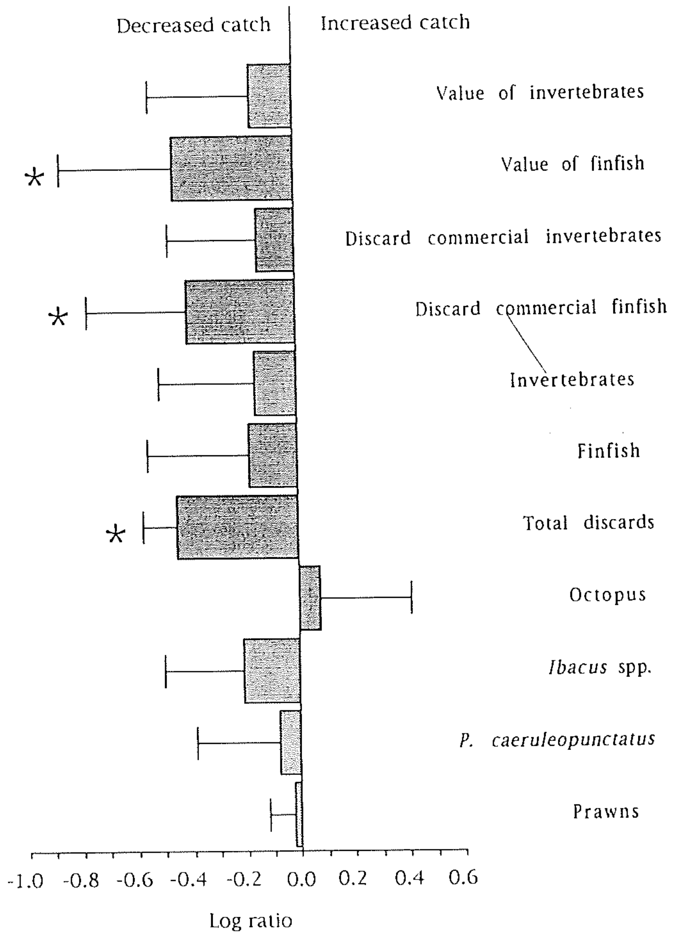

Fig. 2. Differences in mean log ratios of TED: control nets from the TED experiment. Data are presented as mean ± 95% C.I., based on 18 d.f. Asterisks indicate significant departures from the null hypothesis of no difference. Negative values indicate that the TED caught less than the control codend.

the control codend. The TED did not significantly reduce catches of *P. plebejus, P. caeruleopunctatus, Ibacus* spp. or *Octopus* spp. (Fig. 2). In many tows, catches of *Octopus* spp., *Ibacus* spp. and *P. caeruleopunctatus* were actually greater in the TED codend.

There were no significant differences in total weights of retained commercial finfish and invertebrates caught in the TED and control nets (Fig. 2). The TED did, however, significantly reduce the catches of commercial finfish discarded because they were too small or were considered not worthy of sorting (Fig. 2). There were no significant differences in the weights of catches of discarded commercial invertebrates.

The TED significantly reduced the value of the catch of finfish but not in-

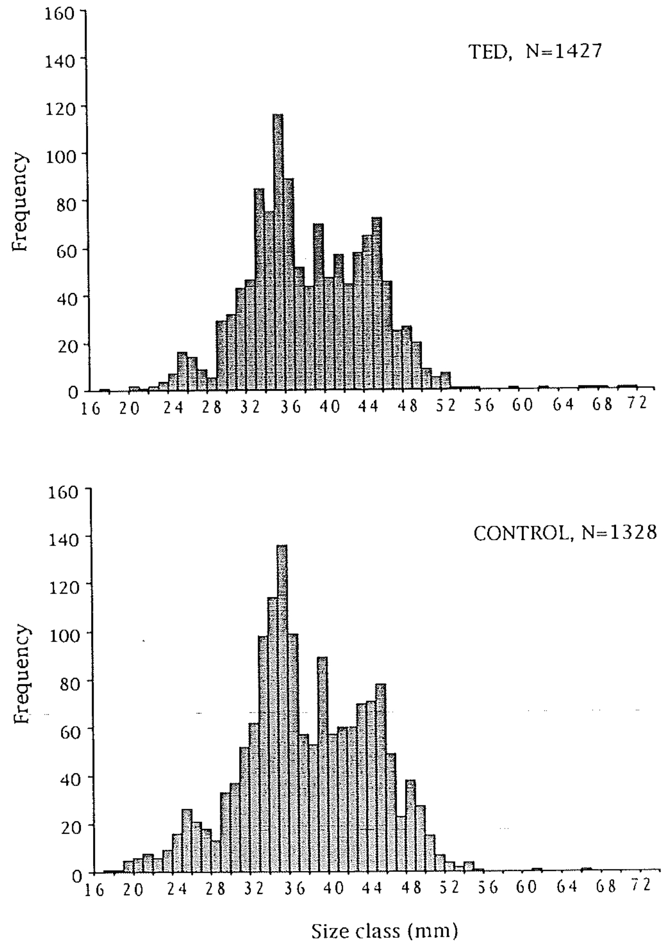

Fig. 3. Length–frequency distributions of *P. plebejus* caught in the TED and control codends. Sample sizes as indicated on the graphs.

vertebrates (Fig. 2). The total income from bycatch and prawns derived from the codend with the TED was greater than that from the control in 7 of 24 tows. The TED codend earned A$ 40.91 less than the control over all tows and all nights out of a total income of A$ 1020 earned from the control codend.

The size-distributions of *P. plebejus* were similar between the TED and control codends (Fig. 3, samples pooled among tows and boats). The sizes of discarded *P. caeruleopunctatus* were similar in the two codends, although only relatively small numbers were measured (Fig. 4). Fish larger than 33 cm were of legal size and, therefore, should have been retained by the fishermen, hence the six fish of legal size discarded from the TED codend cannot be interpreted as being due to the TED, but rather inefficient sorting.

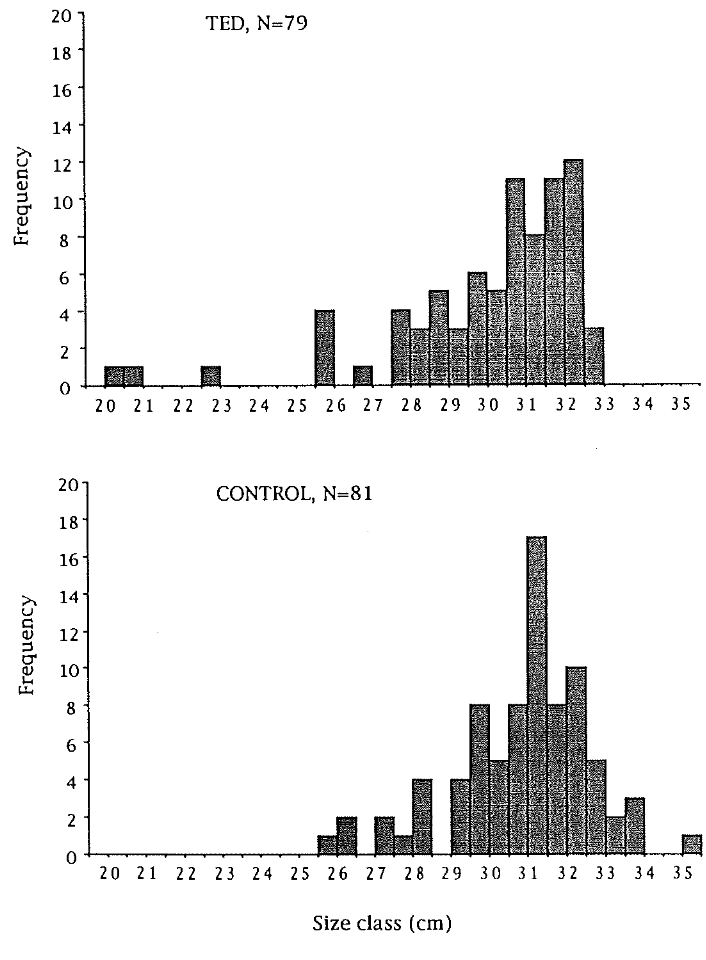

Fig. 4. Length–frequency distributions of *P. caeruleopunctatus* caught in the TED and control codends. Sample sizes as indicated on the graphs.

DISCUSSION

In this study, the Morrison soft TED reduced the total amount of bycatch by an average of 32% or 9.0 kg per 90 min tow. This result confirms Kendall's (1990) finding that this TED significantly reduced bycatch. The bycatch predominantly comprised species of no commercial value. This component of the bycatch contained 15–25 species of benthic fishes and invertebrates. Under normal operating conditions, almost all of this bycatch is dead when returned to the sea.

There was also a significant reduction in the weight of catch of discarded commercial species of finfish. These fish were rejected because they were either too small or did not return sufficient money to warrant sorting. This component of the bycatch was primarily composed of undersize flatheads (*Platycephalus* spp.), flounders (*Pseudorhombus* spp.) and whiting (principally *Sillago bassensis*). In the case of *P. cuerueleopunctatus*, there was no evidence that the TED excluded different sizes of fish, but rather that it reduced catches of fish of all sizes. This interpretation is tentative, however, because relatively few individuals were measured. The great variability in catches of finfishes made comparisons difficult, particularly for schooling fishes such as trawl whiting (*Sillago* spp.). Catches of these species differed greatly between tows and codends, seemingly irrespective of the presence of the TED. In one tow, the codend with the TED caught 5.8 times the catch of *S. bassensis* than in the control codend.

The significant reduction of discarded commercial finfishes found in this study has implications for the management of the prawn trawl fishery and interacting finfish fisheries. It is precisely those individuals that are not yet large enough to be landed that, ideally, should not be caught by the prawn trawl fleet. If fewer were caught when small, more would grow to become available, both as saleable bycatch for the prawn trawl fleet and in fisheries that target finfish. This is particularly so for fishes like *Platycephalus* spp. and *Pseudorhombus* spp. which are consistently worth landing. *Sillago* spp., in contrast, have no minimum legal size, but are nevertheless not often landed by fishermen because of their small value. The implications of catching fewer *Sillago* spp. are therefore different, but no less far-reaching. The extent to which fishermen are willing to forego income (from reduced catches of commercially valuable bycatch) in order to have potentially greater or more sustained catches later is yet to be tested.

The TED did not significantly reduce catches of invertebrate bycatch, either retained or discarded. The difference in the effect of the TED between finfishes and invertebrates is probably a reflection of the relative mobility and benthic habit of the species involved. Catches of retained invertebrates were dominated by slipper lobsters (*Ibacus* spp.) and *Octopus* spp. It is likely that these species remained in the lower parts of the net and were not sorted by the TED. Underwater observations of this TED by divers suggested that many species of finfish and elasmobranch approached the TED higher in the trawl and appeared to be aware of the TED before reaching it (N. Andrew, personal observation, 1991). This behaviour would increase their likelihood of being rejected.

The Morrison soft TED had little impact on catches of prawns, both in terms of weight or sizes of individuals. Across the whole experiment, the TED reduced catches of prawns by only 1.1 out of a total catch of 93.2 kg (1.2%) and the sizes of prawns caught were similar. The financial cost of using the TED with respect to prawns was therefore minimal. This result compares favourably with that of Kendall (1990), in which the Morrison soft TED reduced the catch of shrimps in Georgia by 8.5% (SE=3.98, n=27). Acceptance of the TED by the commercial fleet will, however, largely depend on the relative importance of prawns and bycatch to total income. During periods when catches of prawns are small, income derived from bycatch is an important component of total income. At other times, when catches of prawns are larger, the 2.4% reduction in catch reported in the present study may translate into appreciable losses of income.

The benefits of more efficient designs of trawls, and therefore smaller total catches, include an ability to do fewer, longer tows and cause less damage to prawns by crushing. Further advantage may be gained through the use of lighter webbing in the construction of trawls, thereby reducing costs of fuel (Seidel, 1975). Development of more efficient TEDs (those that exclude more bycatch, but retain the prawns) will no doubt continue as the perceived need to minimize bycatch increases (Andrew and Pepperell, 1992). As noted by Kendall (1990), greater involvement of commercial fishermen will accelerate the development of more efficient TEDs.

There is clearly a potential to decrease bycatch in prawn trawl fisheries using selective trawl designs such as the Morrison soft TED. The ecological consequences of such a reduction are, however, poorly understood. There is currently insufficient knowledge about the ecological interactions among benthic species caught by prawn trawlers to state what the impact of reducing this incidental catch will be (Andrew and Pepperell, 1992). Without knowledge of the standing stock of benthic communities, it is not possible to state whether the amount of bycatch removed by the commercial fleet has any measurable impact on the abundances of fishes, including those that may be predators of prawns (see also Blaber et al., 1990).

In this study, the Morrison soft TED, although originally designed to reduce the incidental capture of jellyfish and turtles in the Gulf of Mexico shrimp fisheries, has the potential to reduce the incidental capture of finfish bycatch off the east coast of Australia. Most of this bycatch was unwanted species that would otherwise be discarded. Further research is needed to provide better estimates of both the cost to fishermen of using such trawls and the ecological impact of reducing bycatch. In particular, the efficiency of this TED needs to be understood when catches of prawns are large (> 100 kg per night) and when there is a greater bycatch of juveniles of commercially important finfishes.

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APPENDIX G

Reducing the by-catch of juvenile fish (mulloway) in the Hawkesbury River prawn-trawl fishery using square-mesh panels in codends.

Fisheries Research, in press.

Broadhurst, M.K. and S.J. Kennelly.

Reducing the by-catch of juvenile fish (mulloway *Argyrosomus hololepidotus*) using square-mesh panels in codends in the Hawkesbury River prawn-trawl fishery, Australia.

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Running Head: Reducing finfish by-catch using square-mesh panels in prawn trawls

Fish. Res. (in press)

ABSTRACT

The numbers of prawns and small fish (mulloway) caught by two designs of prawn-trawl codends with square-mesh panels were compared in a manipulative field experiment in the Hawkesbury River prawn-trawl fishery. Compared to a conventional codend, catches from a codend made entirely of square-meshes showed a 52% reduction in the mean weight of prawns caught and a 95% reduction in the numbers of mulloway caught. A codend with the posterior half made of diamond-shaped meshes and the anterior half made of square-shaped meshes showed no significant difference in the catches of prawns compared to the control, but reduced to 46% the mean numbers of mulloway caught. There were no differences in the sizes of prawns and mulloway caught by the half-square and the control codends. The codend made of all square meshes did not catch the smallest prawns and mulloway available. The results are discussed in terms of the probable behaviour of prawns and mulloway in trawls and possibilities for future developments of these fishing gears. It was concluded that there is great potential for square-mesh panels in codends to reduce the by-catch of fish such as juvenile mulloway in the Hawkesbury River prawn-trawl fishery whilst maintaining catches of prawns.

INTRODUCTION

Estuarine prawn trawling occurs in five estuaries in New South Wales (NSW), Australia and is valued at approximately A$7 million per annum (1990-91). As with most trawl fisheries, significant numbers of non-target organisms are caught incidentally with the targetted species (collectively termed "by-catch," sensu Saila, 1983). In New South Wales, the by-catch from estuarine prawn trawling often includes a large and diverse assemblage of small fishes, some of which are juveniles of species caught in other commercial and recreational fisheries (Kennelly *et al.*, 1992). The mortality of large numbers of these juveniles due to prawn trawling and the negative effects this may have on subsequent stocks of these species have resulted in significant conflicts between prawn-trawl fishers and other user groups (particularly recreational fishers) (see also Gordon, 1988; Foldren, 1989).

Mulloway (*Argyrosomus hololepidotus*) is an important commercial species in NSW and a key target species for a large recreational fishery (Grant, 1985). It is a euryhaline demersal species inhabiting nearshore environments and estuaries during the juvenile stages of development (0 to 2 years) (Bennett, 1985). In NSW, this is evident from March to July each year when newly-spawned individuals occur in several estuaries throughout the state.

The Hawkesbury River is an estuary in NSW which supports a year-round school prawn (*Metapenaeus macleayi*) fishery valued at approximately A$725 000 per year. A survey of the by-catches of prawn trawl fisheries throughout NSW showed that there are relatively large by-catches of juvenile mulloway during winter months in the Hawkesbury River (Kennelly *et al.*, 1992). The current management of this fishery is mainly based on spatial and temporal closures to trawling but, because of increasing conflicts with other fishers concerning the by-catch of juvenile finfishes, alternative procedures may be required if prawn trawling is to continue in those places and times where conflicts occur.

Recent studies on modifications to trawling gear have concentrated on designs that reduce by-catch whilst maintaining catches of prawns. Many of these studies have shown clear results and have often led to changes in the management strategies of the fisheries concerned (e.g. Kendall, 1990; Renaud *et al.*, 1990; Thorsteinsson, 1992). One suite of modifications to trawl nets that has been tested successfully in a number of fisheries involves square-mesh panels in codends (Robertson, 1983a; Isaksen and Valdermarsen, 1986; Robertson and Stewart, 1988; Carr, 1989; Suuronen, 1990; Briggs, 1992; Casey *et al.*, 1992; Fonteyne and M'Rabet, 1992; Thorsteinsson, 1992; Walsh *et al.*, 1992). These papers attempted to determine the selective properties of square-mesh panels in codends for benthic species and identified them as possible solutions to release roundfish whilst retaining a large proportion of the targetted catch.

Given this recent and quite successful history, the present situation in the Hawkesbury River suggests that square-mesh panels in codends may reduce by-catch, thereby reducing conflict. Our specific goals in this paper were to complete a manipulative field experiment under normal commercial fishing operations to determine the characteristics of retaining prawns and excluding mulloway of two designs of codend which incorporate square-mesh panels.

MATERIALS AND METHODS

This study was done in April 1992 on established prawn-trawl grounds in the Hawkesbury River using a commercial prawn trawler (10m). This fishery uses single-rigged otter-board prawn trawls (based on the Florida Flyer design). A single locally-designed prawn net with a headline length of 11 metres (mesh size 40 mm) was rigged so that the codend could be exchanged. This trawl was used in replicate 30 minute tows at approximately 2.5 knots in depths ranging from 2 to 8m.

FIG 1 HERE PLEASE

The codends used in this experiment measured 50 meshes long (2 m) and were constructed from 40 mm mesh netting (see Fig. 1). These codends comprised two panels: the anterior panel was 25 meshes long and constructed of 2 mm diameter twisted twine; the posterior panel was 25 meshes long and constructed of 3 mm diameter braided twine. Three designs of codend were examined. The control codend (conventionally used in the Hawkesbury River fishery) was hung such that all meshes were diamond-shaped (Fig. 1a). The second codend (referred to as the all-square codend) had the netting cut on the bar such that the whole codend was comprised of square-shaped meshes (Fig. 1b). The third codend (referred to as the half-square codend) was intermediate between these, with the posterior section of the codend hung with conventional diamond-shaped meshes and the anterior section hung with square-shaped meshes (Fig. 1c). We predicted that this latter codend would provide a means for water and swimming fish to escape from the codend through the larger anterior openings.

The three codends were interchanged between tows in a random order so that each codend was used three times per day (total of 9 tows per day). Over ten consecutive days during the trawling season when mulloway were in great abundance, we completed a total of 30 replicate tows for each of the three codends.

To ensure independence among tows, the location of each tow was randomly selected from the available prawn-trawl locations that were possible under the particular conditions. These locations were determined by the fisher's local knowledge and dependent upon such factors as the tide and clarity of the water.

After each tow, the codend was emptied onto a tray. All organisms were sorted into different species, the most abundant being prawns, mulloway and catfish (*Euristhmus lepturus*). Data recorded from each tow were: the total weight of prawns, the total weight of by-catch, the weights, numbers and sizes of mulloway (to the nearest 0.5 cm), the weights and numbers of catfish, the numbers and sizes of other commercially and/or recreationally important species (to the nearest 0.5 cm), the numbers of non-commercial/recreational species and the number of species in the assemblage. All prawns in a subsample of the total prawn catch from each tow were measured in the laboratory (to the nearest mm).

Data for all variables were analysed using Cochran's test for homogeneity of variances, transformed if necessary and then analysed in the appropriate 2-factor analysis of variance (see Underwood, 1981). Significant differences detected in these analyses were investigated using Student-Newman-Keuls multiple comparisons of means. Size-frequencies of prawns and mulloway were graphed and compared.

RESULTS

Both codends with square-mesh panels significantly reduced the weight of by-catch and the numbers of catfish and mulloway (Fig. 2a, b and Table 1). The mean numbers of mulloway were reduced by 95% in the all-square codend and 54% in the half-square codend. The half-square codend did not significantly reduce the numbers of species in the assemblage nor the catches of prawns, although the mean weight of prawns was 16% lower in this codend (Fig. 2a, c and

TABLE 1 AND FIG 2 HERE PLEASE

Table 1). The all-square codend, however, significantly reduced the weights of prawns (difference between means of 52%) and the numbers of species.

Of all variables, only the weight of prawns caught was significantly different among days in the experiment (Table 1). No variables displayed significant interactions between type of codend and days of sampling.

FIGS 3 AND 4 HERE PLEASE

School prawns, *Metapenaeus macleayi* and mulloway were represented by two easily identifiable cohorts in the control and half-square codends (Figs. 3 and 4). The size-distributions of these species in the all-square codend showed only the larger of the two cohorts. The size compositions of greasyback prawns, *Metapenaeus bennettae* and king prawns, *Penaues plebejus* were similar in the half-square and control codends, whilst the all-square codend proportionally caught fewer small prawns (Fig. 3).

DISCUSSION

The data presented above illustrate that codends with square-mesh panels selectively reduced the catch of non-target species (see also Robertson 1983b; Robertson and Stewart, 1988; Arkley, 1990; Briggs, 1992; Fonteyne and M'Rabet, 1992). In addressing possible reasons for these patterns, it is useful to examine various behavioural characteristics which may cause apparent selectivities of square-mesh panels. Previous studies have shown that fish and invertebrates display different reactions to mechanical stimuli (Watson, 1976; Wardle, 1983, 1989; Main and Sangster, 1985; Newland and Chapman, 1989). Generally fish, unlike slower-moving benthic invertebrates, exhibit a herding response to trawls. In an attempt to maintain position with a moving net, fish invariably tire and fall back towards the tapering codend (Wardle, 1983). Chapman (1964) suggested that a possible area of escape for these fish may occur at this point because, as they are herded close together, the balance of the school is upset initiating an escape response towards the sides of the net. The school may even continue this escape response by attempting to push through the meshes at the sides of the net. Briggs (1992) observed the behaviour of North Sea whiting (*Merlanguis merlanguis*) in a codend with a square-mesh panel and concluded that the fish nosed along the diamond mesh panels of the codend, actively seeking escape. Once they encountered the panel of square-mesh, they were able to pass through the larger openings.

In contrast, the response of benthic invertebrates such as prawns to stimuli from trawled gears appears to be limited (Lockhead, 1961; Main and Sangster, 1985; Newland and Chapman, 1989). SCUBA observations by Watson (1976) indicated that a strong external stimulus (such as the ground chain of a trawl) resulted in penaid prawns contracting their abdomens ventrally, effectively propelling themselves backwards. This initial escape response was repeated three to five times after which the prawns attempted to orientate themselves to the seabed using their swimmerets. Because prawns are not capable of maintaining such activity for long, the flow of water generated by the moving trawl quickly forced the prawns against the meshes and they eventually tumbled down the net. Once in the rear of the codend, their retention depended on the mesh-size of the codend rather than any active escape response. Because openings in the meshes in the all-square codend used in the present study were larger than in the control codend, there was less likelihood that smaller individuals could have been retained, thus explaining the relatively small catches and larger sizes of prawns caught. Similarly, any fish that did not escape at the point of codend taper in this codend would likewise be subjected to the same selectivity as the prawns, hence the small numbers of mulloway and catfish retained (Fig. 2). Although the most efficient in excluding mulloway, the all-square configuration is probably economically unacceptable in terms of catching prawns (52% reduction in mean catches) and therefore should not be considered as a viable option for management.

The half-square codend retained less mulloway than the control codend (54% difference in mean catches) with no statistically significant reduction in prawn weights (Fig. 2 and Table 1). This result may be attributed to the differences in behaviour discussed above and differences in hydrodynamic pressure anterior to the diamond-mesh section. Because meshes in the posterior section of the codend are virtually closed, waterflow through the codend is restricted, causing a back-pressure of water to be directed out through the anterior square-meshes. Such a movement of water would assist the escape of free swimming fish. Chapman (1964) labelled this "the damming phenomenon" and suggested that such a disturbance may stimulate the lateral-line receptors of fish and contribute to their escape responses.

There were no significant differences between the size compositions of prawns and mulloway captured in the half-square and control codends (Figs. 3 and 4). The all-square codend only retained the larger of these organisms, probably because openings in the meshes in the posterior section were larger. There were no interspecific differences in the length-frequencies of the prawns caught during the experiment, suggesting that these three species reacted similarly once inside the net.

This experiment showed that there is great potential for the eventual development of a codend with square-mesh panels that excludes a large proportion of fish (including juvenile mulloway and catfish) whilst retaining an acceptable amount of prawns. Because Briggs (1992) observed that most fish escape through the first few rows of such panels, a modification to the codends described in the present paper would be to reduce the size of the square mesh panel in the half-square codend. Such a modification may maintain the escape of fish like mulloway, whilst reducing the likelihood that prawns will 'flick' through the open meshes during their initial escape response. Further, because larger fish are more likely to avoid capture initially (because they swim faster), a reduction of the mesh size in the square-mesh panel may enhance the retention of prawns whilst still excluding small fish.

Whilst the mulloway-exclusion characteristics of square-mesh panels were apparent, there remains a question surrounding the physical trauma associated with escaping (Main and Sangster, 1988; DeAlteris and Castro, 1992). For example, Briggs (1992) observed that clupeoids lost scales during escape through netting. In addition, fish may also damage fins and gills during movement through square meshes, contributing to overall stress and possibly post-trawl mortality. In two of the few studies which have examined such mortalities, DeAlteris and Reifsteck (in press) found negligible mortalities of fishes that had passed through square-mesh panels and Main and Sangster (1988) showed that fish passing through square-meshes had greater rates of survival than those passing through diamond-meshes. Obviously, any future research to refine modifications to codends should include an assessment of such effects.

In this study, we have demonstrated that square-mesh panels have the potential to reduce the incidental capture of juvenile mulloway by the Hawkesbury River prawn-trawl fleet whilst retaining the majority of prawns caught. Further research needs to be done in refining the designs of these codends so that more juvenile fish are excluded, catches of prawns are maintained and the extent of post-trawl mortalities of excluded fish are assessed.

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TABLE 1a. - Summaries of F-ratios from analyses of variance to determine effects on variables due to fishing with different codends and on different days. To stabilize variances the weights of prawns, by-catch and the numbers of mulloway and catfish were transformed using ln(x+1). The data for numbers of species were treated in the raw form. ** significant (p<0.01).

Treatment	df	Weight of prawns	Weight of by-catch	Numbers of mulloway *A. hololepidotus*	Numbers of catfish *Euristhmus sp.*	Numbers of species
Codends	2	21.61**	29.0**	80.65**	65.22**	21.1**
Days	9	6.38**	0.94	1.5	1.38	1.03
C x D	18	1.62	1.45	1.2	1.1	1.31
Residual	60					

TABLE 1b. Summaries of Student-Newman-Keuls multiple comparisons of the means of each codend for the five variables.

Weight of prawns	Control	=	1/2	>	All Square
Weight of by-catch	Control	>	1/2	>	All Square
Numbers of catfish	Control	>	1/2	>	All Square
Numbers of mulloway	Control	>	1/2	>	All Square
Numbers of species	Control	=	1/2	>	All Square

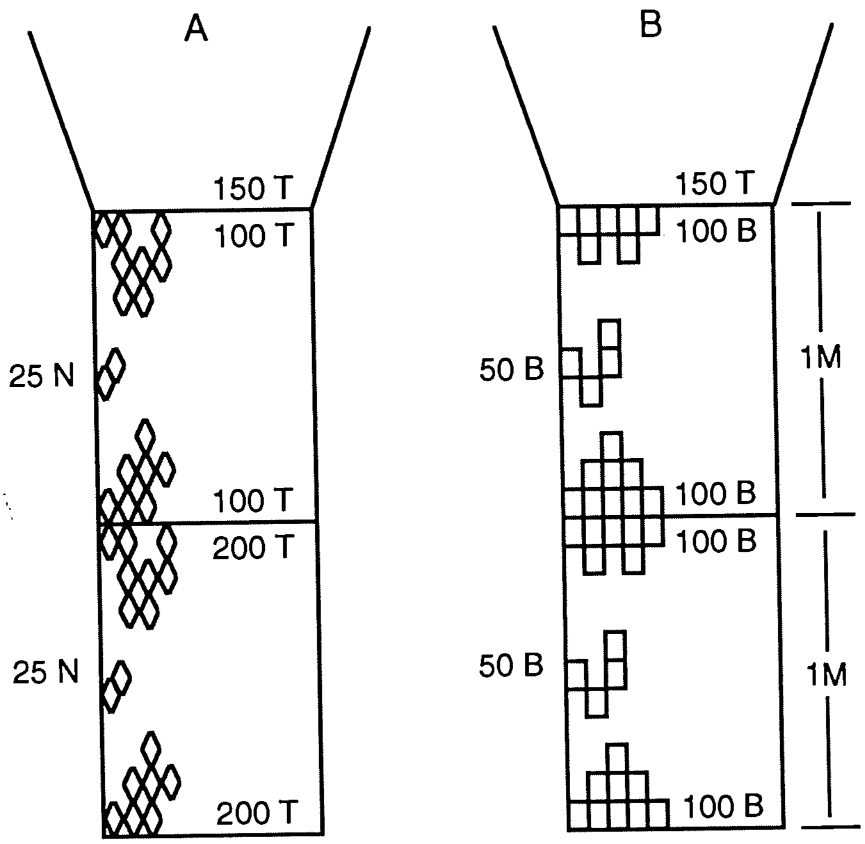
CAPTIONS TO FIGURES

Fig. 1. Diagramatic representation of codends used in this experiment: (A) control codend, (B) half-square codend, (C) all-square codend (where T= transversals, B = bars and N = normals).

Fig. 2. Differences in mean catches ± SE (per 30 min tow) of (A) the weights of prawns and all by-catch, (B) the numbers of catfish and mulloway and (C) the numbers of species (n = 30 for each codend pooled across days).

Fig. 3. Length-frequency distributions of school prawns (*Metapenaeus macleayi*), greasyback prawns (*Metapenaeus bennettae*) and king prawns (*Penaeus plebjus*) from each of the three codends.

Fig. 4. Length-frequency distributions of mulloway (*Argyrosomus hololepidotus*) from each of the three codends.


A
150 T
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1M
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C
150 T
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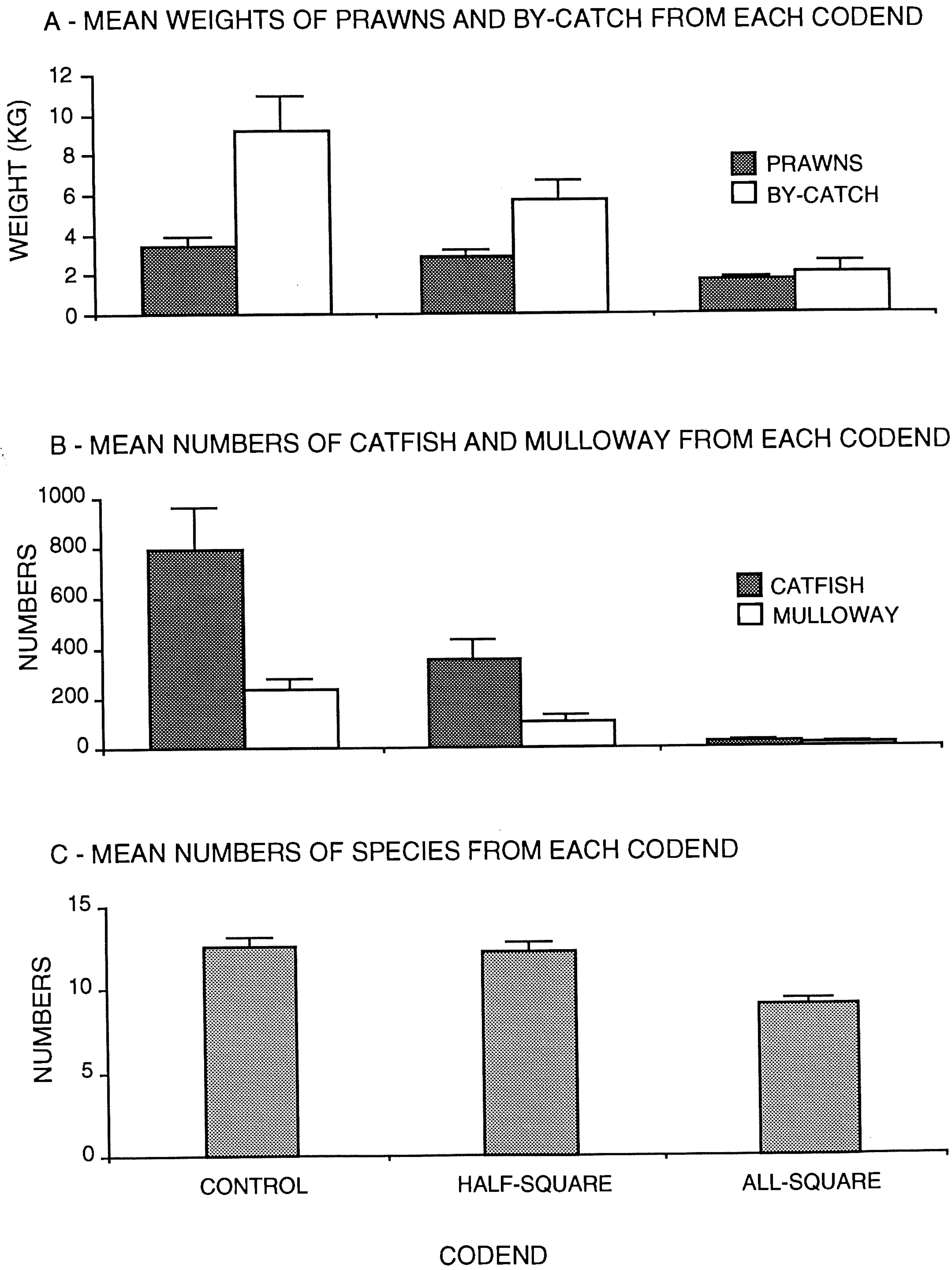
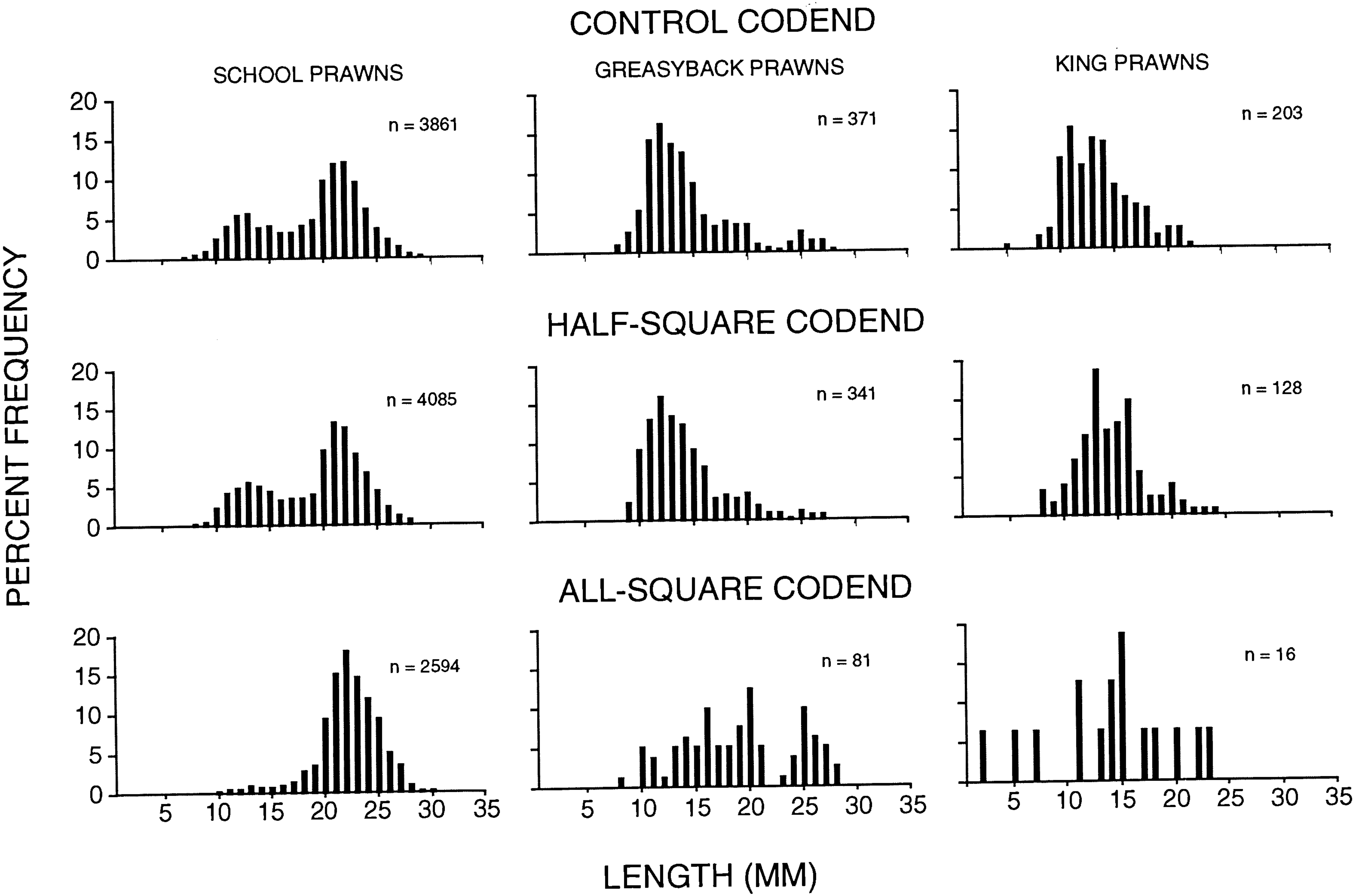
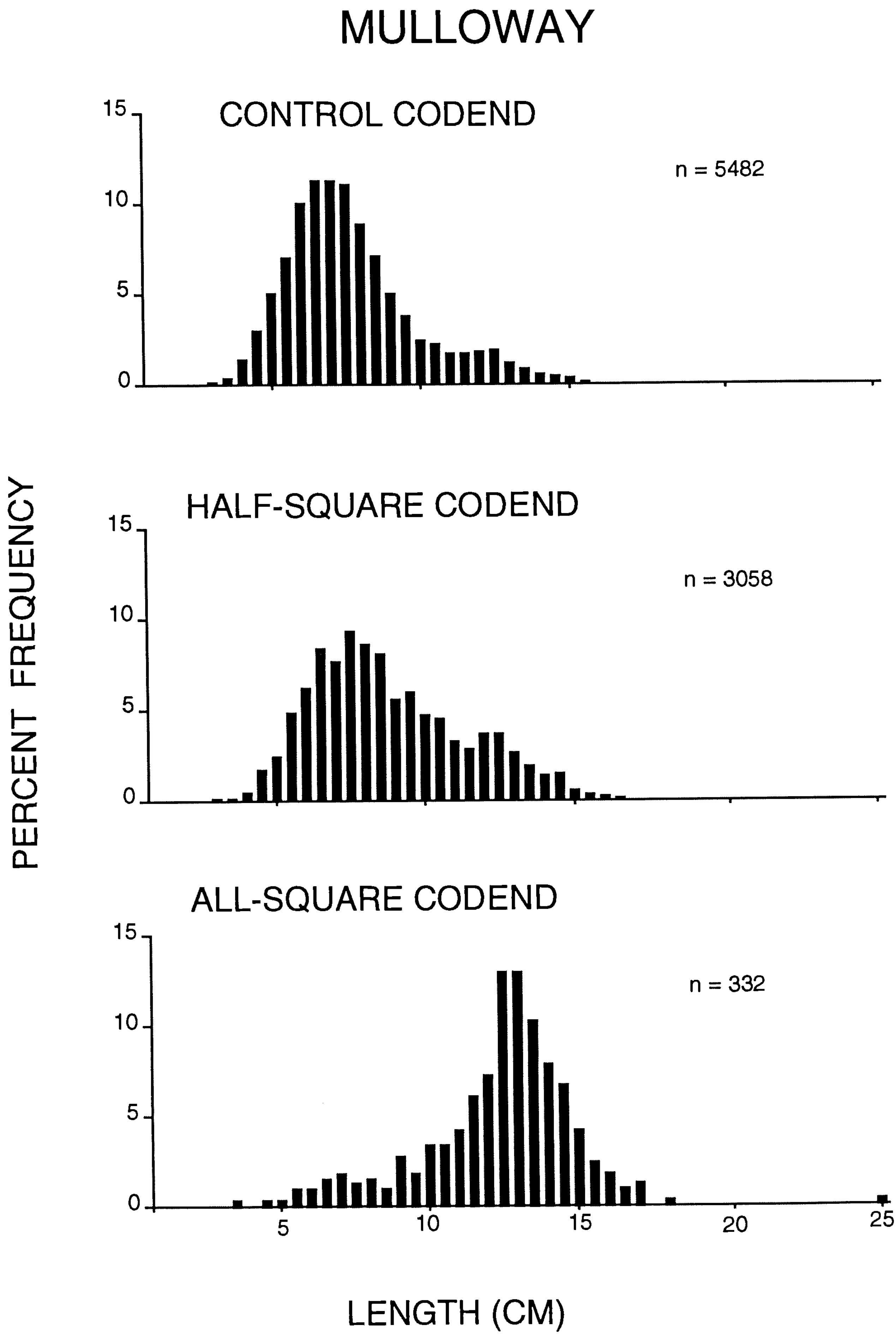
200 T
25 N
200 T


A - MEAN WEIGHTS OF PRAWNS AND BY-CATCH FROM EACH CODEND
WEIGHT (KG)
0
2
4
6
8
10
12
PRAWNS
BY-CATCH
B - MEAN NUMBERS OF CATFISH AND MULLOWAY FROM EACH CODEND
NUMBERS
0
200
400
600
800
1000
CATFISH
MULLOWAY
C - MEAN NUMBERS OF SPECIES FROM EACH CODEND
NUMBERS
0
5
10
15
CONTROL
HALF-SQUARE
ALL-SQUARE
CODEND



CONTROL CODEND
SCHOOL PRAWNS
GREASYBACK PRAWNS
KING PRAWNS
n = 3861
n = 371
n = 203
HALF-SQUARE CODEND
n = 4085
n = 341
n = 128
ALL-SQUARE CODEND
n = 2594
n = 81
n = 16
PERCENT FREQUENCY
0
5
10
15
20
5
10
15
20
25
30
35
LENGTH (MM)


MULLOWAY
CONTROL CODEND
n = 5482
HALF-SQUARE CODEND
n = 3058
ALL-SQUARE CODEND
n = 332
PERCENT FREQUENCY
15
10
5
0
5
10
15
20
25
LENGTH (CM)

APPENDIX H

A trouser-trawl experiment to assess codends that exclude small fish (mulloway) in the Hawkesbury River prawn-trawl fishery.

ICES Journal of Marine Science, submitted manuscript

Broadhurst, M.K. and S.J. Kennelly.

A trouser-trawl experiment to assess codends that exclude juvenile fish (mulloway) in the Hawkesbury River prawn-trawl fishery

M.K. Broadhurst, and S.J. Kennelly

Broadhurst, M.K., and Kennelly, S.J., 1993. A trouser-trawl experiment to assess codends that exclude juvenile fish (mulloway) in the Hawkesbury River prawn-trawl fishery. - ICES J. mar Sci., ??: ??-??.

Abstract

A trouser-trawl was used to assess new designs of codends that reduce the by-catch of juvenile fish in the Hawkesbury River prawn-trawl fishery. Simultaneous comparisons were made between the catches and by-catches from new codends with those from a conventional codend. The new designs incorporated panels of netting (40 mm mesh and 85 mm mesh respectively) sewn such that the meshes were square-shaped. These panels were placed into the tops of the anterior sections of each codend to allow water and swimming fish to escape through these larger openings whilst allowing prawns to tumble along the conventional diamond-shaped mesh on the bottom of the codend (and be retained in the posterior section). Comparisons with a conventional codend (where all meshes were diamond-shaped) showed that the codend with the 45mm mesh panel reduced the by-catch of small mulloway by a mean of 44% without significantly reducing the catch of prawns. The 85mm mesh panel was less effective, making no significant differences to catches of prawns or mulloway but it did reduce the numbers of species in the by-catch and the weights of catfish. The results are discussed in terms of changing the management of this fishery by incorporating square-mesh panels in codends. The advantages of using trouser-trawls in simultaneous comparisons of new gears is discussed in terms of (i) the acceptance of the results by industry and (ii) overcoming problems caused by spatial and temporal heterogeneity in comparing control and modified gears using alternate hauls.

Keywords: by-catch, codends, mulloway, prawn-trawl, square-mesh panels, trouser-trawl.

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Introduction

The incidental capture of non-target species (collectively termed "by-catch", *sensu* Saila, 1983) from prawn trawling has been of world-wide concern for several years (Saila, 1983; Sheridan *et al.*, 1984; Collins and Wenner, 1988; Andrew and Pepperell, 1992). Of particular interest is the by-catch and subsequent mortality of many juveniles of species that form the basis of other target fisheries (Howell and Langan, 1987; Gordon, 1988; Foldren, 1989; Cooper, 1990; Ohaus, 1990).

In New South Wales, Australia, estuarine prawn trawling occurs in five locations and is valued at approximately $A7 m per annum (1990-91). A survey of the by-catches of the various estuarine and oceanic prawn-trawl fisheries in NSW showed that there are relatively large by-catches of juveniles of commercially and recreationally important finfishes in some of these estuaries (Kennelly *et al.*, 1992). Of particular concern is the capture of juvenile mulloway (*Argyrosomus hololepidotus* (Lacepede)) from late autumn to early spring in the Hawkesbury River (see Kennelly *et al.*, 1992; Broadhurst and Kennelly, in press). The current management of this fishery is based mainly on spatial and temporal closures to trawling but, to alleviate increasing conflicts over by-catch, additional strategies have to be examined.

Several fisheries throughout the world have alleviated problems of trawl by-catch by developing gears that are more selective. In particular, square-mesh panels in codends have been used to reduce unwanted by-catch of fusiform fishes whilst retaining a large proportion of the targeted catch (Robertson, 1983a; Isaksen and Vandermarsen, 1986; Robertson and Stewart, 1988; Carr, 1989; Suuronen, 1990; Briggs, 1992; Casey *et al.*, 1992; Fonteyne and M'Rabet, 1992; Thorsteinsson, 1992; Walsh *et al.*, 1992).

Quantifing the effectiveness of square-mesh panels in codends has been approached by comparing the catches and by-catches from control and modified codends. This has been done in two ways: (i) alternately towing each type of codend on a particular fishing ground (see Robertson and Stewart, 1988; Casey *et al.*, 1992; Fonteyne and M'Rabet, 1992; Broadhurst and Kennelly, in press); or (ii) towing both types of codend at the same time, either by one vessel towing twin gear (Briggs, 1992), two adjacent vessels towing single gear (Thorsteinsson, 1992) or one vessel towing a net with two vertically-separated codends (termed a "trouser-trawl") (Suuronen, 1990; Millar and Walsh, 1992; Walsh *et al.*, 1992). The experimental approach used to compare different configurations is usually determined by the characteristics of the particular fishery under examination (e.g. legal gear configurations, area of trawlable ground, location, etc.) and logistics (the funding and facilities available).

A previous experiment used alternate hauls to compare two designs of square-mesh panels in codends with a conventional codend in the Hawkesbury river prawn-trawl fishery (see Broadhurst and Kennelly, in press). Although this work showed promising results in reducing the by-catch of juvenile mulloway, some reduction in the catches of prawns was detected. Representatives of industry expressed concern over the reduction in prawn catches and because of variability between one tow and the next, they questioned the use of alternate hauls to compare the different designs. To make our comparisons of modified codends similar to normal commercial operations and so facilitate the acceptance of new designs by industry, we adapted a prawn net so that it included two vertically-separated codends (i.e. a trouser-trawl). This permitted the direct and simultaneous comparison of a conventional codend with codends that included different square-mesh panels.

The trouser-trawl method for testing codends has been used successfully elsewhere (Nicolajsen, 1988, Millar and Walsh, 1992) and its relatively straight forward analysis and interpretation assumes that fish encountering the gear have an equal chance of entering the control and modified codends (see Fig. 1). It is particularly applicable to fisheries that are restricted to single gear (like the Hawkesbury River prawn-trawl fishery). Our specific goal in this paper was to use a trouser-trawl configuration to compare the conventional codend used in this fishery with two new designs of codends that incorporate square-mesh panels in terms of the extent to which each excludes juvenile mulloway whilst retaining catches of prawns.

Methods

This study was done in June, 1993 on established prawn-trawl grounds in the Hawkesbury River using a commercial prawn trawler. A single locally-designed prawn net (based on the Florida Flyer design) with a headline length of 11 metres (mesh size 40 mm) was modified to accommodate two vertically-separated codends and rigged so that each codend could be exchanged easily (see Fig. 1). This trawl was used in normal commercial tows of between 6 and 40 minutes duration (average = 25 min) at approximately 2.5 knots in depths ranging from 2 to 8 m.

The codends used in this experiment measured 50 meshes long (2 m) and were constructed from 40 mm mesh netting (see Fig. 2). These codends comprised two sections: the anterior section was 25 meshes long and constructed of 2 mm diameter twisted twine; the posterior section was 25 meshes long and constructed of 3 mm diameter braided twine. Three designs of codend were examined. The control codend (conventionally used in this fishery) was hung so that all meshes were diamond-shaped (Fig. 2a). The second and third codends had panels of netting (40 mm mesh and 85 mm mesh respectively) cut on the bar and sewn into the tops of the anterior sections of each codend (Figs. 2b and 2c). We predicted that these panels would allow water and swimming fish to escape from the codends through the larger anterior openings and still allow prawns to tumble along the conventional diamond-shaped mesh on the bottom of the codend (and be retained in the posterior section).

Each codend with a square-mesh panel was directly compared with the control codend, one on each leg of the trouser-trawl. The position and order of each codend was randomly determined and each codend with a square-mesh panel was used three times per day (i.e. total of 6 tows per day). Over seven consecutive days during the trawling season when mulloway were thought to be in abundance, we completed 21 replicate comparisons of each of the two treatment codends against the control. To ensure that the experiment represented commercial fishing operations as closely as possible, the location of each tow was selected according to the most likely location of prawns by an experienced Hawkesbury River commercial prawn-trawl fisherman.

After each tow, the codends were emptied separately onto the sorting tray. All organisms were sorted into different species, the most abundant being school prawns (*Metapenaeus macleayi* (Haswell)), mulloway and catfish (*Euristhmus lepturus* (Gunther)). Data recorded from each codend were: the total weight of prawns, the total weight of by-catch, the weights, numbers and sizes of mulloway (to the nearest 0.5 cm), the weights and numbers of catfish, the numbers and sizes of other commercially and/or recreationally important species (to the nearest 0.5 cm), the numbers of non-commercial/recreational species and the number of species in the assemblage. All prawns in a subsample of the total prawn catch from each tow were measured in the laboratory (to the nearest mm).

Data for all replicates that had sufficient numbers of each variable (i.e. >10 fish or >100 g in each comparison), were analysed in one-tailed, paired t-tests. Size-frequencies of prawns and mulloway were graphed and compared using 2 sample Kolmogorov-Smirnov tests.

Results

The codend with the 40 mm mesh panel significantly reduced the total numbers of mulloway (mean reduction of 5.25 fish per tow or 34%) and the numbers of mulloway less than 10 cm (mean reduction of 4.71 fish per tow or 44%) (Figs. 3a, b and Table 1). There were no significant differences for these variables in the codend with the 85 mm mesh panel. Neither codend with square-mesh panels significantly reduced the weights of prawns or total by-catch, although the mean catch of prawns was 35.3g (5%) smaller in the codend with the 40 mm mesh panel and 97.7g (11%) smaller for the codend with the 85 mm mesh panel (Figs. 3c, d and Table 1). The codend with the 85 mm mesh panel significantly reduced the numbers of species in the by-catch and the weights of catfish, whilst the codend with the 40 mm mesh panel had no significant effect on these variables (Figs. 3e, f and Table 1).

Two-sample Kolmogorov-Smirnov tests comparing the size-frequency distributions for the school prawns and mulloway measured from each sample (Figs. 4 and 5) showed no differences in the size compositions between the various codends ($p > 0.05$).

Discussion

The data presented above show that codends with square-mesh panels can selectively reduce the catch of non-target species whilst maintaining the catch of target species in the Hawkesbury River prawn-trawl fishery (see also Robertson, 1982, 1983b, 1983c; Robertson and Stewart, 1988; Briggs, 1992; Fonteyne and M'Rabet, 1992; Broadhurst and Kennelly, in press). In a previous experiment, Broadhurst and Kennelly (in press) examined two designs of codends with square-mesh panels and attributed the characteristics of these designs in retaining prawns and excluding mulloway to differences in the behaviours of the two species. It was suggested that fish are herded together at the taper of the codend, upsetting the balance of the school and initiating an escape response towards the sides and top of the net. If the meshes are open in this area then the school may pass through (see also Briggs, 1992). This may be further enhanced by differences in hydrodynamic pressure at the front of the posterior section of the codend (caused by closed meshes in the posterior section). In contrast, benthic invertebrates like prawns seem to display a limited response to such stimuli (due perhaps to physiological differences) and are forced against the meshes, eventually tumbling down the net. Once in the rear of the codend, their retention depends upon mesh-size rather than any active escape response (Lochhead, 1961; Main and Sangster, 1985; Newland and Chapman, 1989).

The two codends with square-mesh panels examined in the present paper were designed to take advantage of the theory discussed above by incorporating a square-mesh panel on the top of the anterior section of the codend only, so that small fish (mulloway and catfish) might escape without a substantial loss of prawns. The results suggested that this occurred in the codend with the 40 mm square-mesh panel: there was no significant reduction in the weights of prawns but a 34 % reduction in the total numbers of mulloway and a 44 % reduction in the numbers of mulloway less than 10 cm (Figs. 3a, b, c and Table 1).

The codend with the 85 mm square-mesh panel was not as successful as the 40 mm mesh panel, having no significant effect on either the weights of prawns caught nor the numbers of mulloway (Figs. 3c, b and Table 1). One possible reason for this concerns the installation of this square-mesh panel and associated changes in the geometry of the whole codend, since it was difficult to attach 85 mm mesh to 40 mm mesh and maintain an even symmetry of meshes. As a result there would have been some distortion and folding-over of meshes which may have affected the actual size of the square-shaped openings. Despite this anomaly, this codend significantly reduced the numbers of species in the by-catch and the total weight of catfish (Figs. 3e, f and Table 1).

Kolmogorov-Smirnov tests failed to detect any differences between the size compositions of prawns and mulloway captured in the various codends (Figs. 4 and 5), but there were proportionally less mulloway under 10 cm retained in the codend with the 40 mm square-mesh panel (Fig. 3b - see above). The exclusion of these small mulloway is a particularly important result in terms of alternative management strategies because larger, faster-swimming fish have a greater chance of avoiding prawn-trawls altogether.

This experiment showed that there is great potential for the development of a codend with square-mesh panels that excludes a large proportion of fish, whilst retaining acceptable quantities of prawns. One possible modification to the codends described in the present paper would be to increase the amount of netting around the anterior section of the codend to about 150 meshes. This should increase the hydrodynamic pressure towards the square openings and further assist the escape of free-swimming fish (see Broadhurst and Kennelly, in press).

Although the effectiveness of these and other designs of codends with square-mesh panels are apparent (see also Broadhurst and Kennelly, in press), there remains a question of the extent of post-trawl mortalities associated with fish escaping (Main and Sangster, 1988; DeAlteris and Castro, 1992). For example, fish may lose scales and damage fins and gills during movement through square meshes, contributing to overall stress and possibly resulting in some mortality (Briggs, 1992). Although results from other studies suggest that these effects may be minimal (Main and Sangster, 1988; DeAlteris and Reifsteck, in press), further research into modified trawl gears should include an assessment of this question.

In this study we have demonstrated the effectiveness of using a trouser-trawl configuration to assess codends with square-mesh panels in a fishery restricted to using single trawl gear (see also Suuronen, 1990; Millar and Walsh, 1992; Walsh *et al.* 1992). The advantage of this technique is that it removes any confounding effects due to spatial and temporal heterogeneity that could occur in experiments involving alternate hauls. This is particularly important in prawn-trawl fisheries that use single gear on trawl grounds where catches of prawns and by-catch can vary greatly from one tow to the next. In such situations the use of a single net with two codends is closely orientated towards commercial fishing techniques, whilst still allowing a simultaneous comparison between conventional and modified codends.

Acknowledgements

This study would not have been possible without the vessel and expertise of Mat Martin Matthews. Other technical support came from Kent Bollinger, Mark Bradley, Greg Collins and John Stewart. Thanks are extended to Prof. Tony Underwood and Dr Derek Staples for critically reading the manuscript.

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TABLE 1. - Summaries of one-tailed paired t-tests comparing different codends. **significant ($p<0.01$); *significant ($p<0.05$).

	Control vs 40 mm square -mesh panel		Control vs 80 mm square -mesh panel	
	Paired t-value	p	Paired t-value	p
Total No. of mulloway	3.187	0.004**	-0.627	0.274
Total Wt. of mulloway	1.570	0.068	1.289	0.108
No. of mulloway <10 cm	2.405	0.026*	0.581	0.289
No. of mulloway >10 cm	0.961	0.178	-1.395	0.100
Wt. of prawns	1.577	0.068	1.718	0.055
Wt. of by-catch	1.204	0.121	1.271	0.109
No. of species	-0.116	0.454	1.840	0.040*
No. of catfish	1.508	0.082	1.51	0.090
Wt. of catfish	0.339	0.37	2.195	0.029*

Captions to Figures

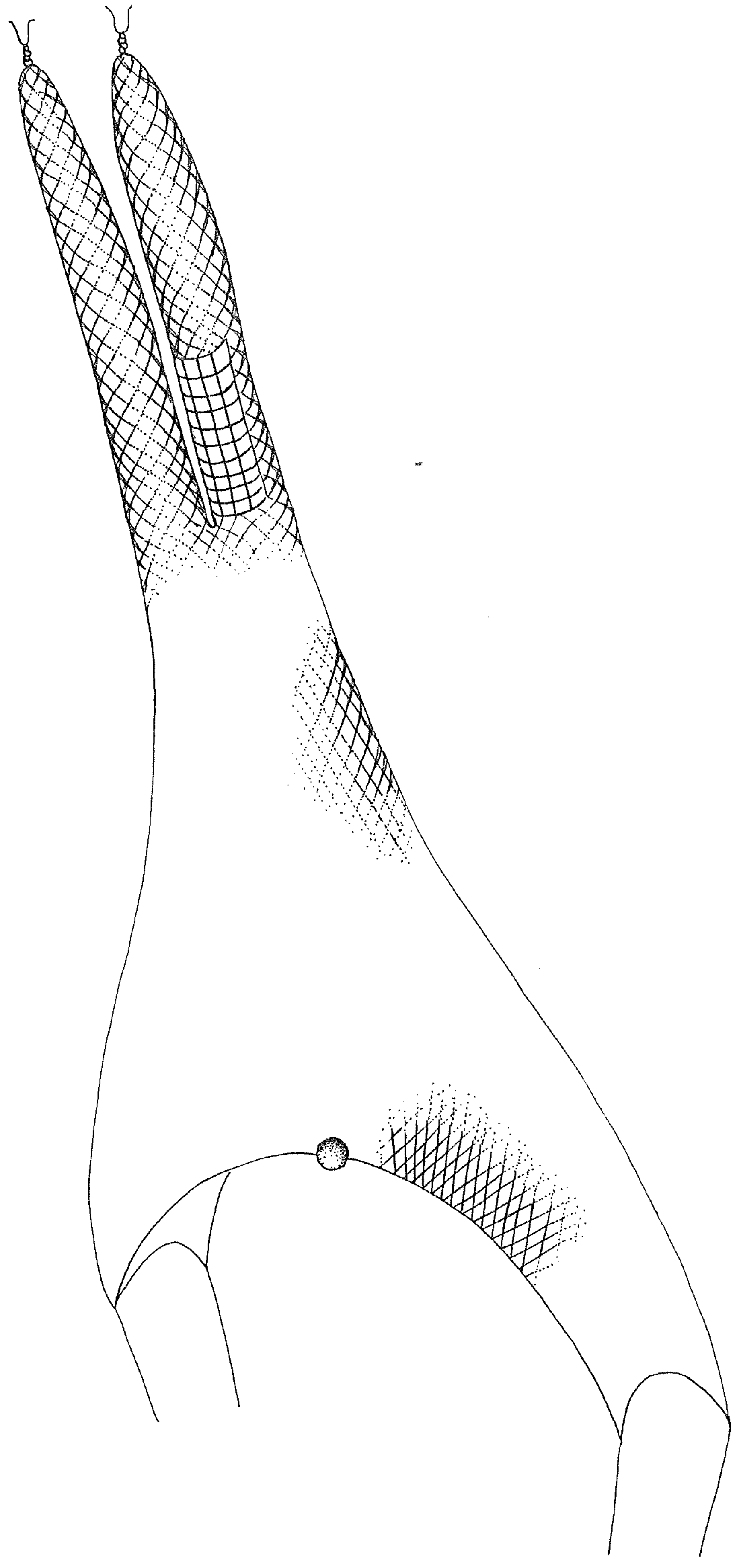
Figure 1. The trouser-trawl configuration used to compare different codends.

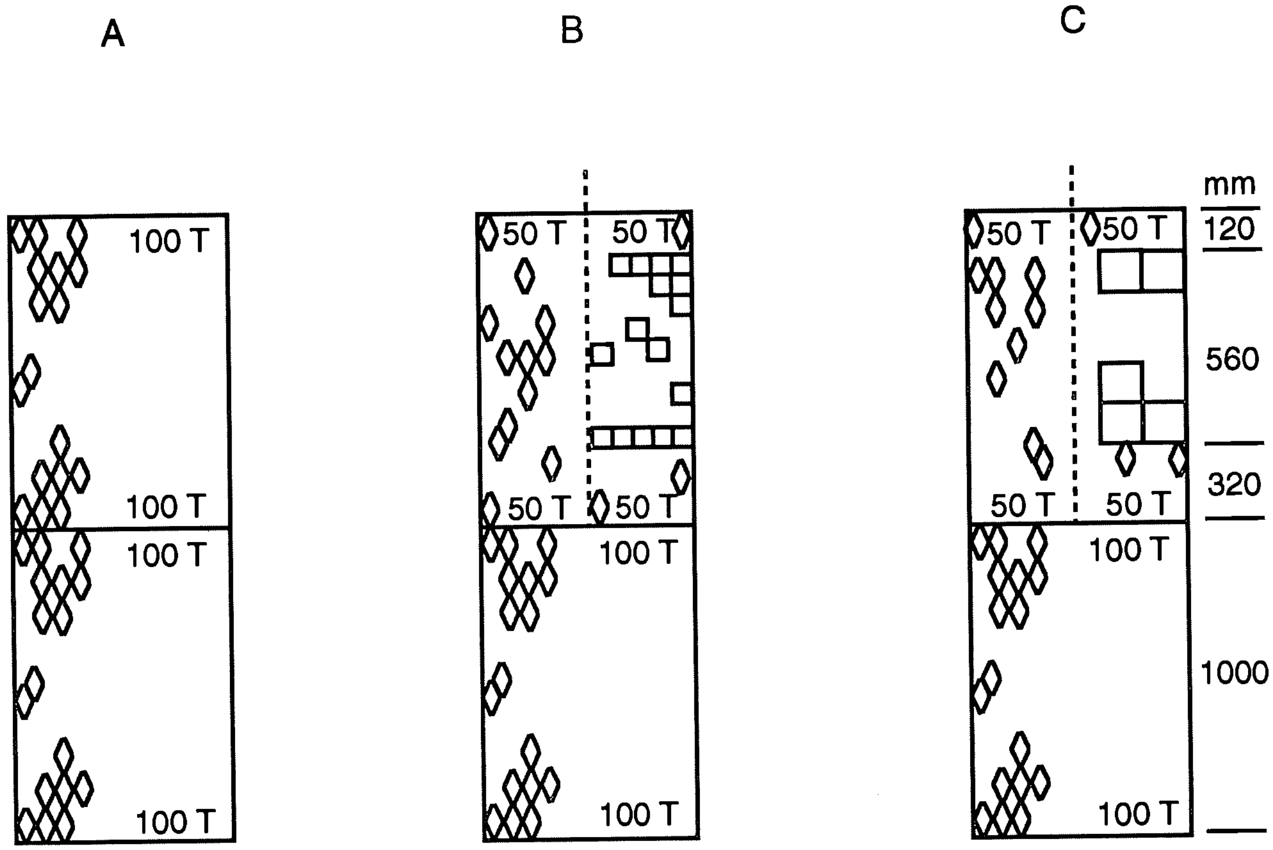
Figure 2. Diagramatic representation of codends used in this experiment: (a) control codend, (b) codend with the 40 mm square-mesh panel, (c) codend with the 85 mm square-mesh panel (where T = transversals and B = bars).

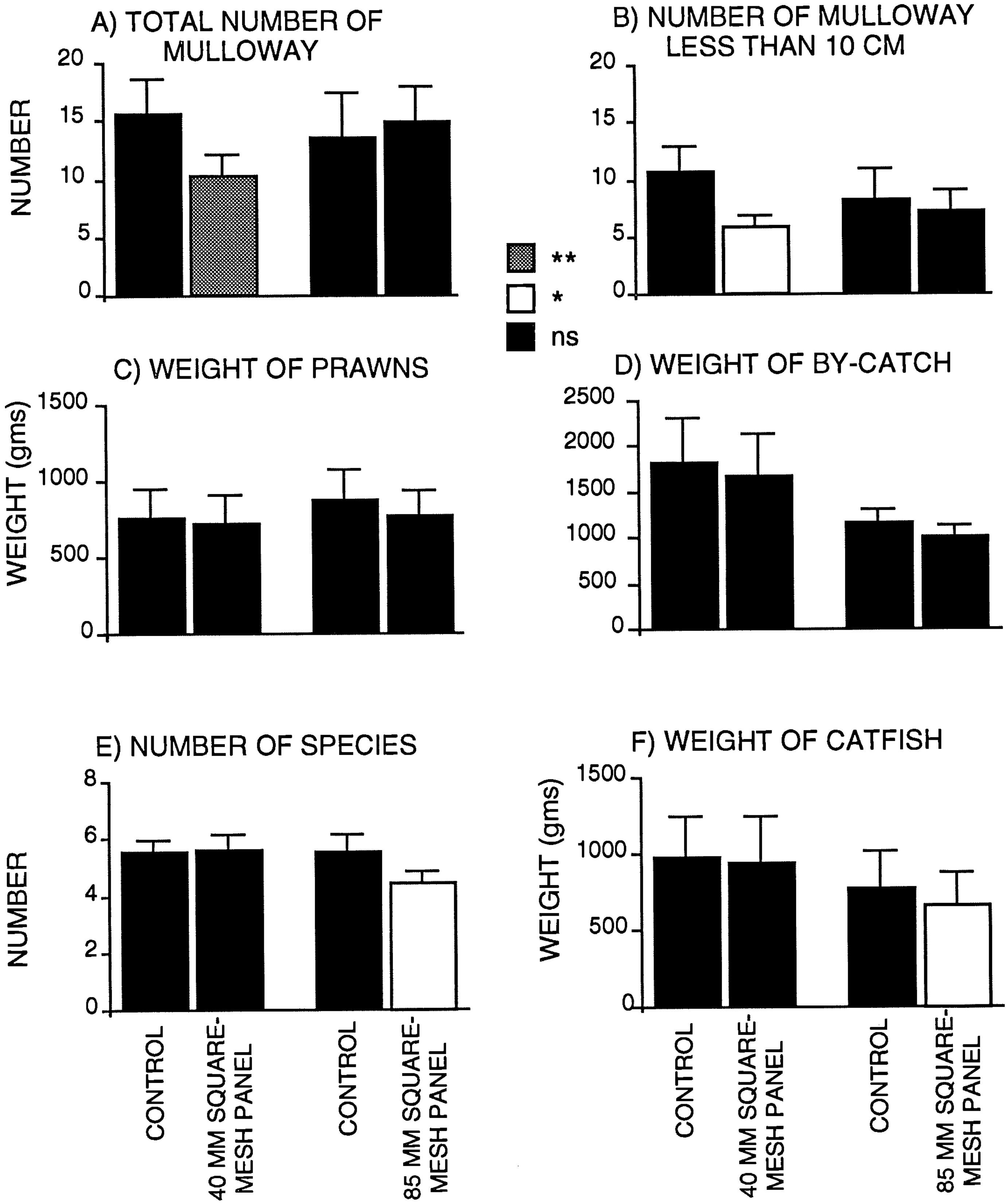
Figure 3. Differences in the mean catches (per tow) $\pm$ SE of (a) the total numbers of mulloway, (b) the numbers of mulloway less than 10cm, (c) the weights of prawns, (d) the weights of by-catch, (e) the numbers of species in the by-catch and (f) the weights of catfish. **significant ($p<0.01$); *significant ($p<0.05$); ns = non-significant ($p>0.05$).

Figure 4. Length-frequency distributions of school prawns (*Metapenaeus macleayi*) from each of the codends.

Figure 5. Length-frequency distributions of mulloway (*Argyrosomus hololepidotus*) from each of the codends.

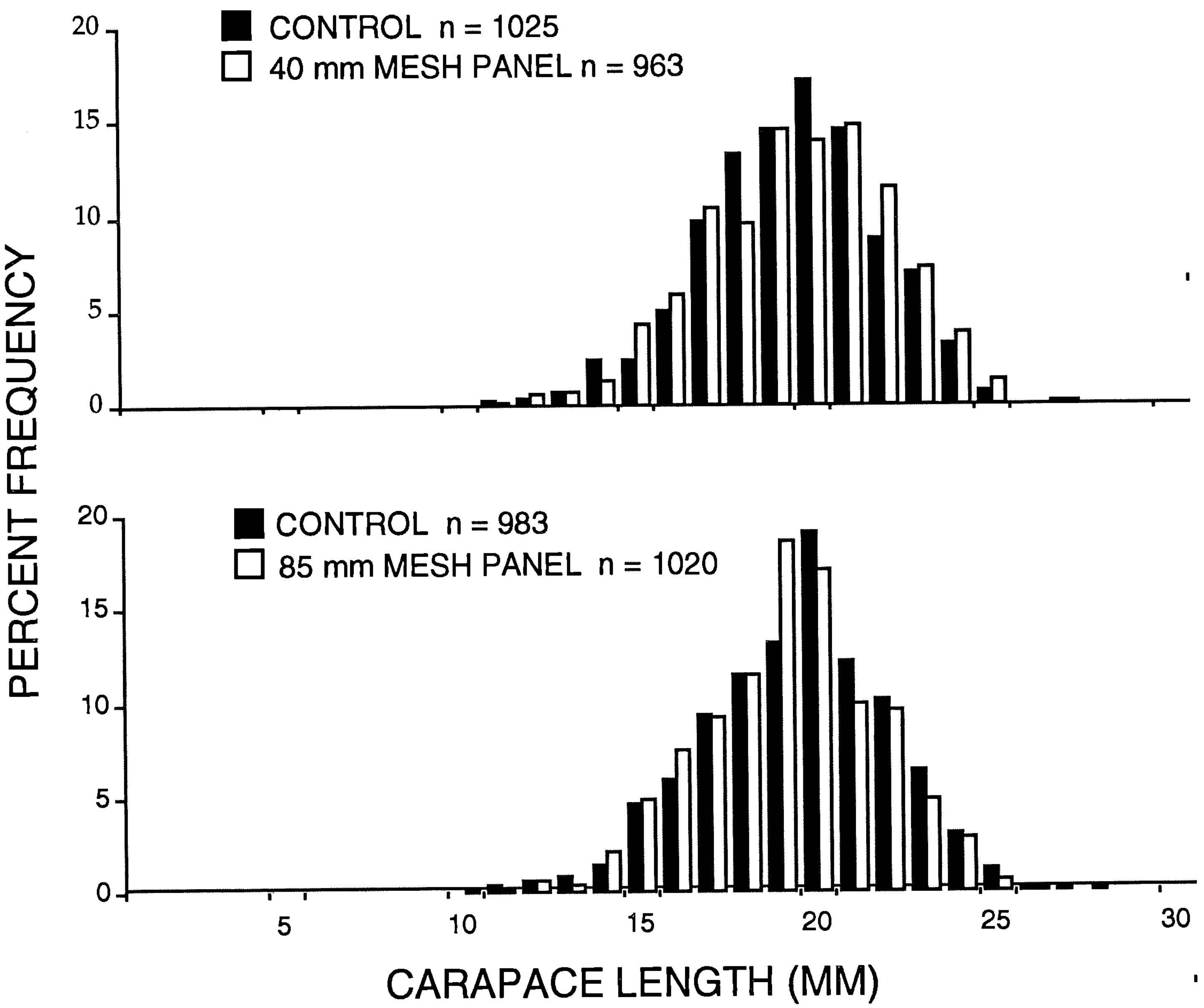



A
B
C
mm
100 T
100 T
100 T
100 T
50 T
50 T
50 T
50 T
100 T
100 T
50 T
50 T
50 T
50 T
100 T
100 T
120
560
320
1000

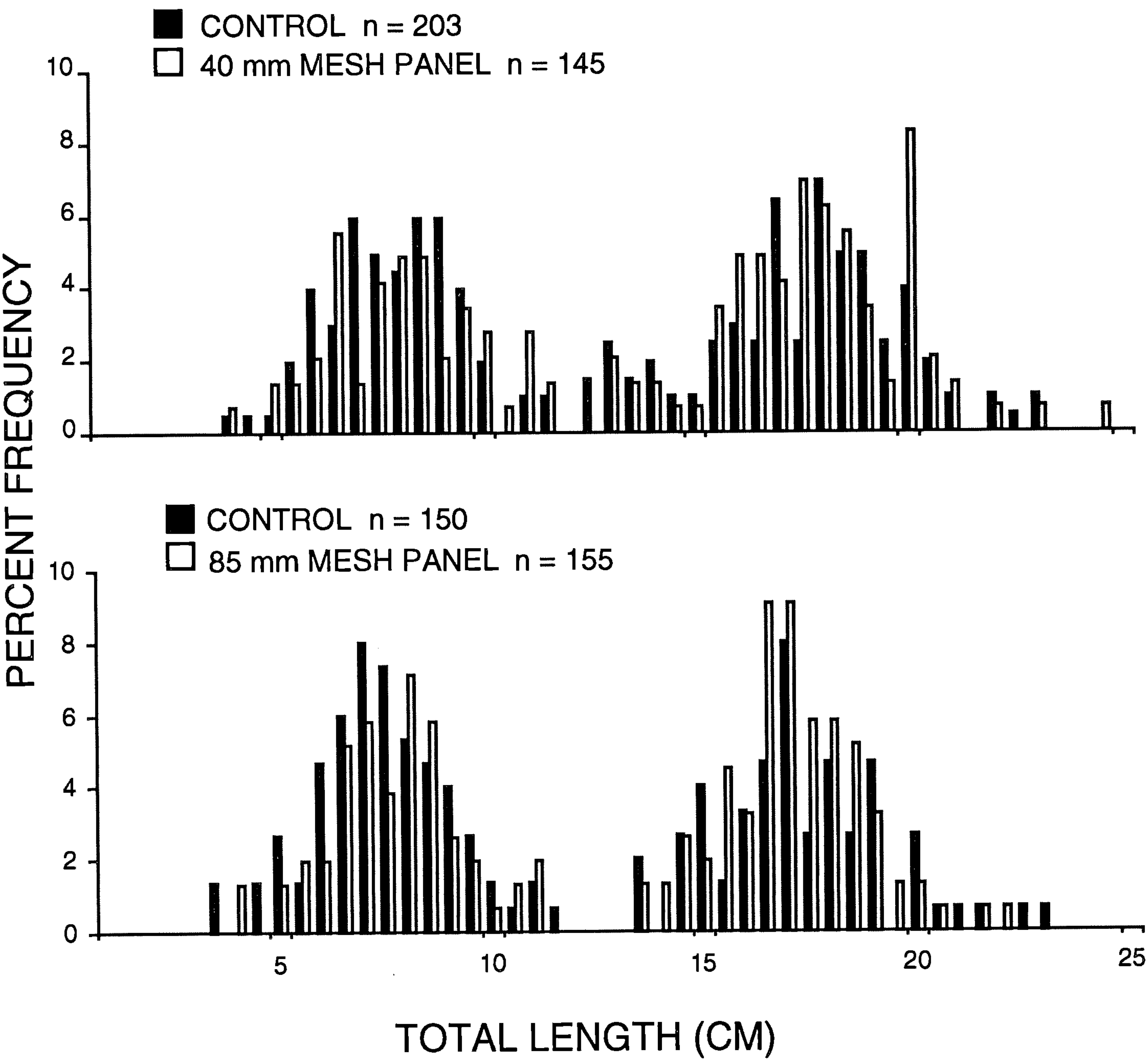


A) TOTAL NUMBER OF MULLOWAY
B) NUMBER OF MULLOWAY LESS THAN 10 CM
C) WEIGHT OF PRAWNS
D) WEIGHT OF BY-CATCH
E) NUMBER OF SPECIES
F) WEIGHT OF CATFISH
NUMBER
WEIGHT (gms)
**
*
ns
0
5
10
15
20
500
1000
1500
2000
2500
2
4
6
8
CONTROL
40 MM SQUARE-MESH PANEL
CONTROL
85 MM SQUARE-MESH PANEL

SCHOOL PRAWNS



MULLOWAY



CONTROL n = 203
40 mm MESH PANEL n = 145
CONTROL n = 150
85 mm MESH PANEL n = 155
PERCENT FREQUENCY
0
2
4
6
8
10
5
10
15
20
25
TOTAL LENGTH (CM)

APPENDIX L

Preliminary report on the the by-catch of prawn trawling in the Hawkesbury River.

NSW Fisheries, Internal publication, 1992.

Kennelly, S.J. and G.W. Liggins.

PRELIMINARY INFORMATION ON THE PRAWN-TRAWL BY-CATCH PROJECT'S WORK IN THE HAWKESBURY RIVER

S.J. Kennelly & G.W. Liggins

September, 1992

INTRODUCTION

This brief report has been compiled in response to a request from Laurie Derwent for any current information from the Prawn-trawl By-catch project which may be of relevance to the production of the Draft Management Plan for the Hawkesbury River Prawn Trawl fishery. Whilst our analyses of these particular sets of data are far from complete, the following information should be of some interest. In the next few months, we will complete all formal analyses and prepare a proper manuscript concerning this work.

In late 1989, we began our survey of the catches and by-catches of the estuarine prawn trawlers operating in Botany Bay, Port Jackson, the Hawkesbury and Clarence Rivers and Lake Woolooweyah. We also surveyed the oceanic prawn trawlers working out of the ports of Port Stephens, Coffs Harbour, Yamba/Iluka and Ballina. The aim of this work was to quantify the catches and by-catches of these prawn fleets in order to fill our void in the data on these aspects of NSW's prawn fisheries and so complete the first logical step in the eventual provision of management recommendations for these fisheries.

We would like to take this opportunity to acknowledge most sincerely the excellent co-operation that we have experienced with the prawn trawl fishermen of NSW in doing this research. Quite simply, without their help over the past 3 years, we could not have done this work nor be in a position to present the data that is contained in this preliminary report. At the recent International Conference on Bycatch in the Shrimp Industry (held in Florida), the following point was made many times by fishermen, scientists and managers from around the world: that the NSW prawn-trawl by-catch research project has enjoyed a level of industry-participation and good-will that is the equal of any such project in the world. We believe that this conclusion from this very high-level conference speaks volumes for the attitude and courtesy of NSW's prawn trawlers.

The attached map shows the north coast of NSW, encompassing the range of the prawn trawl fisheries in the state. These fisheries mainly target two species, the eastern king prawn (*Penaeus plebejus*) at night and the eastern school prawn (*Metapenaeus macleayi*) during the day. Estuarine prawn trawling occurs in 5 estuaries in NSW, mainly during the summer period although in the Hawkesbury River, trawling occurs throughout the year. Oceanic prawn trawling occurs out of 11 ports along the coast throughout the year.

This report provides a preliminary examination of the data generated by our sampling of the catch and by-catch of estuarine prawn trawling in the Hawkesbury River. In addition to providing estimated rates of catch and by-catch, it describes some of the other ways that this data may be used - including the generation of extrapolations of catch rates to total catches by whole fleets and the generation of size-frequency information for key species.

METHODS AND PRELIMINARY RESULTS

Field sampling

In each month that prawn trawling has occurred between late 1989 and June 1992, we have attempted to place scientists on 4 randomly-selected trawler-trips. For the Hawkesbury River prawn trawl fleet, we used those vessels based in Brooklyn who usually worked the prawn grounds between Spencer and Brooklyn. Since November, 1991, we have attempted to do the same thing with the trawl fleet that targets on squid around the mouth of the Hawkesbury River. This latter sampling will be completed in October, 1992 when we have 12 months of data. As a consequence of this incomplete data set, this report contains no data concerning the catches and by-catches of the squid fleeet, but rather concentrates on data that is available for the prawn fleet.

During each trip, the catch and by-catch from each tow were sorted by the crew and our scientist, separating the various species. The weights of prawns from each tow were recorded. All by-catch species of commercial and recreational importance were counted, weighed and measured. Crustaceans, cephalopods and non-commercial finfish species were counted. For each tow, we also recorded the time, duration, location of the tow, as well as the basic gear configuration used.

Calculation of rates of catch and by-catch

Because boat-trips were randomly sampled each month, average catch rates and variances were calculated per month from replicate boat-trips rather than "replicate" tows. Whilst the latter method would have provided greater replication (and probably smaller variances), one cannot assume that individual tows were independent - in fact, usual fishing practices indicate the opposite. Further, estimates of effort by fleets (used in extrapolating catch and by-catch rates to total catches and by-catches by whole fleets) are only available in units of fisherman-days (boat-trips).

It is also possible (although not presented in this report) to calculate catch per unit time (rather than catch per fisherman-day). Because trawl-time per trip does not appear to be consistent between months, catch per unit time should be a more accurate means for comparing relative abundances of species across time and/or location, whilst catch per fisherman-day is the most appropriate figure to use in estimating monthly and seasonal catches by the fleet.

The catch and by-catch rates of species and other variables that may be of interest are shown in the attached table.

Calculation of total month/year catches and by-catches by the fleet
The catch rates per trip (and associated variances) for each month/year can be extrapolated to estimate catches by the whole Brooklyn fleet in each month/season using the total numbers of boat-trips done by the fleet (using rules for the derivation of standard errors of combination estimates, e.g. Mood, Graybill and Boes, 1974). These estimates of trawling effort are available in NSW via reports that fishermen are legally required to submit on a monthly basis. Whilst such effort data may be inaccurate due to many reasons (e.g. incorrect completion of forms by fishermen and/or incomplete or inaccurate data entry), they are the best available.

At the time of writing this report, we had not completed these extrapolations so we do not include them here.

Length-frequency distributions of by-catch species
Large quantities of length-frequency data were collected during the project but, as they are not yet fully analysed for the Hawkesbury fleets, we do not include them here. Obviously, however, in general the sizes of finfishes in the by-catch were usually quite small and most individuals would have been in the 0+ age-class.

DISCUSSION

The simplest preliminary interpretation of the data on rates of by-catches contained in the attached table identifies the key commercially-important species which occur in the Hawkesbury River prawn trawl fishery. Many species are by-caught in quite small, almost trivial quantities, whilst a handful of species stand out as quite abundant. These abundant (and therefore key species in any assessment of the fisheries-interaction issue) are: jewfish, bream and large-tooth flounder with occasionally large but highly variable quantities of tarwhine, trumpetter whiting and blue-swimmer crabs.

Studies such as ours often assume that all discarded by-catch dies as a result of the trauma associated with capture, removal from the water and handling. Whilst our study has not examined the fate of discards, those few studies that have considered the mortality of such by-catch have concluded that a small but variable proportion of the by-catch survives. Survival of capture and discard depends on species-specific vulnerabilities, operational factors (soak time, sorting time) and the time of exposure on deck. Our own observations have been mixed: for example, it does appear common for bream to swim more actively when returned to the water than mulloway. However, we also know from aquaculture research that it is not uncommon for even the most carefully-handled juvenile snapper and mulloway to die 2-3 weeks after any form of handling. Whilst we have not attempted to quantify the actual mortality of discarded by-catch, we have had very positive discussions with the Hawkesbury trawlers concerning their ideas on how to quantify and possibly minimize this impact (through the use of alternative sorting practices involving sorting in water). This fishery wish to take the lead in developing a FREND (Finfish Rehabilitation and Expiration-Negating Device) which may prove to be useful in reducing the by-catch mortality of juvenile finfish if the proper experimental trials are done. Industry have even expressed a desire to contribute towards the funding of a joint Research/Industry experiment.

Even if all the juvenile finfish discarded by prawn trawlers die, this may mean very little to subsequent stocks of commercial and recreational fisheries for these species if most of these juveniles would have died of natural causes anyway (i.e. in the absence of prawn trawling). Only by incorporating estimates of the natural mortalities of by-catch species, their ages at legal-size and our estimates of mortality due to prawn trawling, can we begin to estimate any causal effects of prawn trawl by-catch on subsequent stocks in fisheries for these species. Unfortunately, we have virtually no estimates of the natural mortalities of the key by-caught finfishes.

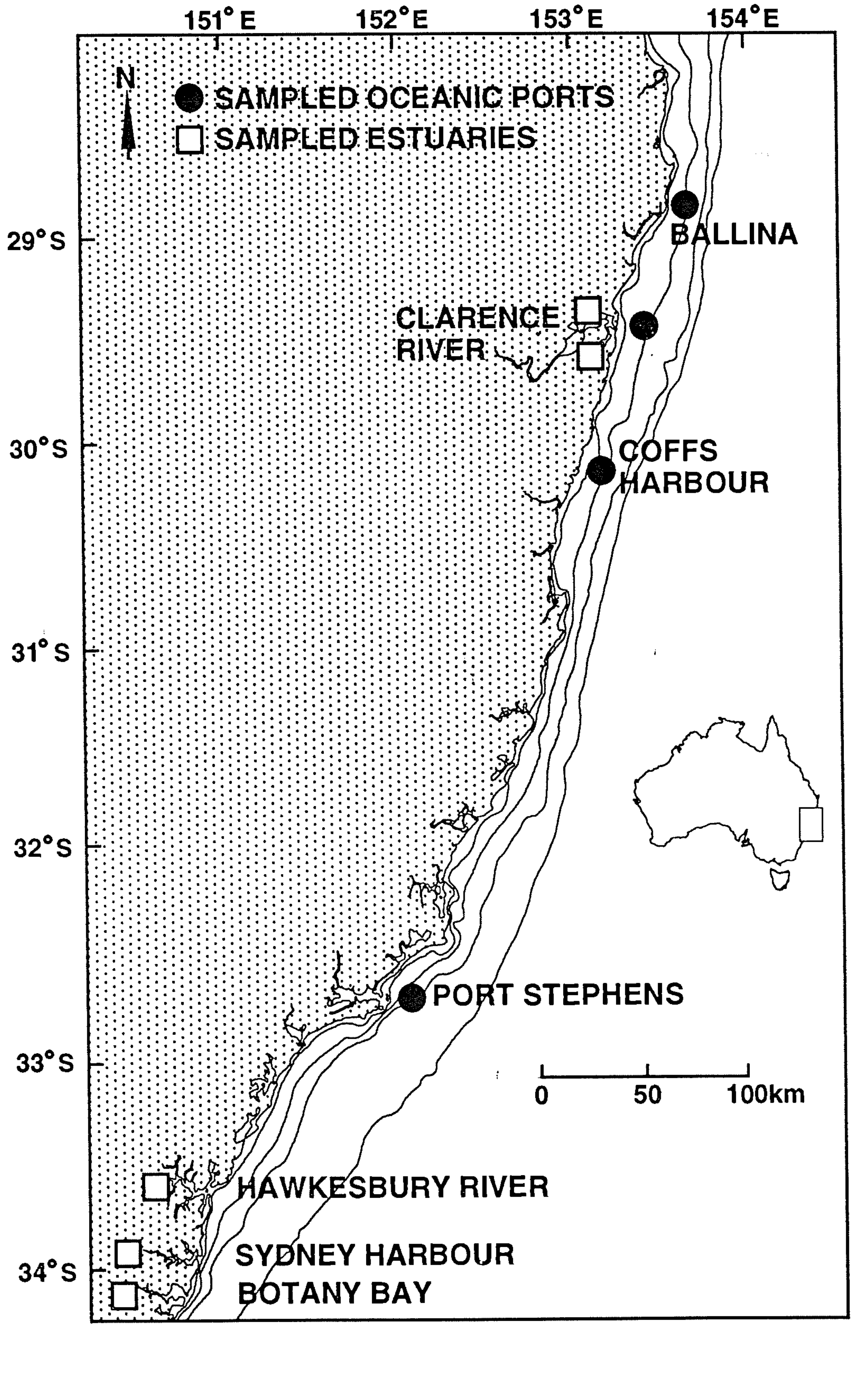
It is also clearly relevant to have some understanding of the relative proportion of the available biomass that by-caught species represent. For example, estimates of by-catches of particular species in particular areas that are in the order of hundreds of thousands of fish, may be negligible if the biomass of these fish in these places are orders of magnitude larger. Unfortunately, we have no estimates of these biomasses for the relevant species.

Despite the above uncertainties however, we feel that estimates of by-catches detected during our surveys (see attached table) and the large extrapolations that will arise from these catch rates (once estimates of fishing effort have been incorporated) suggest that it would be unwise for NSW Fisheries and Industry to ignore ways for minimizing the potentially deleterious effects of by-catch. That is, the fact that our study will result in the publication of by-catches of juvenile finfish numbering in the hundreds of thousands of fish per year per fleet, probably will lead to serious reactions from other commercial and recreational fisheries, despite a lack of information concerning mortalities of discards, their natural mortalities and their overall biomasses (as discussed above). The involvement of Industry in developing ways to minimize any deleterious effects of by-catch is an important first step in circumventing any future outcries from interacting fisheries. We see the development of better sorting practices (the FREND idea mentioned above) as one such option and other experiments we have done (offshore and in the Hawkesbury River) imply the very great potential for gear modifications to minimize negative aspects of prawn trawl by-catch. Data from our experiments which assessed TEDs and square-mesh codends and our knowledge of different gears used in other parts of the world suggest that there is scope to reduce by-catch in NSW through the use of such modified gears. We feel that it is important that Industry be actively involved in such developments so that (i) they are seen to be the driving force in addressing any potential problems that other fisheries may glean from our publication of large by-catches of juvenile finfishes and (ii) we can fully utilize Industry's unique practical knowledge of the relevant gear technology.

The catch rates derived from our study illustrate the utility of this type of data for the examination of temporal patterns in the magnitudes of by-catch. The data in the attached table reveal that catch rates of key commercial and recreational by-catch species vary markedly between species. Moreover, even within particular species, there is considerable variability in the magnitudes of by-catches across months and across years. Further, the pattern across months varies across years. There appear, therefore, to be no obvious periods within the season when rates of by-catch is consistently higher than at other times. This is an important observation to bear in mind if temporal closures are considered as a possible management option - if indeed it is considered that management is necessary. Of course, a different management option would involve a system of flexible closures in which access to the fishery is determined by ongoing monitoring of catches and by- catches.

Another type of closure involves localized spatial closures. Because our project has information on catches and by-catches for each individual tow location, detailed analyses of such information may reveal the existence of "hotspots" for key by-catch species which may assist in determining if and where such closures could be implemented.

On the completion of our study, it will clearly be beneficial to compare the by-catches of the Hawkebury River trawlers to the other surveyed locations. Our impressions of small/large by-catches of particular species may well be tempered by the scale of corresponding by-catches in other estuaries or on offshore grounds. Comparisons of by-catches on such spatial scales may further identify "problem" estuaries / oceanic grounds or indeed localized problem areas within estuaries / oceanic grounds.


151° E
152° E
153° E
154° E
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE
RIVER
COFFS
HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY

HAWKESBURY RIVER PRAWN FLEET

YearMonth	No. of trips	Mean duration of trip (mins)	se	Mean no. of commercial finfish taxa	se	Mean no. of taxa	se	Mean catch of prawns (kgs)	se	Mean bycatch (kgs)	se	Mean no. of by-caught individuals	se	commercial by-caught individuals	se	Mean no. of non-commercial by-caught individuals	se	Mean no. of bream	se	Mean no. of jewfish	se	Mean no. of snapper	se	Mean no. of dusky flathead	se
8907																									
8908																									
8909																									
8910																									
8911	3	569	249	6.33	1	16.67	1.3	89.248	11.39	21.312	8.71	770	128	87.3	51	682	139	20.7	17.2	23.33	8.95	8.33	2.73	0.67	0.33
8912	0																								
9001	4	234.7	74	7.25	1	19.5	2.5	27.22	12.12	25.184	5.78	961	240	104.3	57.3	857	244	57	40.1	5.5	3.5	9.75	7.6	2.25	0.75
9002	4	250.3	72	7	2	22.75	4.3	76.562	28.22	37.767	13.4	1151	395	70.8	22.5	1080	393	22.75	4.5	8.5	3.71	8.5	4.33	0.5	0.29
9003	4	196	26	6	1	19.5	2.4	26.509	9.704	28.879	9.62	1322	361	272	141	1050	317	21	11.5	221	119	0.25	0.25	0.25	0.25
9004	4	267.5	63	5.5	1	22.5	0.3	23.295	9.431	47.938	15.4	1656	638	595	171	1061	527	32	23.3	521	154	2.25	0.75	0	0
9005	3	183.3	13	5	1	15.33	1.2	15.7	1.052	37.233	5.13	2256	270	403.7	29	1852	279	7	2.65	378	37.2	0	0	0	0
9006	4	211	47	4.75	1	15.5	0.6	18.963	7.001	57.77	11.2	3244	564	439	145	2804	504	4.25	1.6	419	138	0	0	0.75	0.25
9007	1	265	*	2	*	19	*	17.65	*	26.575	*	902	*	224	*	678	*	0	*	214	*	0	*	0	*
9008	3	199	45	4.667	0	17	1.2	11.492	4.216	34.846	12.7	2684	1116	210.3	45.3	2474	1072	22	20	163	53.1	0.333	0.33	2.67	2.19
9009	4	215.3	31	5.5	1	15.25	1.4	23.019	2.284	43.871	5.76	1632	247	220	52.3	1411	217	3.75	2.39	205.2	47.5	0	0	0.25	0.25
9010	4	256.5	19	6.5	1	17.25	1	52.794	6.402	40.058	5.97	1040	186	282	90.5	758	185	27.5	14.3	221.3	71.6	0	0	1.5	0.87
9011	4	301.5	28	6	0	17	0.7	57.854	13.49	26.293	7.29	933	395	124	31.9	810	374	17.25	8.05	82.5	29	0	0	0.25	0.25
9012	4	253.3	31	4.75	1	18.75	0.8	62.897	18.05	19.908	6.21	566	113	77.5	35.3	488	106	34.2	18.4	25.7	11	0	0	0	0
9101	4	237.5	32	6.5	0	24.75	3.1	31.845	9.134	19.113	7.14	777	219	175.7	50.5	602	177	12.5	5.42	73.3	24	0	0	0.5	0.29
9102	4	229	49	6	1	20.25	1.3	26.461	6.826	33.767	9.84	2048	908	387	102	1661	838	45.5	43.2	283.3	68.2	0.25	0.25	0.5	0.29
9103	4	194.8	14	5	1	22.75	2.1	17.019	3.741	37.649	8.5	2451	524	194.8	36.2	2257	498	3	2.38	172	32.7	0	0	0	0
9104	4	256.2	33	4	0	19.75	1.1	23.208	5.18	36.145	4.04	2179	566	267.7	57.7	1912	554	42.2	16	203.5	43.3	0	0	1	1
9105	4	203.2	23	6	1	20	3.7	16.152	4.221	30.691	9.59	1817	542	130	18.8	1688	534	8.5	5.14	90.2	18.6	0	0	0	0
9106	4	164.2	20	8.5	2	25	5.6	32.493	17.13	52.113	18.3	1537	227	508	232	1029	208	57.7	32	110.2	21.9	0.25	0.25	4.5	2.9
9107	4	254	20	8.25	0	24	2	21.405	3.451	39.553	5.04	1743	114	234	47	1509.5	92.1	9.25	4.96	51.25	4.53	0	0	8.5	6.18
9108	3	154.7	16	7	0	22.33	1.2	8.08	3.237	36.511	10.8	3026	921	139.7	68.8	2886	895	6.33	1.86	38.7	12.7	0	0	3.67	2.19
9109	0																								
9110	1	199	*	5	*	15	*	17.325	*	10.295	*	688	*	20	*	668	*	1	*	6	*	0	*	0	*
9111	4	227.3	24	7.5	1	25.25	3.5	42.724	13.59	33.94	6.03	1155	506	77.3	19.3	1077	512	13.25	3.38	14.5	4.87	0.5	0.5	1.5	1.19
9112	4	178.5	14	8.25	1	23.5	2.7	24.944	10.24	20.19	3.02	568.7	60.2	57	11.1	512	69	10	5.34	3.25	0.63	1	0.71	1	0.41
9201	4	163.7	32	8.75	0	27	1.6	13.055	3.881	23.127	5.06	727.3	85.9	61.7	12	665.5	94.6	20	6.18	3	0.71	2.25	0.85	1.5	0.29
9202	4	213.8	38	8.25	1	32.25	1.9	17.827	4.834	36.329	8.99	2006	890	116.3	12.6	1890	893	14	6.01	5.75	3.28	1	0.71	4.5	2.1
9203	4	284.2	11	6.75	1	31	1.1	27.545	3.307	42.794	17.3	1639	451	249.5	52.3	1390	494	44.5	17.1	133.5	61.8	0	0	2.5	1.55
9204	4	276.5	56	6.5	1	26.25	1.8	25.737	7.482	52.65	14.1	3766	1003	1010	301	2756	810	11.75	4.7	942	299	0	0	0.5	0.5
9205	4	260.7	31	6.5	2	21.5	3.6	16.142	4.376	45.948	14.3	4433	1801	796	132	3637	1680	65.5	56.7	667	193	0	0	0.5	0.29
9206	4	272	13	5.25	1	20.75	2.1	17.367	2.824	45.44	14.8	2991	296	440.5	38.1	2551	266	1.25	0.946	427.5	37.2	0	0	2	1.53

HAWKESBURY RIVER PRAWN FLEET

Mean no. of sand whiting	se	Mean no. of large tooth flounder	se	Mean no. of golden trevally	se	Mean no. of silver trevally	se	Mean no. of blackfish	se	Mean no. of flat-tail mullet	se	Mean no. of sea mullet	se	Mean no. of e.b.s. flathead	se	Mean no. of north. sand flathead	se	Mean no. of trumpeter whiting	se	Mean no. of stout whiting	se	Mean no. of red spot whiting	se	Mean no. of tarwhine	se	Mean no. of blue swimmer crabs	se
0.333	0	13	4.62	0	0	0.333	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18.7	19	0.667	0.7
2.25	0.25	12.75	6.41	0	0	0	0	0	0	0.25	0.3	0	0	0	0	0	0	0	0	0	0	0	0	10.25	6.7	12.25	7.5
0.5	0.29	8.5	4.92	0	0	0	0	0	0	1.5	1	0	0	0	0	0	0	0.5	0.5	0	0	0	0	12.5	11	40	16
0.25	0.48	3.5	1.76	0.25	0.3	0	0	0	0	0	0	0.25	0.3	0	0	0	0	0.25	0.25	0	0	0	0	0.75	0.8	4	4
0	0.25	22.2	11.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0	0	0	1.5	0.9
0	0	2.67	2.19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.667	0.7	0	0
0.75	0	6	2.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.25	3.3
0	*	10	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	3	*
2.67	1.33	16	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.333	0.33	0	0	0	0	0	0	0.667	0.7
0.25	0.25	2.25	0.63	0	0	0	0	0.25	0.25	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0	0	0	0	0
1.5	0.25	12.75	5.27	0	0	0	0	0	0	0.75	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.25	0.5	2.75	1.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.7	0.25	0.3	0	0	0	0
0	0	5.25	4.03	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	2.75	2.4	2.75	2.1
0.5	0.25	63	22.7	0	0	0	0	0	0	0.5	0.3	0	0	0.75	0.75	0	0	5.75	5.42	0	0	0	0	0.75	0.8	29.5	14
0.5	0.25	48.3	25.8	0	0	0	0	0	0	0	0	0	0	0	0	1	0.7	0.5	0.29	0	0	0	0	2	2	37	14
0	0.25	9.5	3.18	0	0	0	0	0	0	2	2	0	0	1.25	1.25	0.25	0.3	0.25	0.25	0	0	0	0	4.75	4.4	68	23
0	0	17.25	4.71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37.2	21
0	0	18.5	2.6	0	0	0	0	0	0	0.25	0.3	0	0	0	0	1.75	1.1	5.5	4.01	0	0	0	0	0	0	40.5	12
2.5	1.03	240	180	0	0	0	0	0.25	0.25	0	0	1.5	1.5	0	0	1.25	1.3	74.7	53.4	0	0	0	0	0	0	2.75	2.4
3	2.21	127.8	39.6	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.3	23	10.2	0	0	0	0	0	0	0	0
2	4	60	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23.7	21.7	0	0	0	0	0	0	0	0
0	*	4	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*	0	*
0.5	0.29	26.5	6.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.75	4.4	0	0	0	0	2	1.2	26.5	5.9
1	0.25	28.5	8.15	0	0	0	0	0.25	0.25	0.75	0.8	0	0	0	0	0	0	2.5	1.89	0	0	0	0	1.25	0.6	34.7	18
1.5	0.29	11.75	2.84	0	0	0	0	0	0	0.5	0.5	0.25	0.3	0	0	0	0	3.75	1.25	0	0	0	0	3.25	1.6	21.75	3.8
4.5	1	35.75	9.92	0	0	0	0	0.75	0.75	0	0	0	0	0	0	0	0	38.7	12.8	0	0	0	0	0.75	0.5	0.25	0.3
2.5	0.5	15.75	7.95	0	0	0	0	0.25	0.25	0	0	0.75	0.8	0	0	0	0	11	3.08	0	0	0	0	0	0	3.25	2.6
0.5	0.71	7.75	2.95	0	0	0	0	0	0	4.5	4.5	0	0	0	0	0.25	0.3	5.75	2.32	0	0	0	0	0	0	4	3.3
0.5	0.25	14	5.76	0	0	0	0	0.5	0.5	2.25	2.3	0	0	0	0	0.25	0.3	5.25	2.78	0	0	0	0	1.25	1.3	7.25	4
2	0.25	3.25	2.59	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.3	1	0.41	0	0	0	0	0	0	6.5	3.8

ADDENDUM TO:

PRELIMINARY INFORMATION ON THE PRAWN-TRAWL BY-CATCH PROJECT'S WORK IN THE HAWKESBURY RIVER

S.J. Kennelly & G.W. Liggins

March, 1993

As requested, we supply the attached summary of rates of catches and by-catches derived during our sampling of the Hawkesbury River squid fleet. These data should be read in conjunction with the information provided in the preliminary report submitted earlier and all assumptions and limitations of that data also apply to these data on catches. As was the case for the previous summary, the species selected for presentation were selected because of their commercial/recreational importance and the attached rates of catches and by-catches (per day fished) do not reflect total catch and by-catch of the whole fleet as these latter estimates are only possible by incorporating estimates of total fishing effort. Nevertheless, we hope that the attached summary is of some interest and relevance.

HAWKESBURY RIVER SQUID FLEET

YearMonth	No. of trips	Mean duration of trip (mins)	se	Mean no. of commercial finfish taxa	se	Mean no. of taxa	se	Mean catch of squid (kgs)	se	Mean bycatch (kgs)	se	Mean no. of by-caught individuals	se	Mean no. of comm. fish by-caught individuals	se	Mean no. of bream	se	Mean no. of jewfish	se	Mean no. of snapper	se	Mean no. of dusky flathead	se	Mean no. of sand whiting	se	Mean no. of small tooth flounder	se
9111	4	350.3	50	10.8	1.3	32.8	4.7	17.9	5.5	38.7	7.4	997	166	92.3	23.9	5.5	1.6	2.5	2.5	5	1.1	5.3	4	0.8	0.3	0.8	0.5
9112	4	455	29	12	1.5	31	1.9	22.4	5.6	53.5	8.1	980.8	171	145	35.7	4	1.2	11.3	9.5	2	0.6	2.3	3.5	1.5	0.3	0	0.2
9201	4	335.3	53	12.3	1.4	35.5	2.4	19.5	5.4	87.4	15.1	1449.8	389	337	39.7	4.5	2.2	17.3	6.9	33.3	21.4	7.8	3.8	1	0.6	0.5	0.3
9202	1	451	*	13	*	38	*	22.6	*	57	*	1616	*	287	*	2	*	0	*	79	*	3	*	1	*	3	*
9203	4	397	19	11.3	0.8	33	2.8	26.4	3.4	233.5	24.1	4168.5	805	678.8	167	33.5	16.2	13.3	7.7	39.8	15	29.3	24.6	0.3	0.3	7.5	4.6
9204	3	308.7	57	14.3	1.5	38.3	4.3	12.2	4	96.4	25.2	2063.7	305	481	126	25.3	14.1	17.7	16.2	5.7	4.2	32	13.5	0	0	5.7	3.8
9205	4	279.5	24	14.8	1.8	39	5.3	11.1	2.6	42.9	14.4	946.3	312	191.3	56.3	8.8	5.2	5	1.9	3.3	1.8	10.5	7.9	0	0	4.3	2.4
9206	0																										
9207	4	262.8	91	11	2.8	31.8	5.3	12.2	4.3	52	17.7	490.3	113	57	18.7	9.8	3.9	3.8	2.5	1	0.6	2.3	1.4	0	0	1	0.7
9208	4	238.3	50	10.5	1.6	26.5	2.5	12.9	2.9	42.3	12.2	856.3	325	81.8	37.1	14.3	9.1	12.5	9.9	5.3	4	1	0.7	0.5	0.3	0.3	0.3
9209	4	236.3	21	5.5	1.3	18	2.5	16.8	5.8	15.7	0.4	184.3	68.8	71.8	35.1	1.5	1	1.8	1.2	1	0.7	0.5	0.5	2	1.1	0	0
9210	3	232.3	45	10	2.5	25.7	6.6	23.7	7	18.4	4.6	424.3	162	73.7	14.7	1.3	0.7	0.3	0.3	2.3	1.9	1	0.6	0	0	0.3	0.3

HAWKESBURY RIVER SQUID FLEET

Mean no. of large tooth flounder	se	Mean no. of silver trevally	se	Mean no. of blackfish	se	Mean no. of trumpeter whiting	se	Mean no. of tarwhine	se	Mean no. of tailor	se	Mean no. of blue swimmer crabs	se
14.5	10	0.8	0.5	1.5	1.5	28.5	8.1	1	0.6	18	4.1	10.5	3.7
4.3	8.9	6.5	3.3	0	1.3	35	19.9	1	0.5	69	25.4	6	3
83.3	25	23.5	10.4	0.8	0.5	61.3	9.6	2.8	1.4	87	74.2	26.3	12
54	*	28	*	0	*	80	*	3	*	29	*	12	*
110.3	84.2	82.5	31.3	0	0	126.8	18.3	1.8	1	218.8	47.1	41.5	24
90.7	47.8	14	10.1	0	0	43.3	29.9	17	2.1	186.7	123	51	26
56	25.8	2	1	1.3	1.3	26.5	9.9	4.3	2.5	46.5	9.2	8.8	3.6
18.3	7.8	2	1.2	0.5	0.5	6.3	2.6	0	0	5	2.4	3.3	1.4
7.5	6.2	5	2.9	0.3	0.3	6	2.3	3.8	3.1	21.3	17.9	4.5	1.3
3.8	0.6	0.3	0.3	0	0	0	0	0.8	0.5	58.8	33.8	4	2.4
2	1	0.3	0.3	1.7	1.7	44.7	10.4	0	0	6.3	3.9	1.7	0.7

APPENDIX M

Summary reports sent to the 160 participating fishers.

NSW FISHERIES

Mr

Fisheries Research Institute
P.O. Box 21, Cronulla, 2230

Dear

You might remember that between late 1989 and mid 1992, scientists from the Fisheries Research Institute approached you asking permission for them to come on your trawler so they could record data on the catches of prawns and other species during a typical night's fishing. As explained to you at the time, the work those scientists were doing was part of our project (funded by the Fisheries Research and Development Corporation) which studied the catches of the estuarine prawn trawlers operating in Botany Bay, Port Jackson, the Hawkesbury and Clarence Rivers and Lake Woolooweyah and the oceanic prawn trawlers operating from Port Stephens, Coffs Harbour, Yamba/Iluka and Ballina. The aim of this work was to collect information on catch composition, abundances of species from individual shots, locations, depths, shot duration, etc. in order to complete the first logical step in the eventual provision of management recommendations for these fisheries.

We would like to take this opportunity to thank you most sincerely for the excellent co-operation that you and other fishermen gave us when we were doing this research. Quite simply, without your help over the past 3 years, we could not have done this work nor be in a position to present the data that is contained in this summary. At the International Conference on By-catch in the Shrimp Industry held in Florida last year the following point was made many times by fishermen, scientists and managers from all around the world: that our project enjoyed a level of industry-participation and good-will that is the equal of any such project in the world. We believe that this conclusion from this very high-level conference speaks volumes for the attitude and courtesy of NSW's prawn trawlermen.

The attached map shows the north coast of NSW, covering the range of the prawn-trawl fisheries in the state, and shows the places that we sampled during the project. As you know, these fisheries mainly target two species, the eastern king prawn at night and the school prawn during the day. Estuarine prawn trawling occurs in 5 estuaries during summer and all are closed during the winter, with the exception of the Hawkesbury River which is open to trawling all year. Oceanic prawn trawling mainly occurs out of 11 ports along the coast throughout the year.

During our project we promised to provide you, and all fishermen who helped us, a summary of the information we obtained during this research. As we mentioned at the time, we will only present data that are averages across all boats we sampled, not wishing to identify individuals. The attached information is the summary of data for your particular fishing area. All fishermen who permitted us on their vessels during the project have also received a summary for their particular fishing area. We have not sent summaries about fisheries to fishermen who were not in that area but we have given a copy of all the summaries for all fisheries to CFAC.

In each month that prawn trawling occurred between late 1989 and June 1992, we tried to have scientists on 4 randomly-selected trawler-trips from each fishery. During each trip from Iluka/Yamba, the catch from each tow was sorted by the crew and our scientist, separating the prawns from the by-product. The weights of prawns and total by-catch (estimated from a sample) from each tow were recorded. All commercial species (landed by-product including flathead, octopus, squid, crabs, etc) were counted and weighed. A sample of the discarded trash was examined and all the commercially and recreationally important species (such as juvenile snapper, juvenile flathead, etc) were counted, weighed and measured. For each tow, we also recorded the time, depth, duration and location of the tow, as well as the basic gear configuration used.

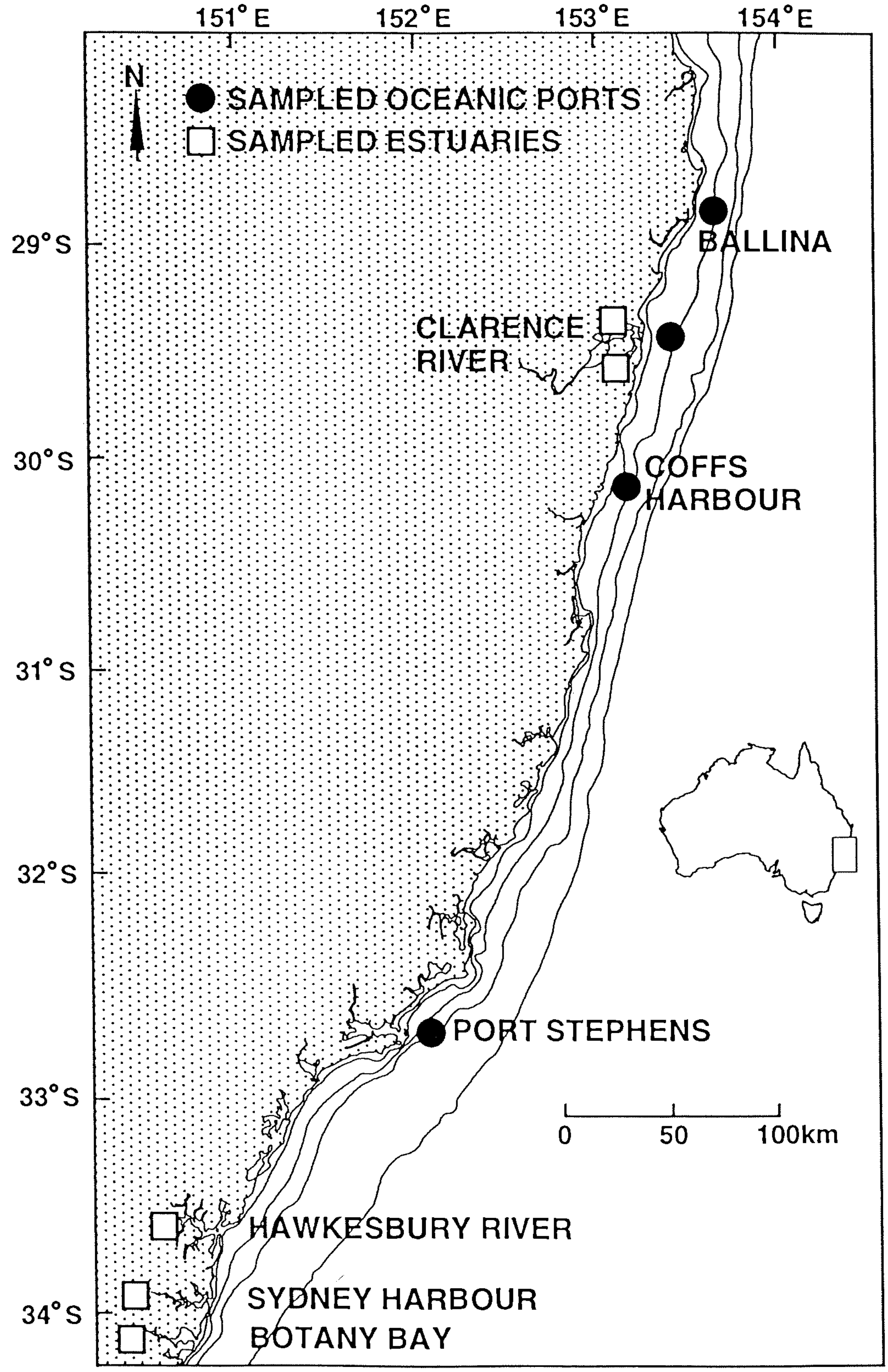
The catch of prawns and other species that may be of interest are shown in the attached figures. The graphs are pretty straightforward, showing the average tow times and catches per night that occurred during each season of sampling. The vertical bars attached to each point (shown as SE in the graphs) is an estimate of the accuracy of that average - i.e. it shows you the slop around the average and the confidence that can be placed on that average.

The graphs show that the average time spent trawling by vessels from Iluka/Yamba was around 500 minutes per night. The catch rates of prawns during the project varied between 35 and 75 kilos per night, with highest catches occuring in the autumn of 1991. The information on by-catches of different species represents total numbers (i.e retained and discarded commercial individuals) and shows that many species are by-caught in reasonable quantities, whilst a handful of species stand out as quite abundant (eg. stout and red spot whiting, octopus, eastern blue-spot flathead, snapper, red mullet, cuttlefish and bugs). We have only presented data on numbers of individuals for these by-caught species but also have estimates of their weights.

Thank you for your help over the past few years. To show our gratitude, we have enclosed a T-shirt as a small token of our appreciation. We look forward to working with you again in the future.

Yours sincerely,

Steven J. Kennelly
(on behalf of Geoff Liggins, Matt Broadhurst, Geoff Nemec, Keith Chilcott and Mark Bradley)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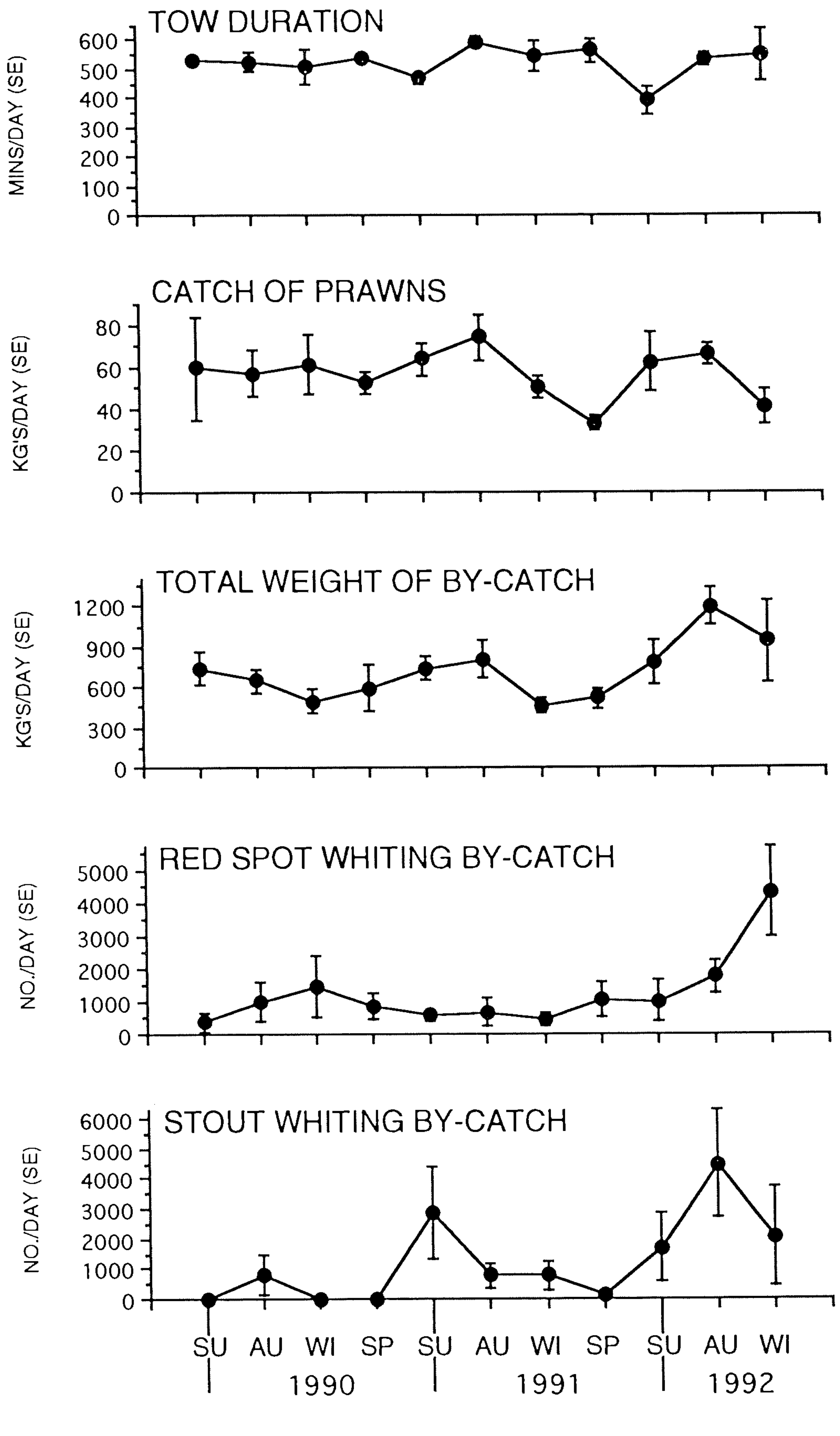
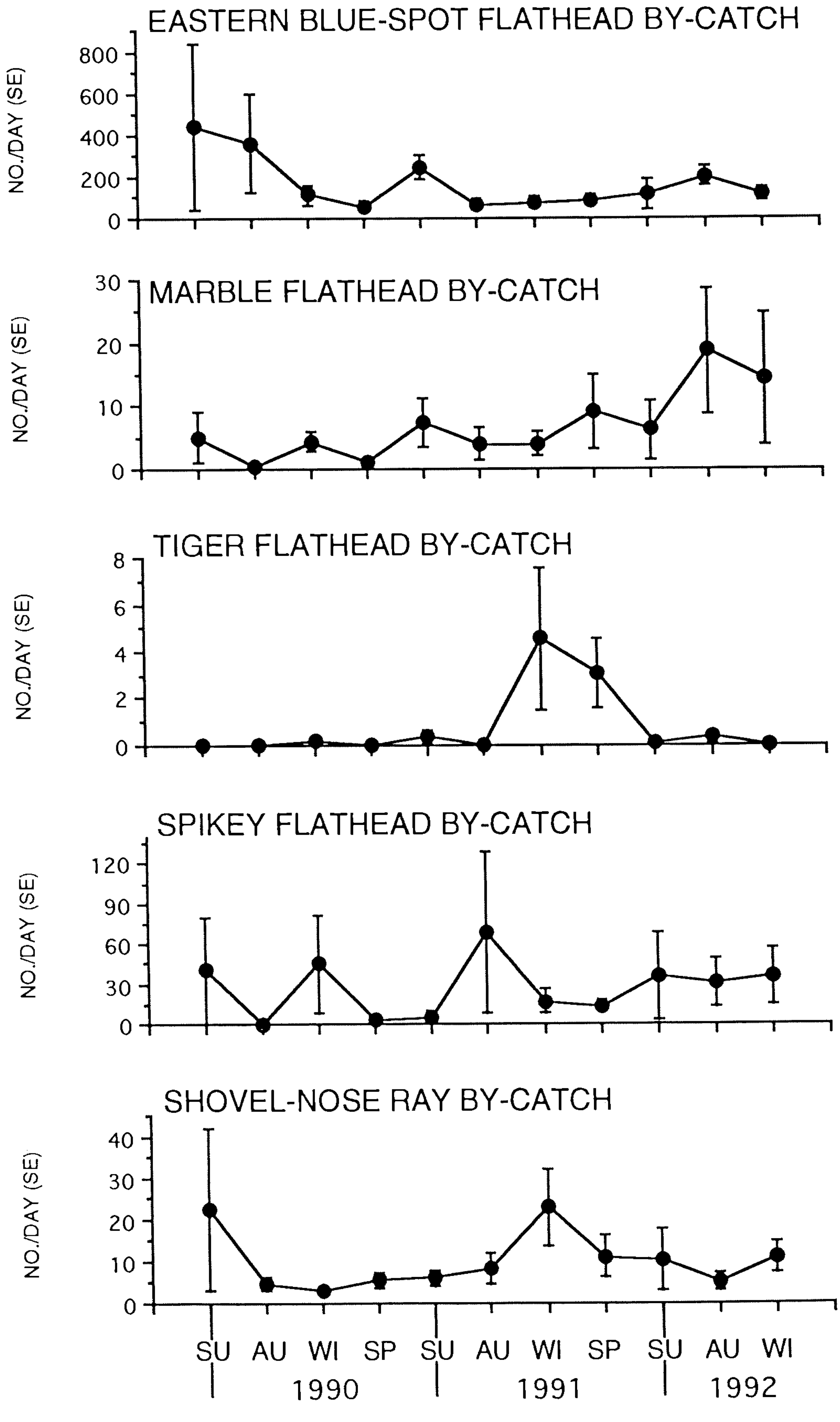
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE
RIVER
COFFS
HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY

ILUKA/YAMBA PRAWN TRAWL FLEET



ILUKA/YAMBA PRAWN TRAWL FLEET



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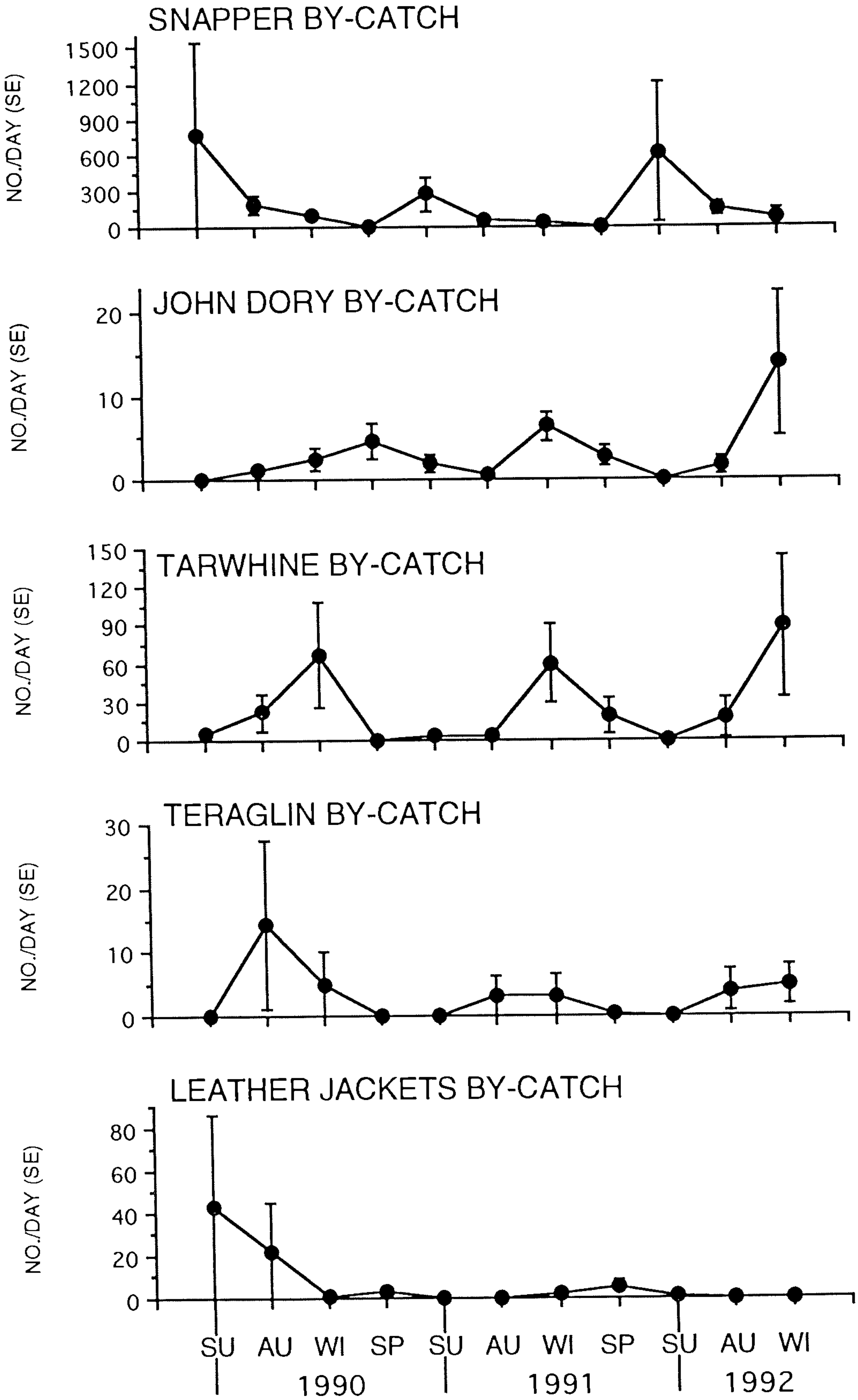
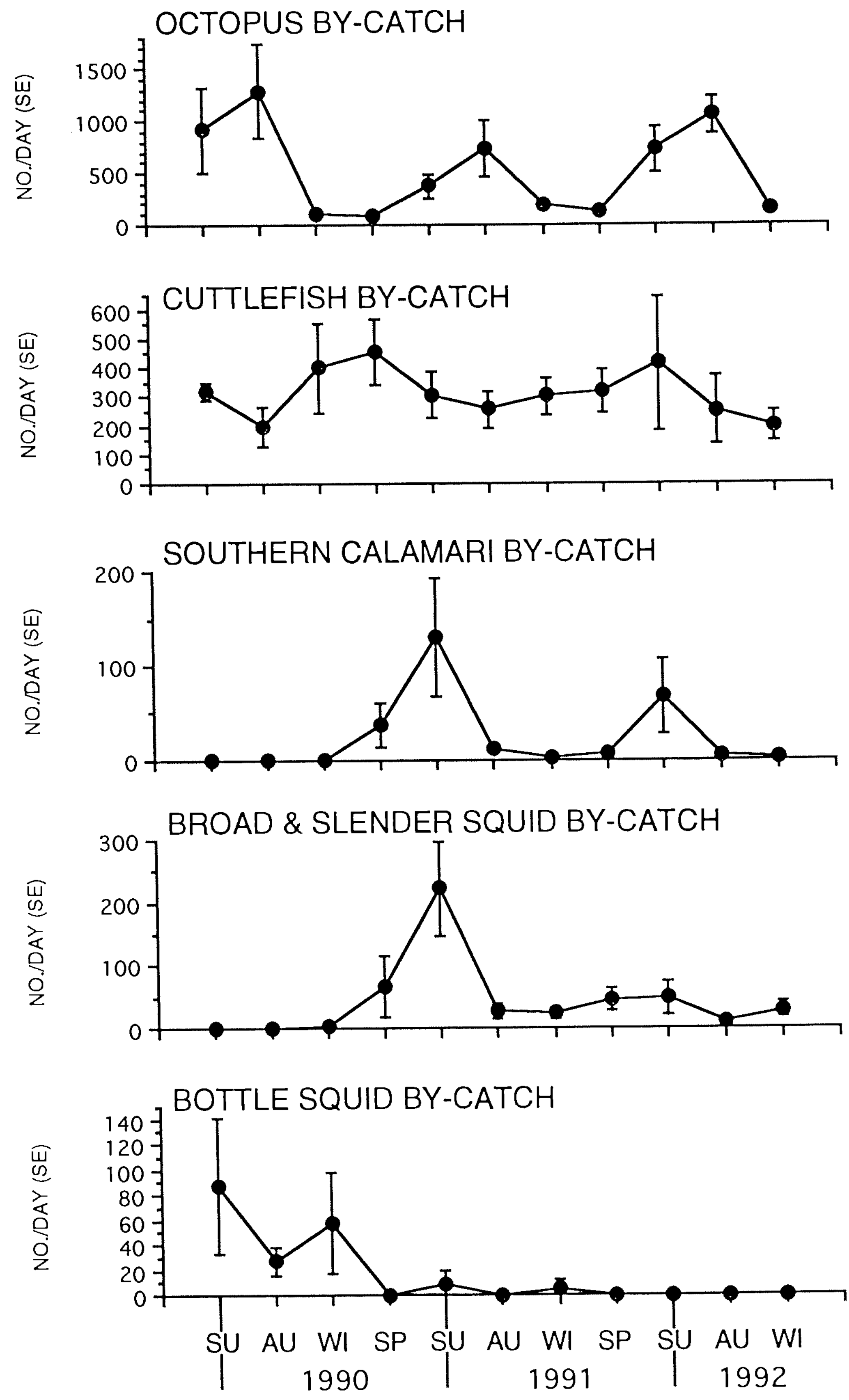
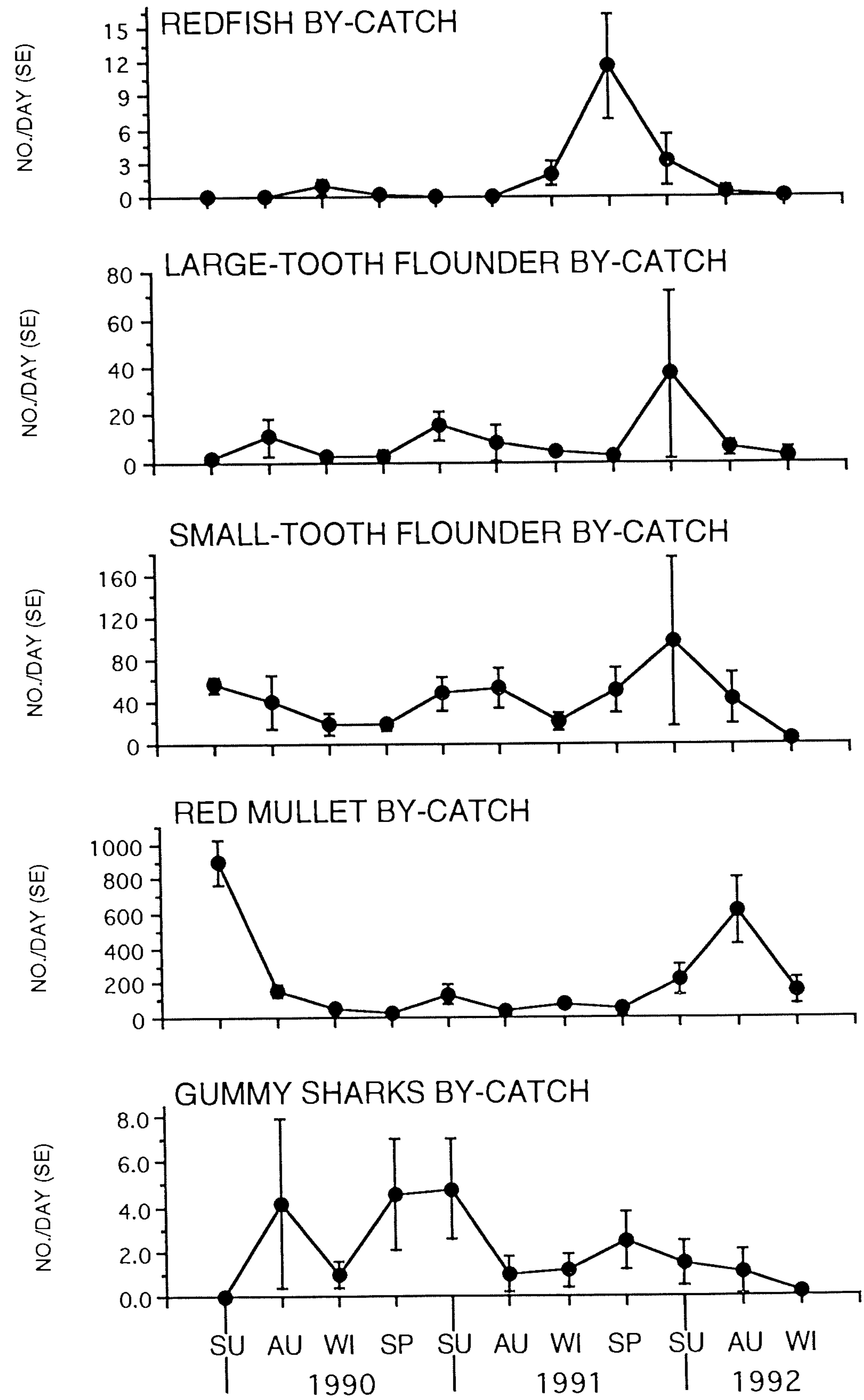


ILUKA/YAMBA PRAWN TRAWL FLEET



ILUKA/YAMBA PRAWN TRAWL FLEET



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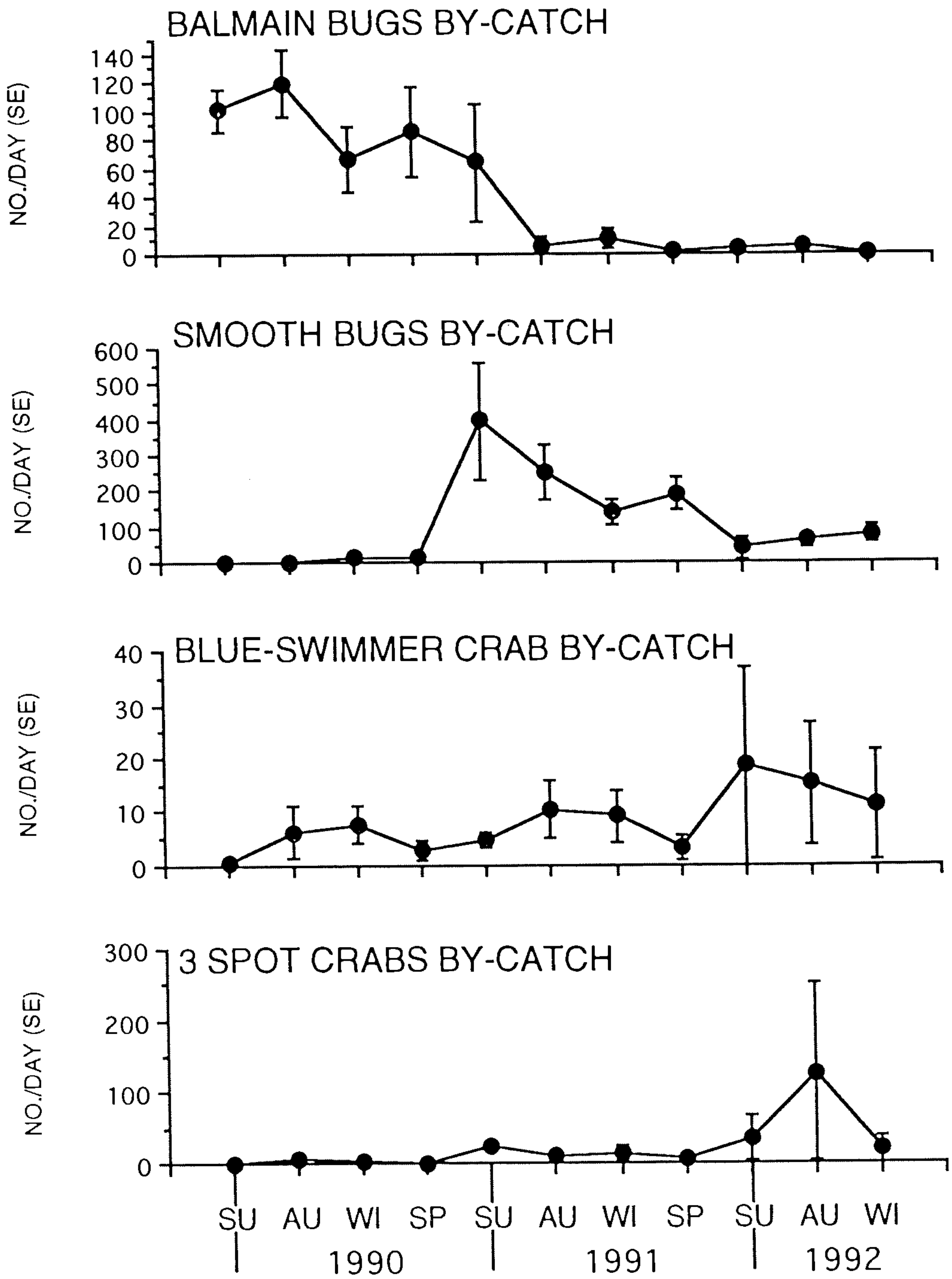

NSW FISHERIES

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202 Nicholson Parade — PO Box 21 Cronulla NSW Australia 2230
Telephone: (02) 527 8411 • **Facsimile:** (02) 527 8576

In each month that prawn trawling occurred between late 1989 and June 1992, we tried to have scientists on 4 randomly-selected trawler-trips from each fishery. During each trip on the Clarence River, the catch from each tow was sorted by the crew and our scientist, separating the various species. The weights of prawns and total by-catch from each tow were recorded. All finfish species of commercial and recreational importance were counted and measured. Crustaceans (crabs etc), cephalopods (squid and octopus) and non-commercial finfish species (catfish etc) were counted. For each tow, we also recorded the time, duration and location of the tow, as well as the basic gear configuration used.

The catch of prawns and other species that may be of interest are shown in the attached figures. The graphs are pretty straightforward, showing the average tow times and catches per day that occurred during each month of sampling. The vertical bars attached to each point (shown as SE in the graphs) is an estimate of the accuracy of that average - i.e. it shows you the slop around the average and the confidence that can be placed on that average.

The graphs show that the average time spent trawling on the River was around 100-350 minutes per day. The catch rates of prawns during the project varied between 20 and 180 kilos per day. The information on by-catches shows that the catch rates varied considerably over the sample period and that some species occurred in quite large numbers (bream, sand whiting and dusky flathead).

Thank you for your help over the past few years. To show our gratitude, we have enclosed a T-shirt as a small token of our appreciation. We look forward to working with you again in the future.

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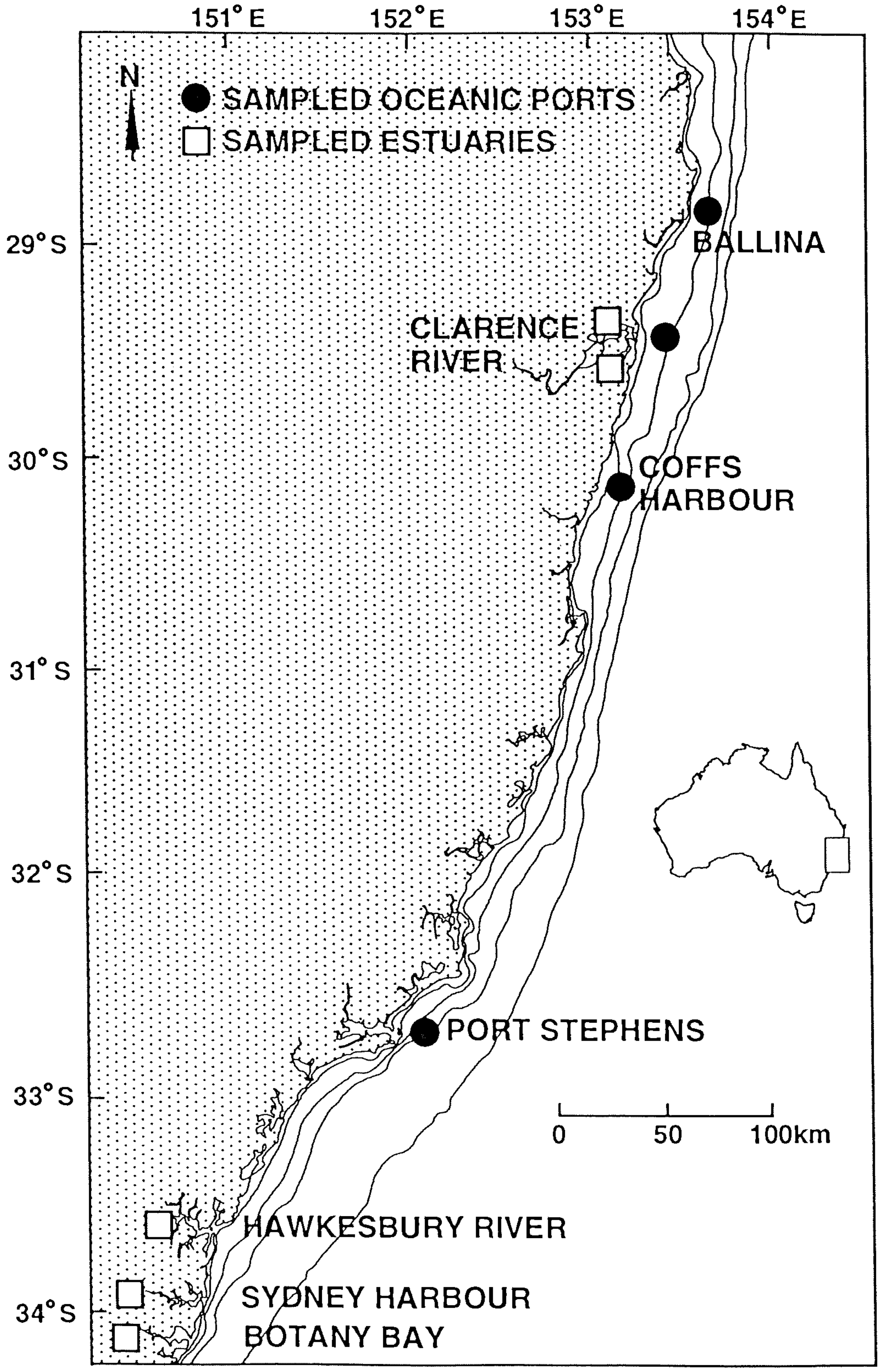
151° E
152° E
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N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE RIVER
COFFS HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
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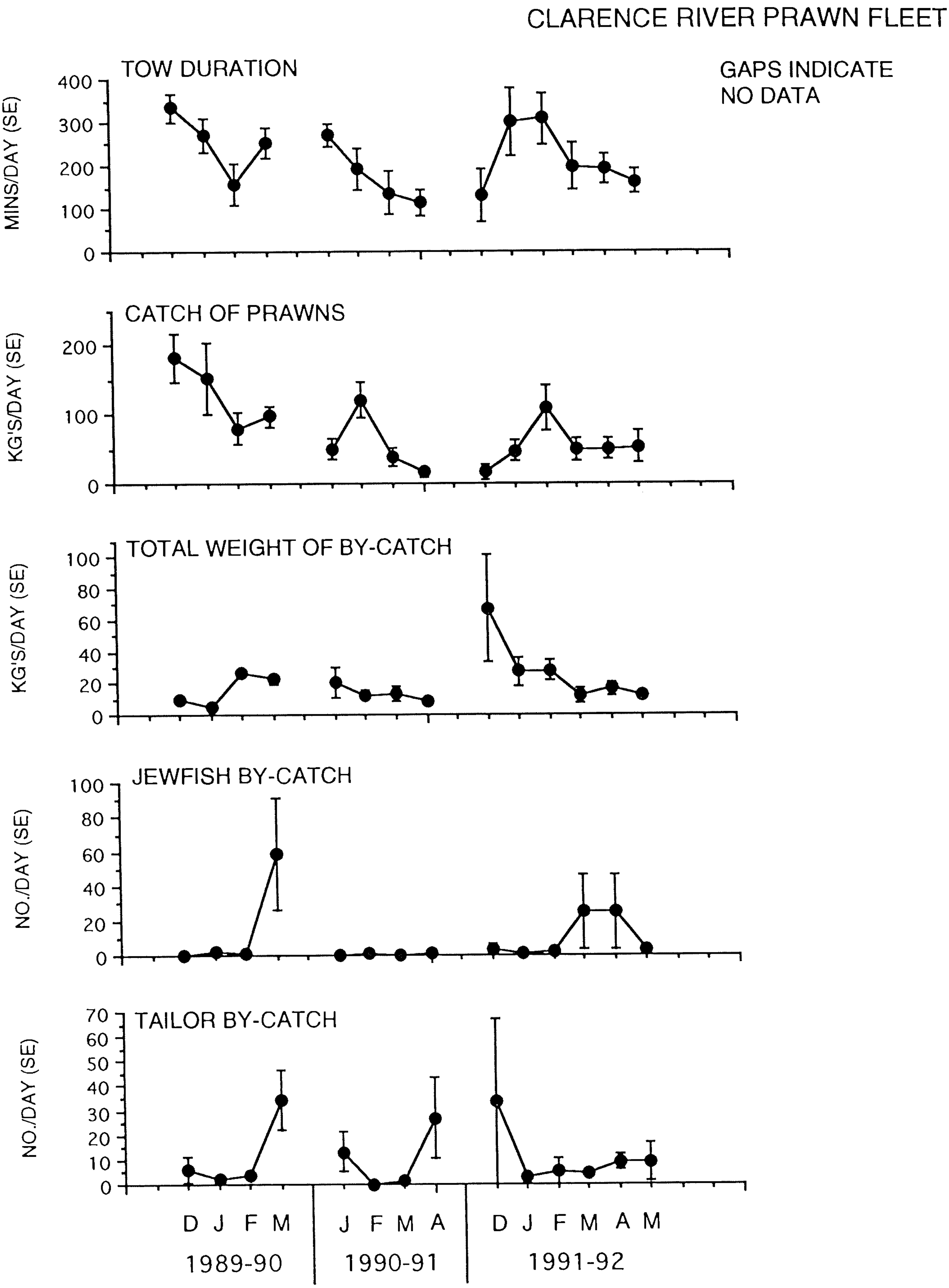
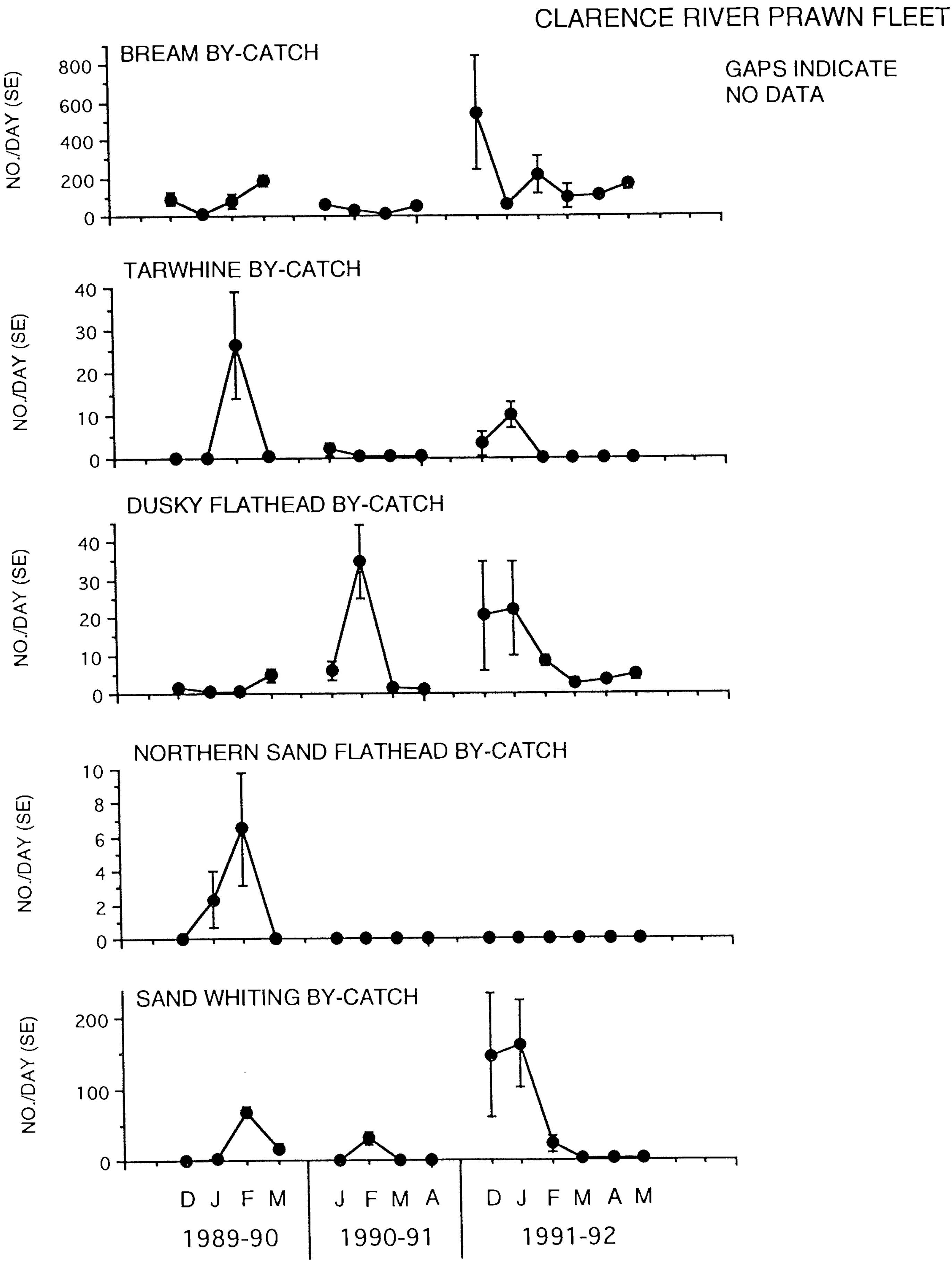
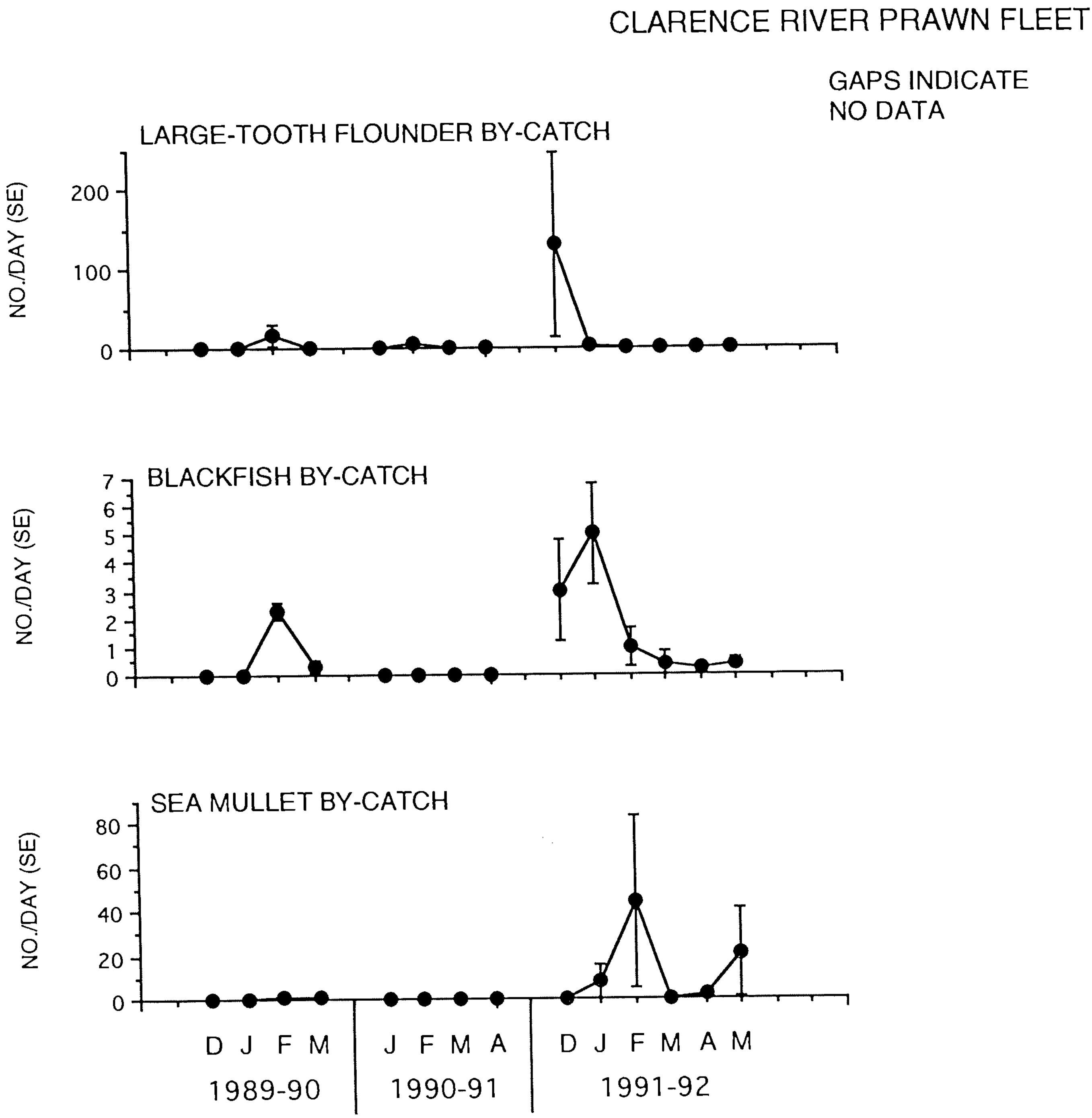

CLARENCE RIVER PRAWN FLEET
GAPS INDICATE NO DATA
TOW DURATION
MINS/DAY (SE)
400
300
200
100
0
CATCH OF PRAWNS
KG'S/DAY (SE)
200
100
0
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
100
80
60
40
20
0
JEWFISH BY-CATCH
NO./DAY (SE)
100
80
60
40
20
0
TAILOR BY-CATCH
NO./DAY (SE)
70
60
50
40
30
20
10
0
D J F M
1989-90
J F M A
1990-91
D J F M A M
1991-92



CLARENCE RIVER PRAWN FLEET
GAPS INDICATE
NO DATA
BREAM BY-CATCH
NO./DAY (SE)
800
600
400
200
0
TARWHINE BY-CATCH
NO./DAY (SE)
40
30
20
10
0
DUSKY FLATHEAD BY-CATCH
NO./DAY (SE)
40
30
20
10
0
NORTHERN SAND FLATHEAD BY-CATCH
NO./DAY (SE)
10
8
6
4
2
0
SAND WHITING BY-CATCH
NO./DAY (SE)
200
100
0
D J F M
1989-90
J F M A
1990-91
D J F M A M
1991-92


CLARENCE RIVER PRAWN FLEET
GAPS INDICATE NO DATA
LARGE-TOOTH FLOUNDER BY-CATCH
NO./DAY (SE)
200
100
0
BLACKFISH BY-CATCH
NO./DAY (SE)
7
6
5
4
3
2
1
0
SEA MULLET BY-CATCH
NO./DAY (SE)
80
60
40
20
0
D J F M
1989-90
J F M A
1990-91
D J F M A M
1991-92

NSW FISHERIES

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The graphs show that the average time spent trawling on the Lake was around 200-400 minutes per day. The catch rates of prawns during the project varied between 10 and 110 kilos per day. The information on by-catches shows that many species were by-caught in quite small quantities, whilst some species stand out as quite abundant (eg. tailor and bream).

Thank you for your help over the past few years. To show our gratitude, we have enclosed a T-shirt as a small token of our appreciation. We look forward to working with you again in the future.

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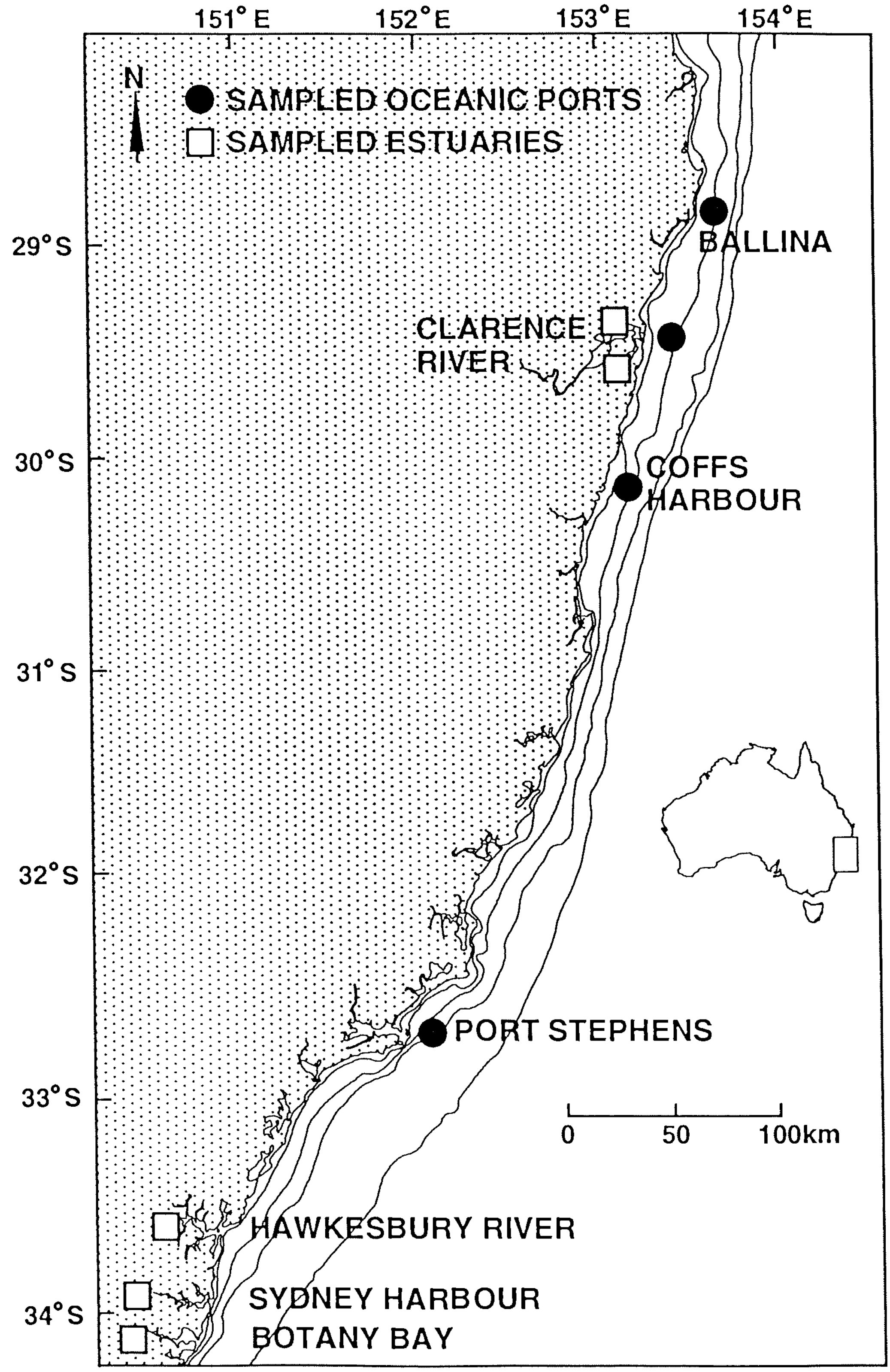
(on behalf of Geoff Liggins, Matt Broadhurst, Geoff Nemec, Keith Chilcott and Mark Bradley)


151° E
152° E
153° E
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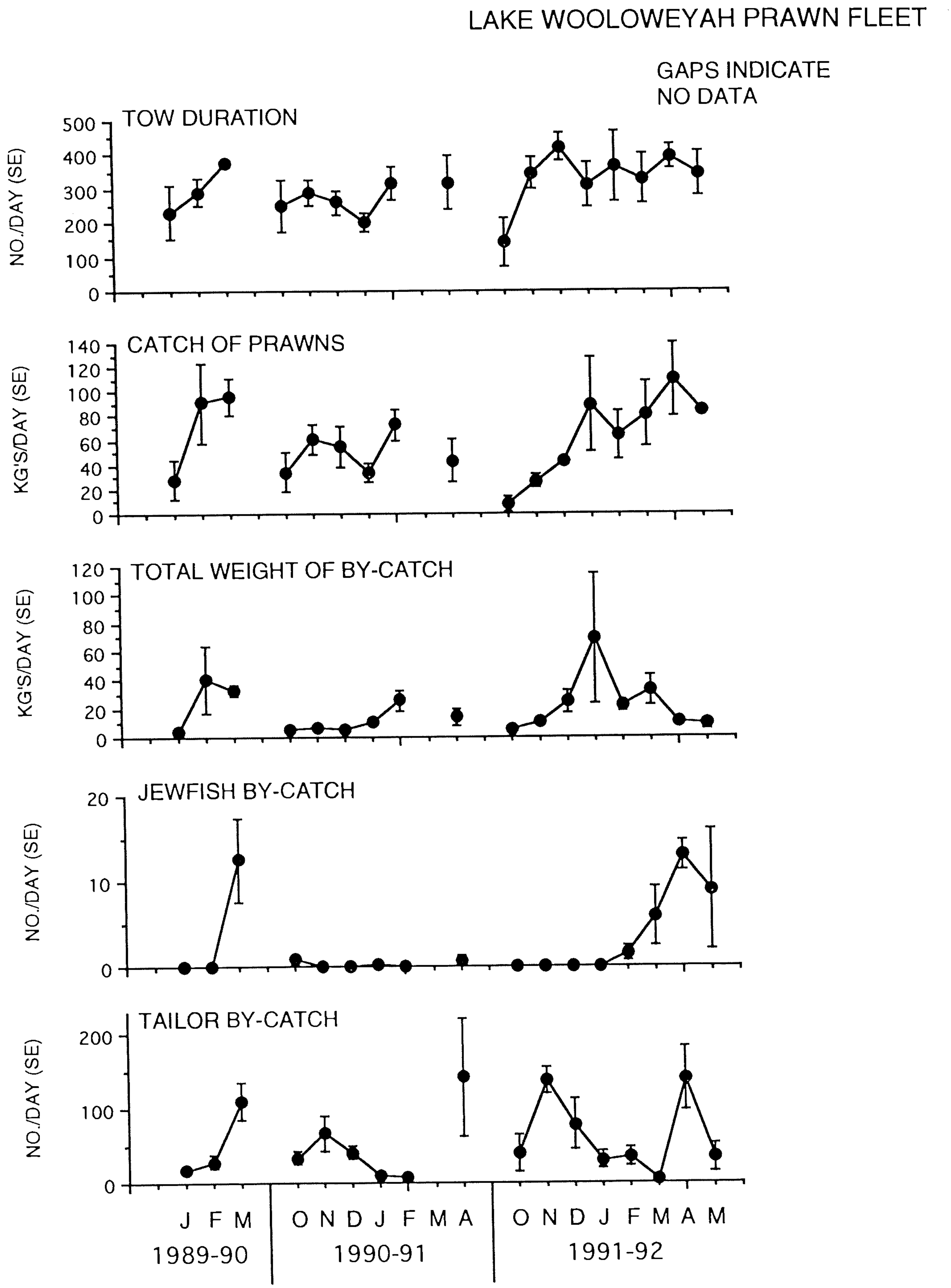
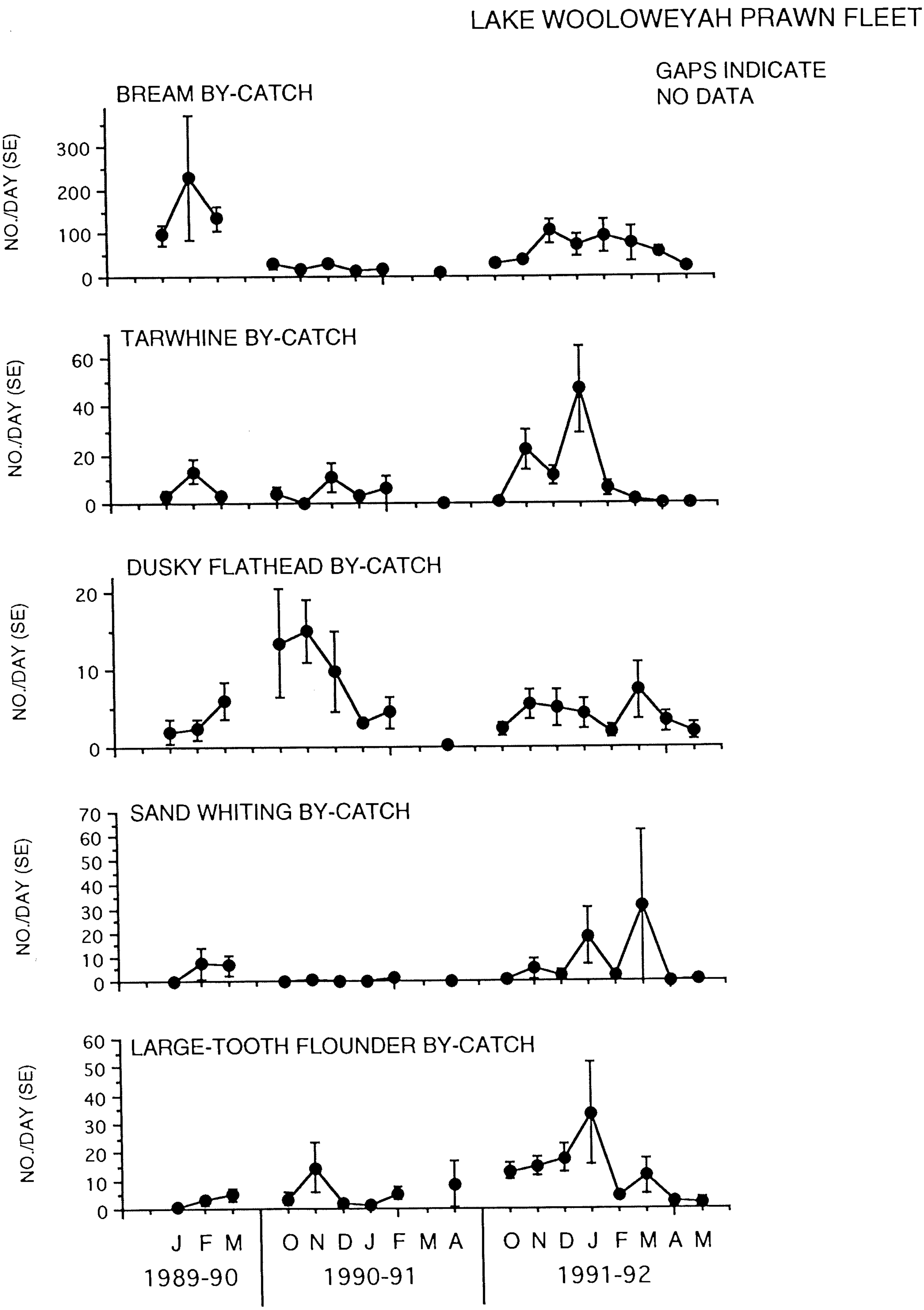
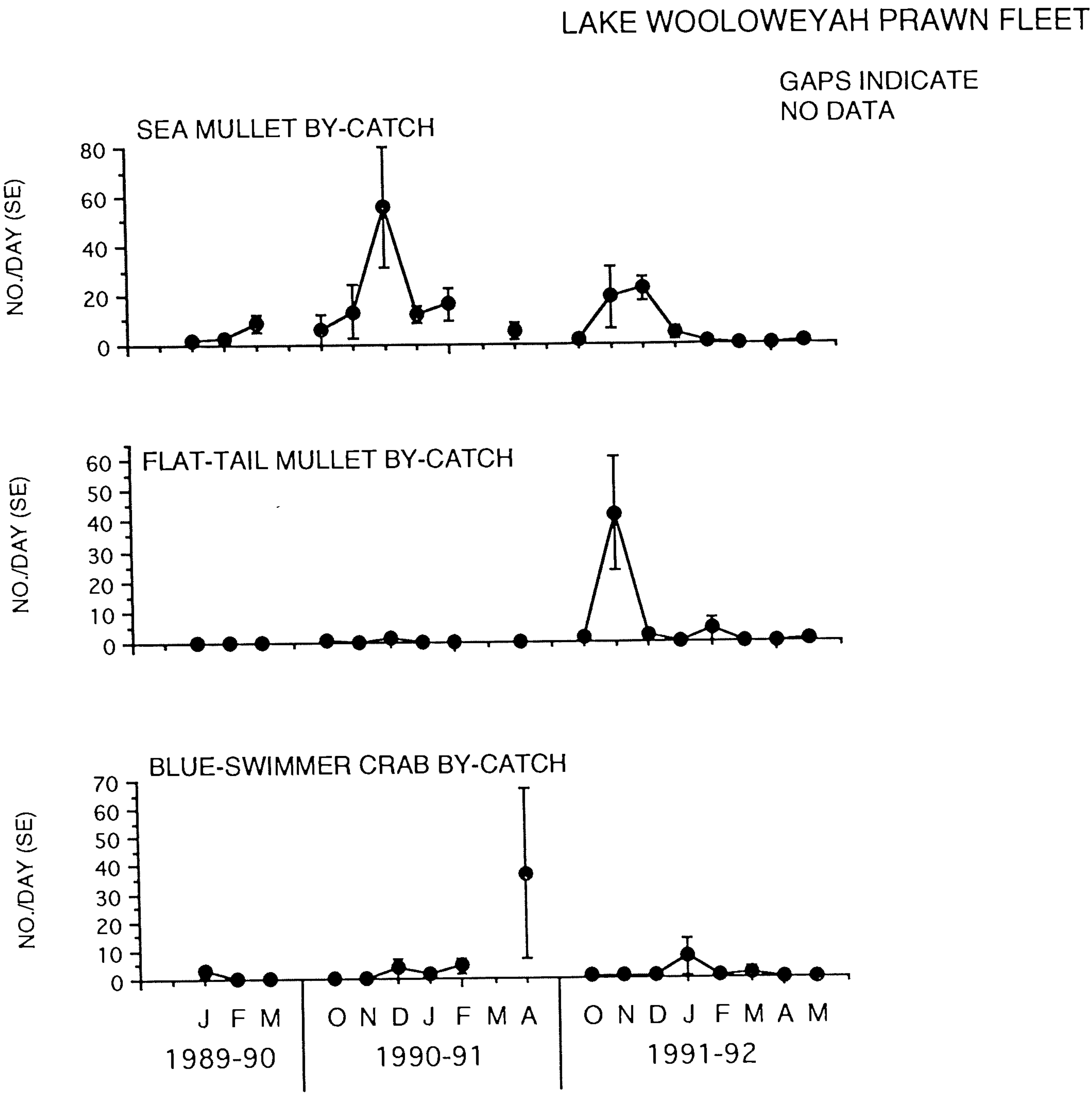
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE
RIVER
COFFS
HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY



LAKE WOOLOWEYAH PRAWN FLEET
GAPS INDICATE NO DATA
TOW DURATION
NO./DAY (SE)
0
100
200
300
400
500
CATCH OF PRAWNS
KG'S/DAY (SE)
0
20
40
60
80
100
120
140
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
0
20
40
60
80
100
120
JEWFISH BY-CATCH
NO./DAY (SE)
0
10
20
TAILOR BY-CATCH
NO./DAY (SE)
0
100
200
J F M
1989-90
O N D J F M A
1990-91
O N D J F M A M
1991-92



LAKE WOOLOWEYAH PRAWN FLEET
GAPS INDICATE NO DATA
BREAM BY-CATCH
TARWHINE BY-CATCH
DUSKY FLATHEAD BY-CATCH
SAND WHITING BY-CATCH
LARGE-TOOTH FLOUNDER BY-CATCH
NO./DAY (SE)
J F M
O N D J F M A
O N D J F M A M
1989-90
1990-91
1991-92


LAKE WOOLOWEYAH PRAWN FLEET
GAPS INDICATE
NO DATA
SEA MULLET BY-CATCH
NO./DAY (SE)
80
60
40
20
0
FLAT-TAIL MULLET BY-CATCH
NO./DAY (SE)
60
50
40
30
20
10
0
BLUE-SWIMMER CRAB BY-CATCH
NO./DAY (SE)
70
60
50
40
30
20
10
0
J F M
O N D J F M A
O N D J F M A M
1989-90
1990-91
1991-92

NSW FISHERIES

Mr

Fisheries Research Institute
P.O. Box 21, Cronulla, 2230

Dear

You might remember that between late 1989 and mid 1992, scientists from the Fisheries Research Institute approached you asking permission for them to come on your trawler so they could record data on the catches of prawns and other species during a typical day's fishing. As explained to you at the time, the work those scientists were doing was part of our project (funded by the Fisheries Research and Development Corporation) which studied the catches of the estuarine prawn trawlers operating in Botany Bay, Port Jackson, the Hawkesbury and Clarence Rivers and Lake Woolooweyah and the oceanic prawn trawlers operating from Port Stephens, Coffs Harbour, Yamba/Iluka and Ballina. The aim of this work was to collect information on catch composition, abundances of species from individual shots, locations, depths, shot duration, etc. in order to complete the first logical step in the eventual provision of management recommendations for these fisheries.

We would like to take this opportunity to thank you most sincerely for the excellent co-operation that you and other fishermen gave us when we were doing this research. Quite simply, without your help over the past 3 years, we could not have done this work nor be in a position to present the data that is contained in this summary. At the International Conference on By-catch in the Shrimp Industry held in Florida last year the following point was made many times by fishermen, scientists and managers from all around the world: that our project enjoyed a level of industry-participation and good-will that is the equal of any such project in the world. We believe that this conclusion from this very high-level conference speaks volumes for the attitude and courtesy of NSW's prawn trawlermen.

The attached map shows the north coast of NSW, covering the range of the prawn-trawl fisheries in the state, and shows the places that we sampled during the project. As you know, these fisheries mainly target two species, the eastern king prawn at night and the school prawn during the day. Estuarine prawn trawling occurs in 5 estuaries during summer and all are closed during the winter, with the exception of the Hawkesbury River which is open to trawling all year. Oceanic prawn trawling mainly occurs out of 11 ports along the coast throughout the year.

During our project we promised to provide you, and all fishermen who helped us, a summary of the information we obtained during this research. As we mentioned at the time, we will only present data that are averages across all boats we sampled, not wishing to identify individuals. The attached information is the summary of data for your particular fishing area. All fishermen who permitted us on their vessels during the project have also received a summary for their particular fishing area. We have not sent summaries about fisheries to fishermen who were not in that area but we have given a copy of all the summaries for all fisheries to CFAC.

FISHERIES RESEARCH INSTITUTE
202 Nicholson Parade — PO Box 21 Cronulla NSW Australia 2230
Telephone: (02) 527 8411 • **Facsimile:** (02) 527 8576

In each month that prawn trawling occurred between late 1989 and June 1992, we tried to have scientists on 4 randomly-selected trawler-trips from each area. During each trip on Lake Wooloweyah and the Clarence River, the catch from each tow was sorted by the crew and our scientist, separating the various species. The weights of prawns and total by-catch from each tow were recorded. All finfish species of commercial and recreational importance were counted and measured. Crustaceans (crabs etc), cephalopods (squid and octopus) and non-commercial finfish species (catfish etc) were counted. For each tow, we also recorded the time, duration and location of the tow, as well as the basic gear configuration used.

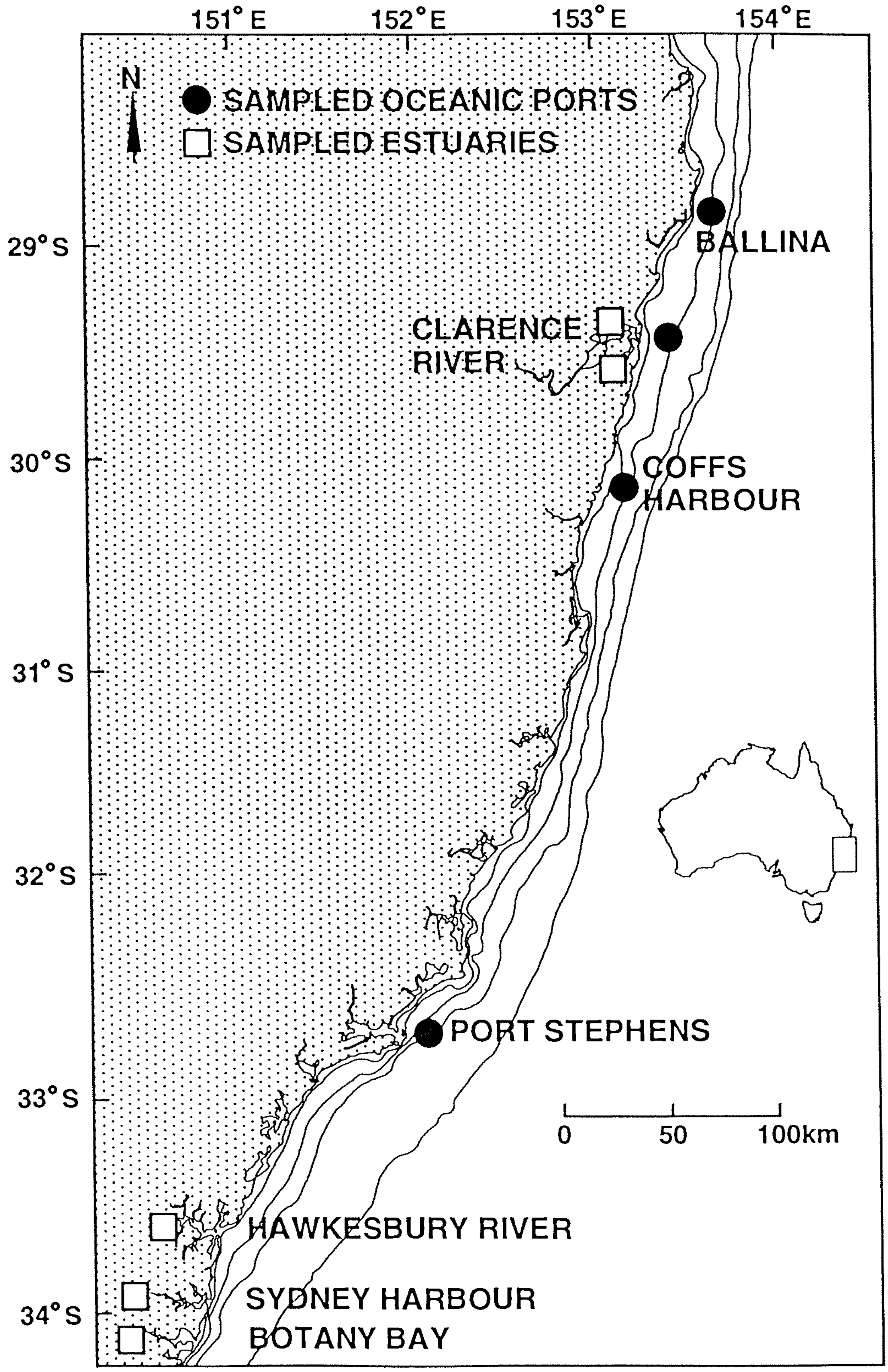
The catch of prawns and other species that may be of interest are shown in the attached figures. The graphs are pretty straightforward, showing the average tow times and catches per day that occurred during each month of sampling. The vertical bars attached to each point (shown as SE in the graphs) is an estimate of the accuracy of that average - i.e. it shows you the slop around the average and the confidence that can be placed on that average.

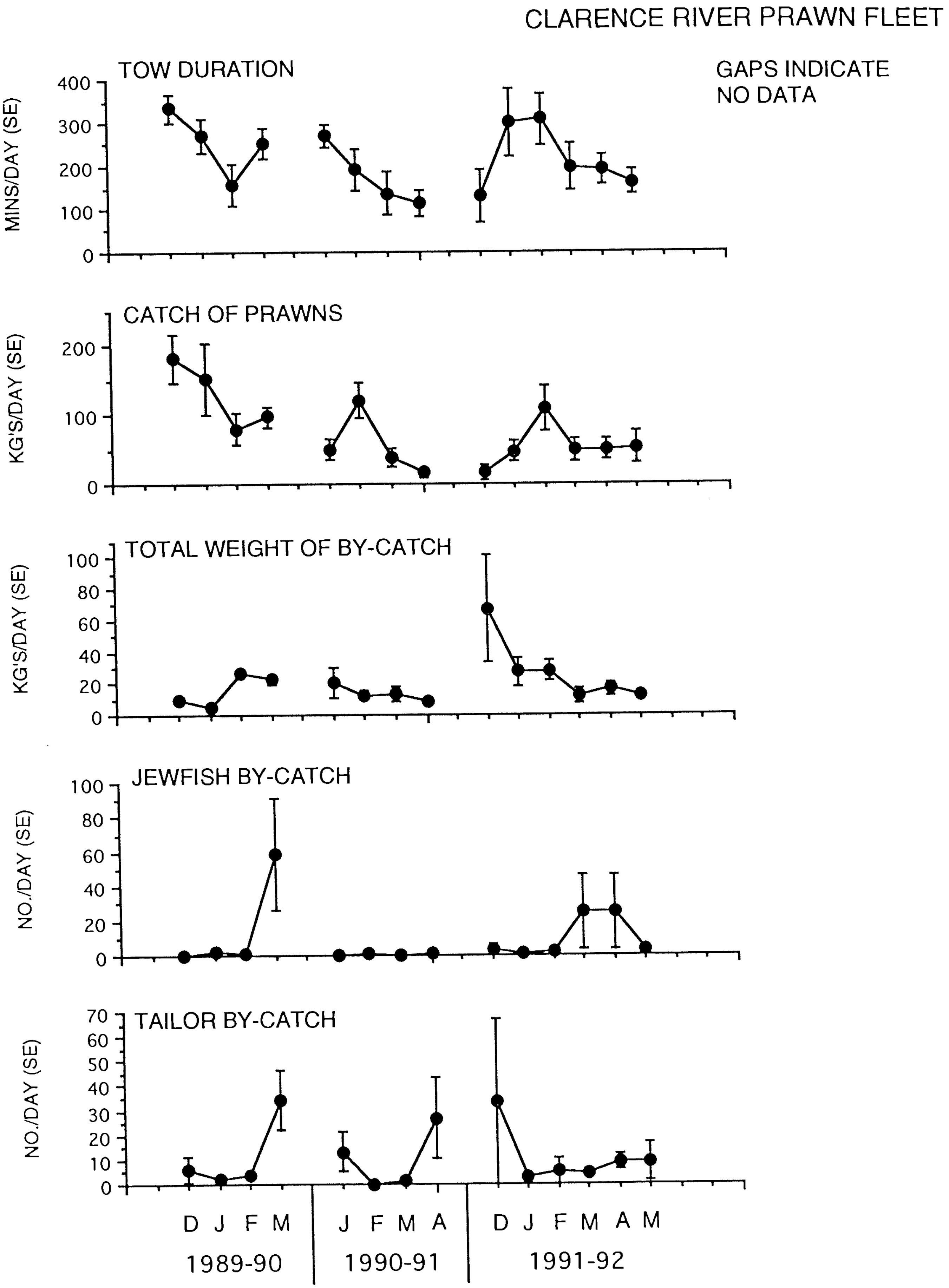
The graphs show that the average time spent trawling on the Lake was around 200-400 minutes per day and around 100-350 minutes per day on the River. The catch rates of prawns during the project varied between 10 and 110 kilos per day on the Lake and between 20-180 Kilos per day on the River. The information on by-catches shows varies results with quite large by-catches of tailor and bream in the Lake and bream, sand whiting and dusky flathead in the River.

Thank you for your help over the past few years. To show our gratitude, we have enclosed a T-shirt as a small token of our appreciation. We look forward to working with you again in the future.

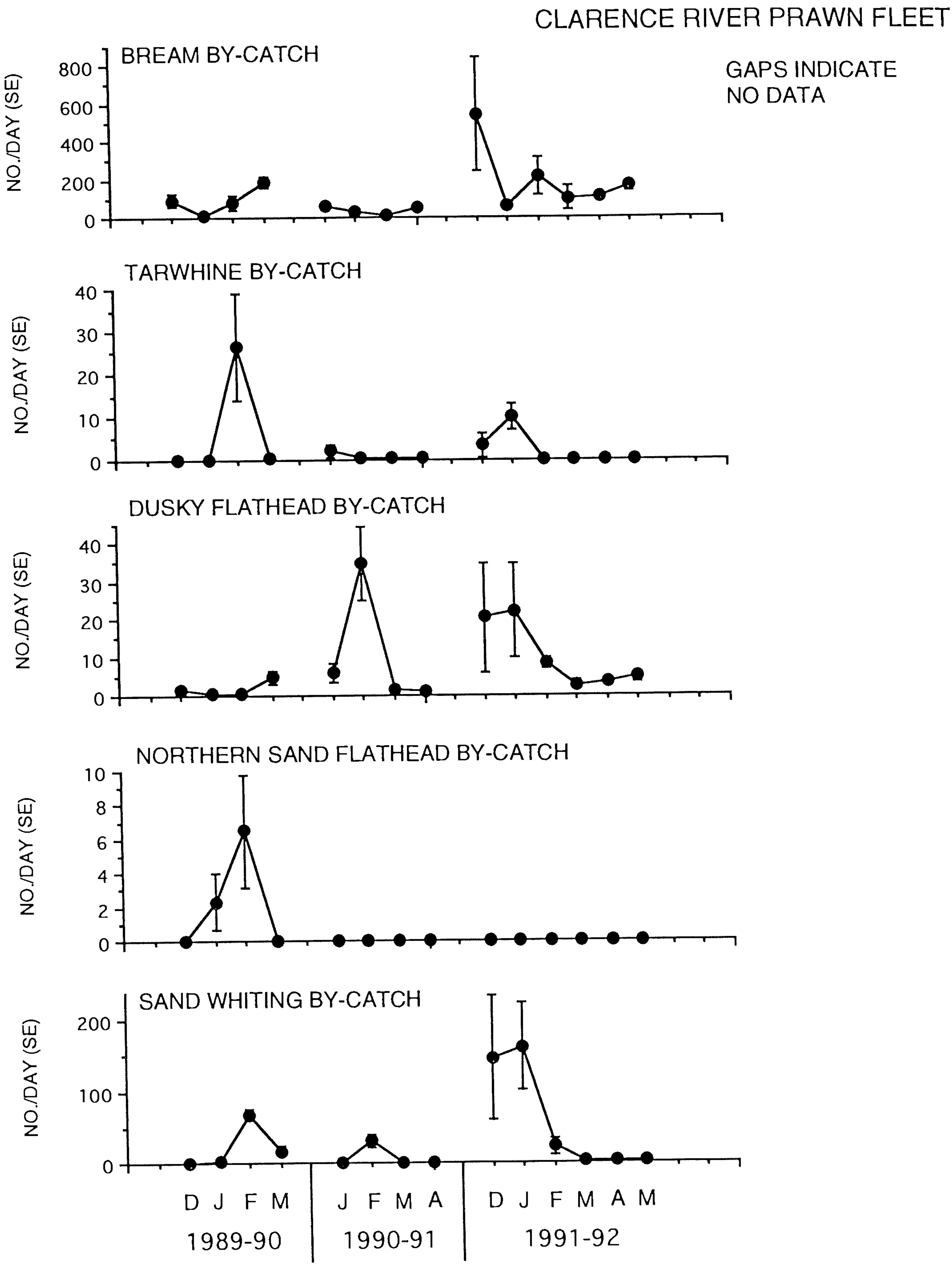
Yours sincerely,

Steven J. Kennelly
(on behalf of Geoff Liggins, Matt Broadhurst, Geoff Nemec, Keith Chilcott and Mark Bradley)

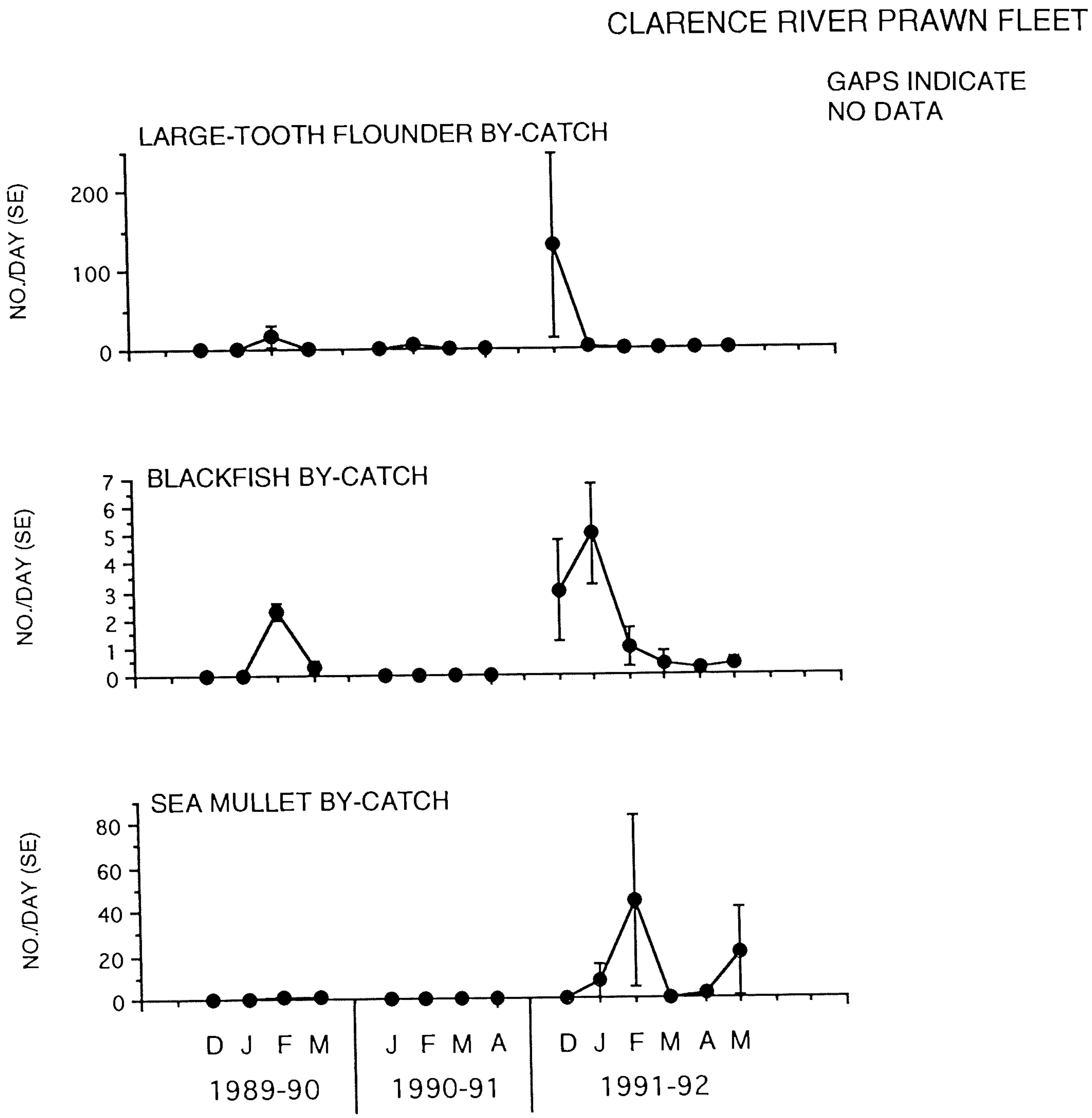

151° E
152° E
153° E
154° E
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE RIVER
COFFS HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY

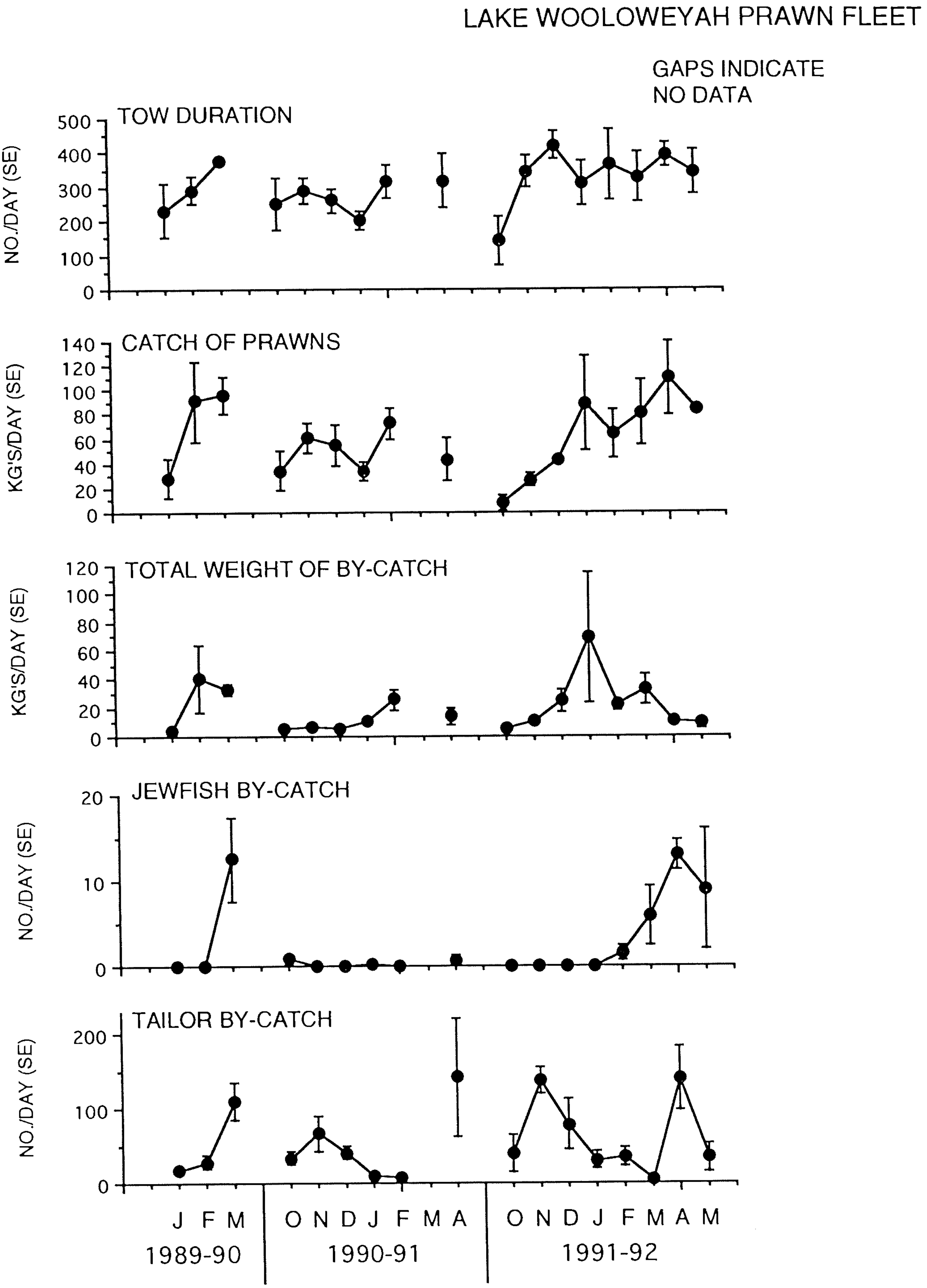


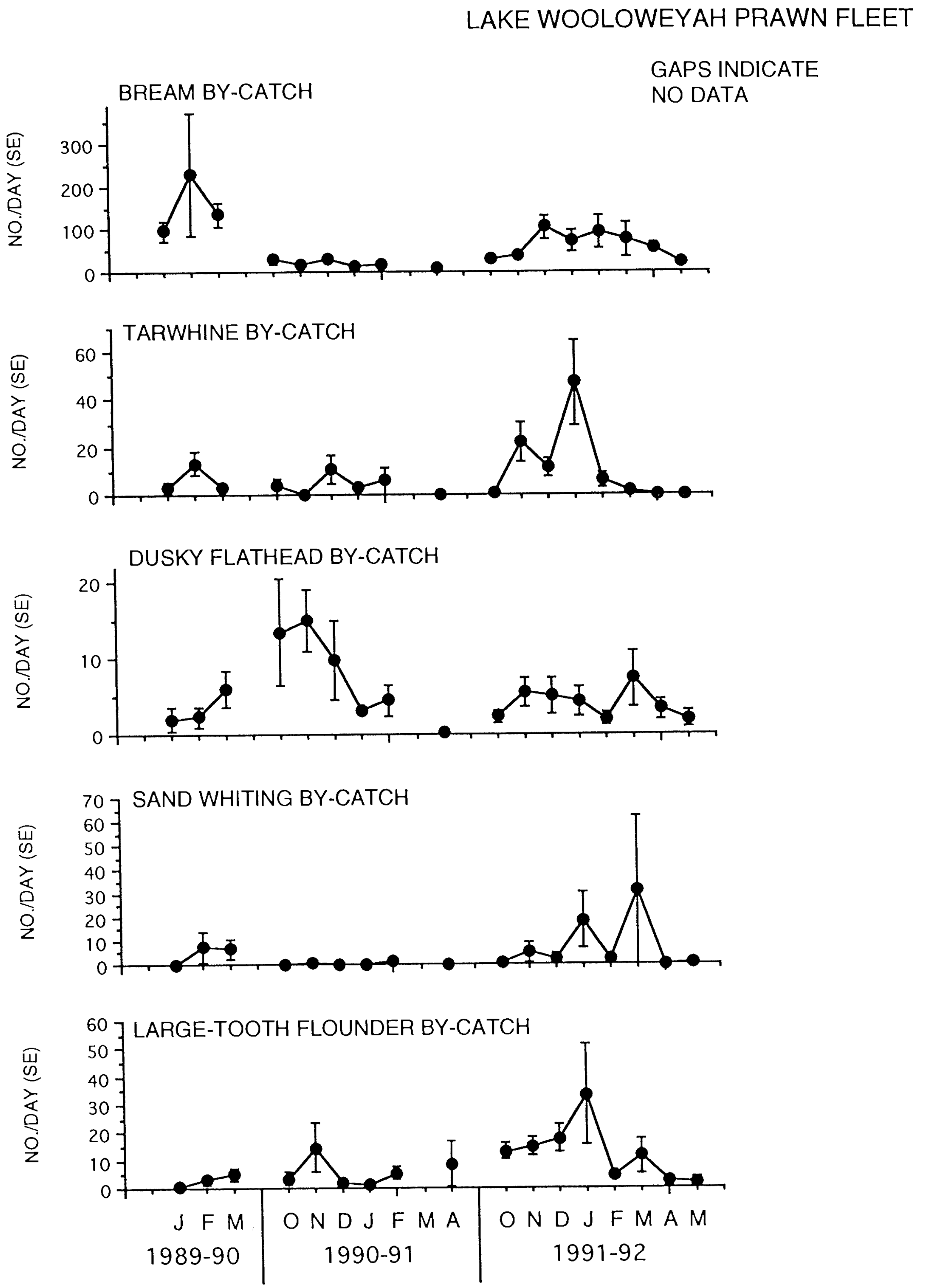
CLARENCE RIVER PRAWN FLEET
GAPS INDICATE NO DATA
TOW DURATION
MINS/DAY (SE)
0
100
200
300
400
CATCH OF PRAWNS
KG'S/DAY (SE)
0
100
200
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
0
20
40
60
80
100
JEWFISH BY-CATCH
NO./DAY (SE)
0
20
40
60
80
100
TAILOR BY-CATCH
NO./DAY (SE)
0
10
20
30
40
50
60
70
D J F M
1989-90
J F M A
1990-91
D J F M A M
1991-92



CLARENCE RIVER PRAWN FLEET
GAPS INDICATE NO DATA
BREAM BY-CATCH
TARWHINE BY-CATCH
DUSKY FLATHEAD BY-CATCH
NORTHERN SAND FLATHEAD BY-CATCH
SAND WHITING BY-CATCH
NO./DAY (SE)
0
200
400
600
800
10
20
30
40
2
4
6
8
100
D J F M
J F M A
D J F M A M
1989-90
1990-91
1991-92


CLARENCE RIVER PRAWN FLEET
GAPS INDICATE NO DATA
LARGE-TOOTH FLOUNDER BY-CATCH
NO./DAY (SE)
200
100
0
BLACKFISH BY-CATCH
NO./DAY (SE)
7
6
5
4
3
2
1
0
SEA MULLET BY-CATCH
NO./DAY (SE)
80
60
40
20
0
D J F M
1989-90
J F M A
1990-91
D J F M A M
1991-92

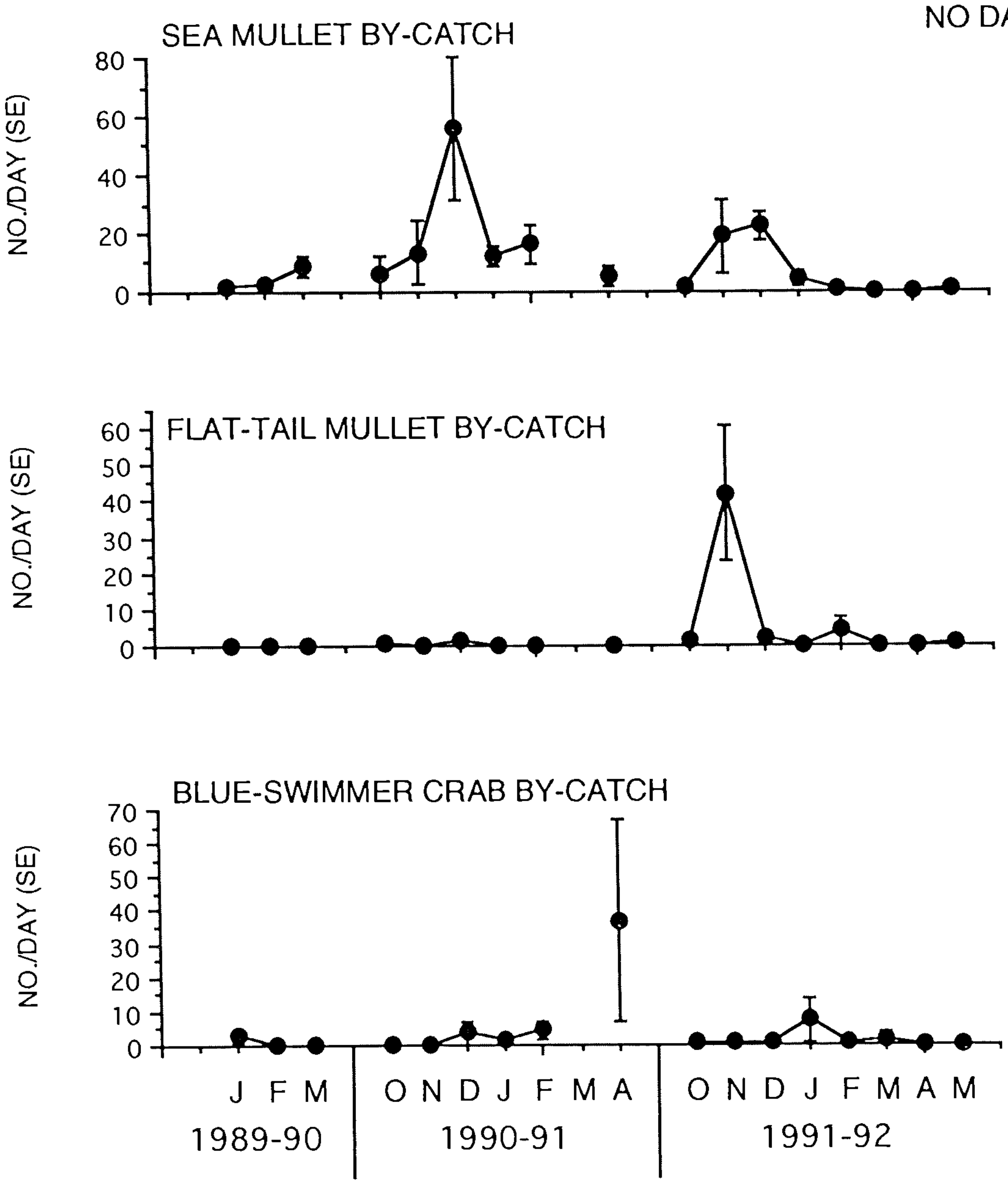

LAKE WOOLOWEYAH PRAWN FLEET
GAPS INDICATE
NO DATA
TOW DURATION
NO./DAY (SE)
500
400
300
200
100
0
CATCH OF PRAWNS
KG'S/DAY (SE)
140
120
100
80
60
40
20
0
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
120
100
80
60
40
20
0
JEWFISH BY-CATCH
NO./DAY (SE)
20
10
0
TAILOR BY-CATCH
NO./DAY (SE)
200
100
0
J F M
O N D J F M A
O N D J F M A M
1989-90
1990-91
1991-92



LAKE WOOLOWEYAH PRAWN FLEET
GAPS INDICATE NO DATA
BREAM BY-CATCH
NO./DAY (SE)
0
100
200
300
TARWHINE BY-CATCH
NO./DAY (SE)
0
20
40
60
DUSKY FLATHEAD BY-CATCH
NO./DAY (SE)
0
10
20
SAND WHITING BY-CATCH
NO./DAY (SE)
0
10
20
30
40
50
60
70
LARGE-TOOTH FLOUNDER BY-CATCH
NO./DAY (SE)
0
10
20
30
40
50
60
J F M
1989-90
O N D J F M A
1990-91
O N D J F M A M
1991-92

LAKE WOOLOWEYAH PRAWN FLEET

GAPS INDICATE NO DATA



Mr

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The graphs show that the average time spent trawling on this section of the Hawkesbury River was around 200-300 minutes per day. The catch rates of prawns during the project varied between 10 and 90 kilos per day, with highest catches occurring around summer each year. The information on by-catches shows that many species are by-caught in quite small quantities, whilst a handful of species stand out as quite abundant (eg. mulloway, bream and large-tooth flounder and to a lesser extent trumpeter whiting and blue-swimmer crabs).

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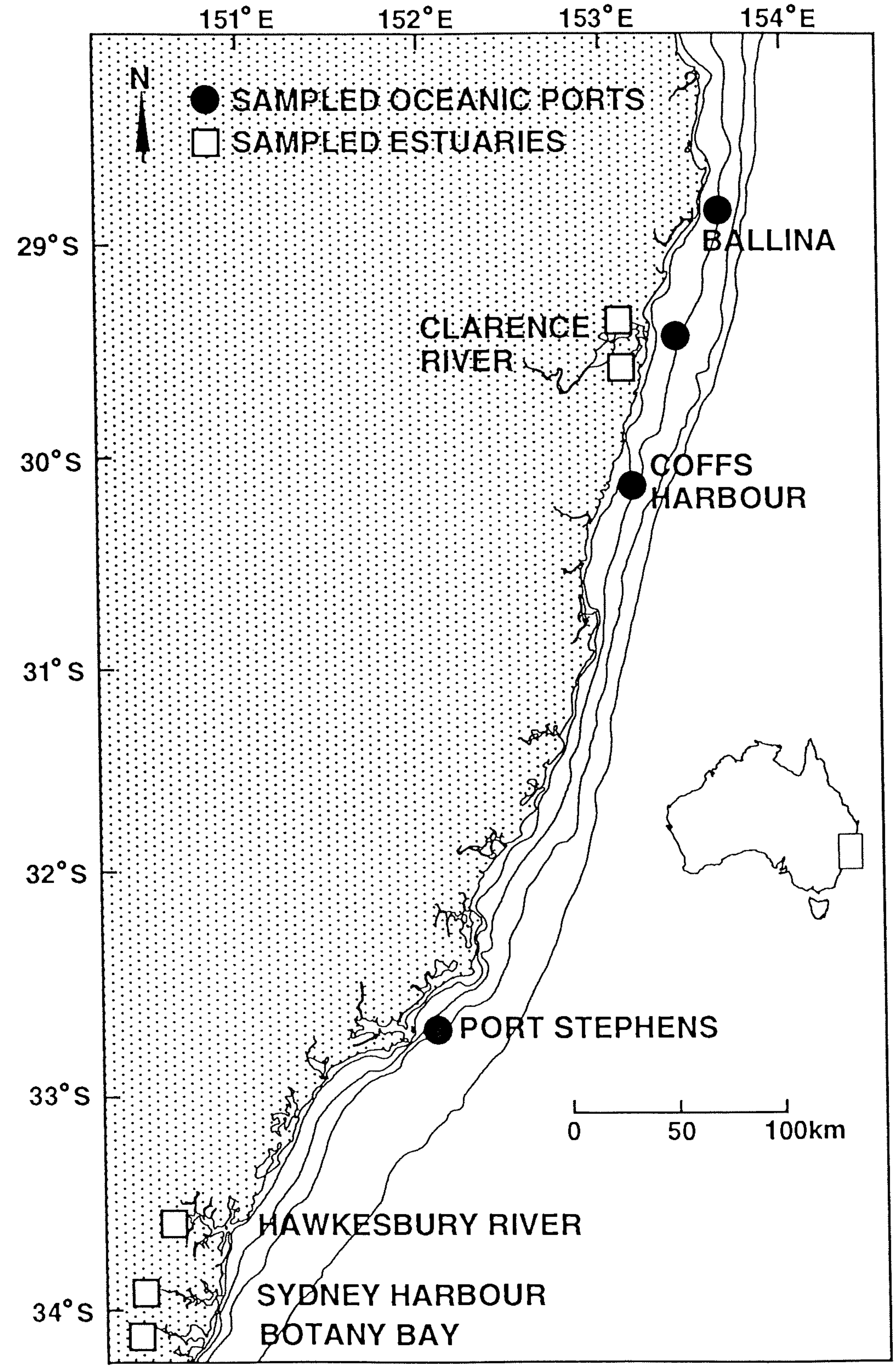
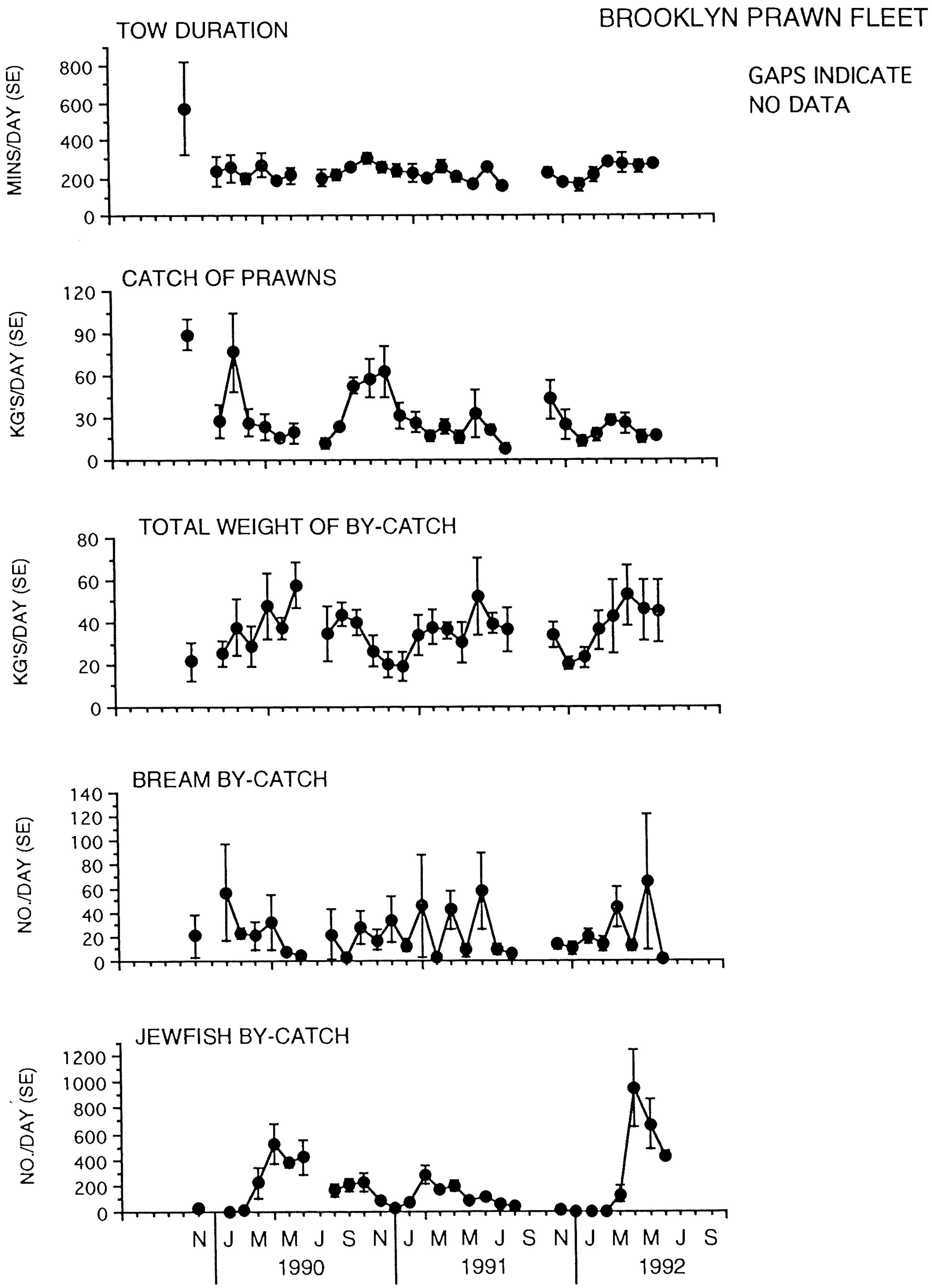
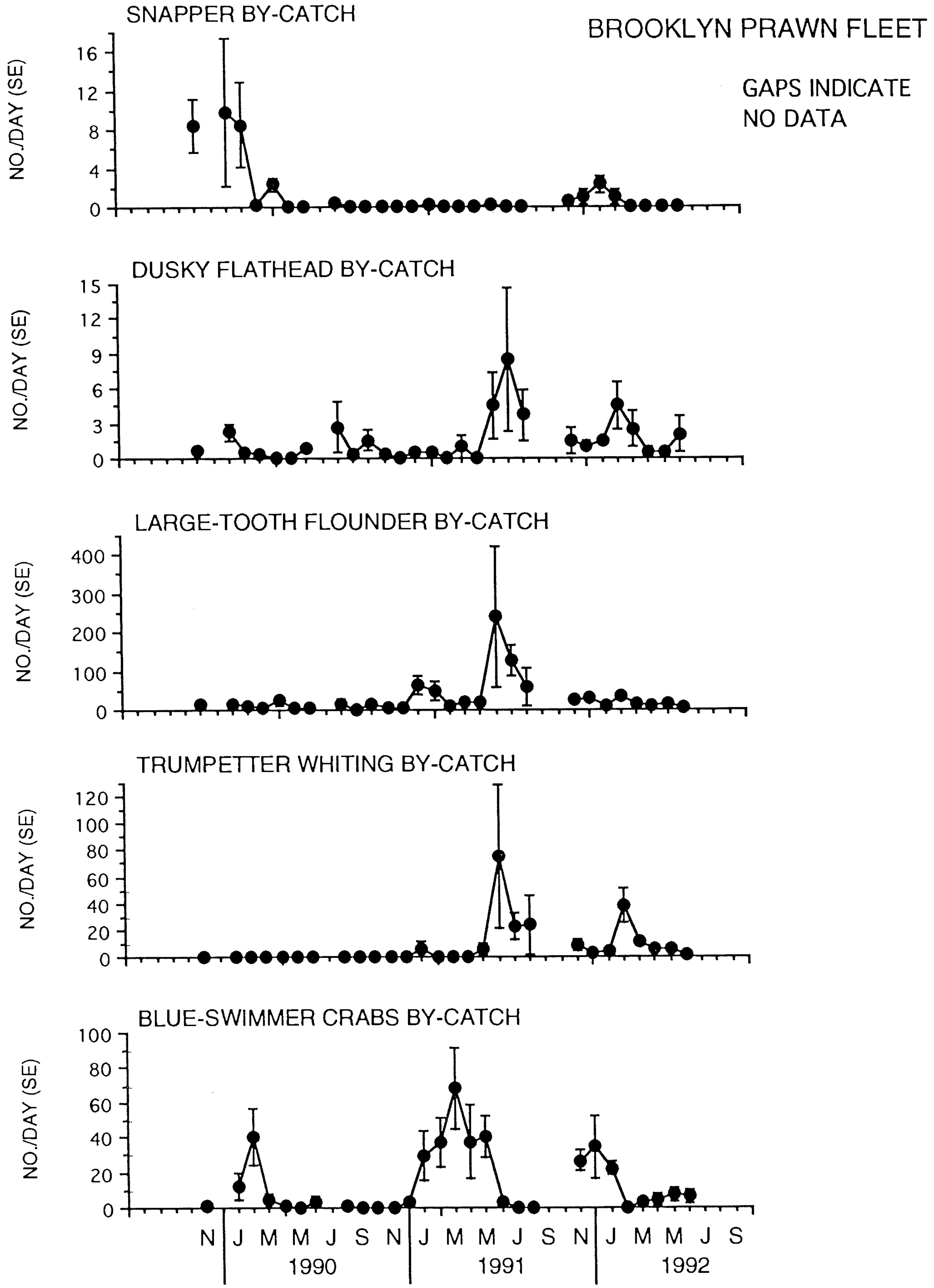


151° E
152° E
153° E
154° E
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE RIVER
COFFS HARBOUR
PORT STEPHENS
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY
0
50
100km



BROOKLYN PRAWN FLEET
GAPS INDICATE
NO DATA
TOW DURATION
MINS/DAY (SE)
0
200
400
600
800
CATCH OF PRAWNS
KG'S/DAY (SE)
0
30
60
90
120
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
0
20
40
60
80
BREAM BY-CATCH
NO./DAY (SE)
0
20
40
60
80
100
120
140
JEWFISH BY-CATCH
NO./DAY (SE)
0
200
400
600
800
1000
1200
N J M M J S N J M M J S N J M M J S
1990
1991
1992



SNAPPER BY-CATCH
BROOKLYN PRAWN FLEET
GAPS INDICATE
NO DATA
NO./DAY (SE)
0
4
8
12
16
DUSKY FLATHEAD BY-CATCH
NO./DAY (SE)
0
3
6
9
12
15
LARGE-TOOTH FLOUNDER BY-CATCH
NO./DAY (SE)
0
100
200
300
400
TRUMPETTER WHITING BY-CATCH
NO./DAY (SE)
0
20
40
60
80
100
120
BLUE-SWIMMER CRABS BY-CATCH
NO./DAY (SE)
0
20
40
60
80
100
N J M M J S N J M M J S N J M M J S
1990
1991
1992

NSW FISHERIES

Mr

Fisheries Research Institute
P.O. Box 21, Cronulla, 2230

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In each month that trawling for prawns occurred between late 1989 and June 1992 and for squid between November 1991 and October 1992, we tried to have scientists on 4 randomly-selected trawler-trips from each fishery. For the Hawkesbury River prawn trawl fleet, we used those vessels based in Brooklyn that usually worked the prawn-grounds between Sentry Box and the rail bridge. For the Hawkesbury River squid trawl fleet, we used those vessels based in Brooklyn, Patonga and Careel Bay that worked the squid grounds in Broken Bay. During each trip, the catch from each tow was sorted by the crew and our scientist, separating the various species. The weights of either prawns or squid and total by-catch from each tow were recorded. All finfish species of commercial and recreational importance were counted and measured. Crustaceans (crabs etc), cephalopods (octopus etc) and non-commercial finfish species (catfish etc) were counted. For each tow, we also recorded the time, duration and location of the tow, as well as the basic gear configuration used.

The catch of prawns/squid and other species that may be of interest are shown in the attached figures. The graphs are pretty straightforward, showing the average tow times and catches per fisherman-day that occurred during each month of sampling. The vertical bars attached to each point (shown as SE in the graphs) is an estimate of the accuracy of that average - i.e. it shows you the slop around the average and the confidence that can be placed on that average.

The graphs show that the average time spent prawn trawling on the rail bridge-Sentry box section of the Hawkesbury River was around 200-300 minutes per day. The catch rates of prawns during the project varied between 10 and 90 kilos per day, with highest catches occurring around summer each year. The information on by-catches shows that many species are by-caught in quite small quantities, whilst a handful of species stand out as quite abundant (eg. mulloway, bream and large-tooth flounder and to a lesser extent trumpeter whiting and blue-swimmer crabs).

The average time spent squid trawling on Broken Bay was around 300 minutes per day. The catch rates of squid during the project varied between 10 and 28 kilos per day. The information on by-catches shows that many species are by-caught in quite small quantities, whilst a few species stand out as quite abundant (eg. tailor, large-tooth flounder, bream, dusky flathead and trumpeter whiting).

Thank you for your help over the past few years. To show our gratitude, we have enclosed a T-shirt as a small token of our appreciation. We look forward to working with you again in the future.

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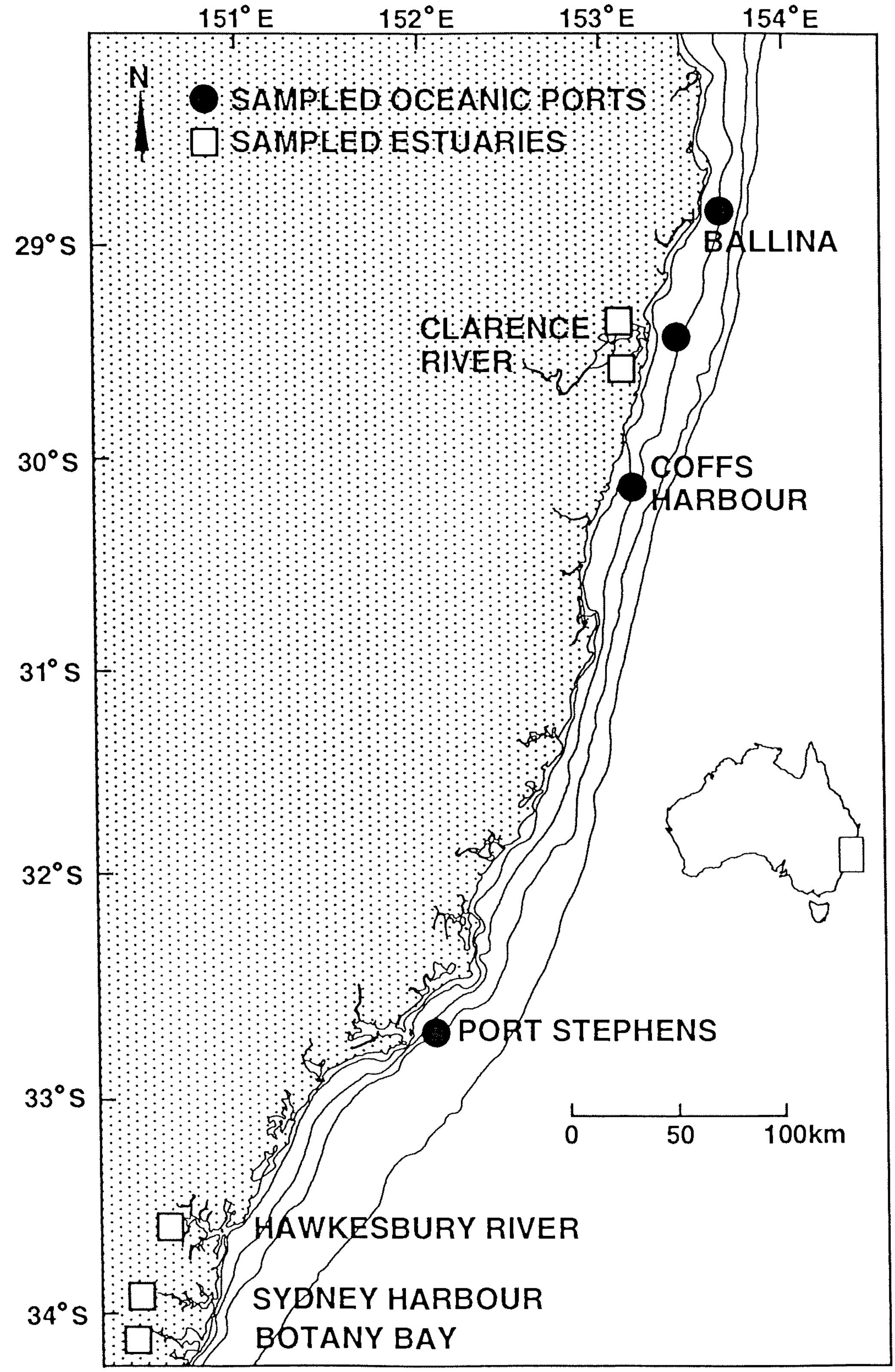
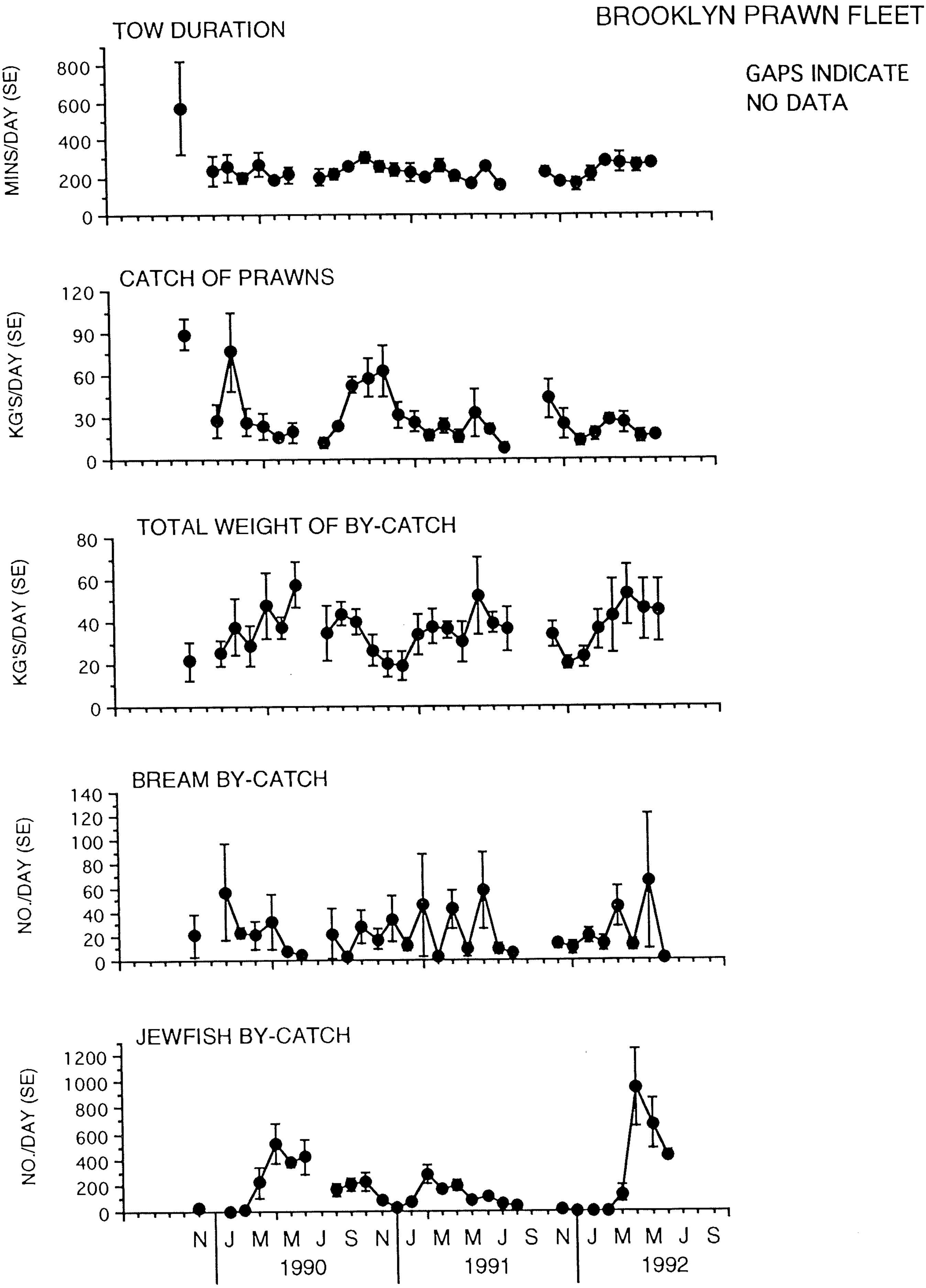
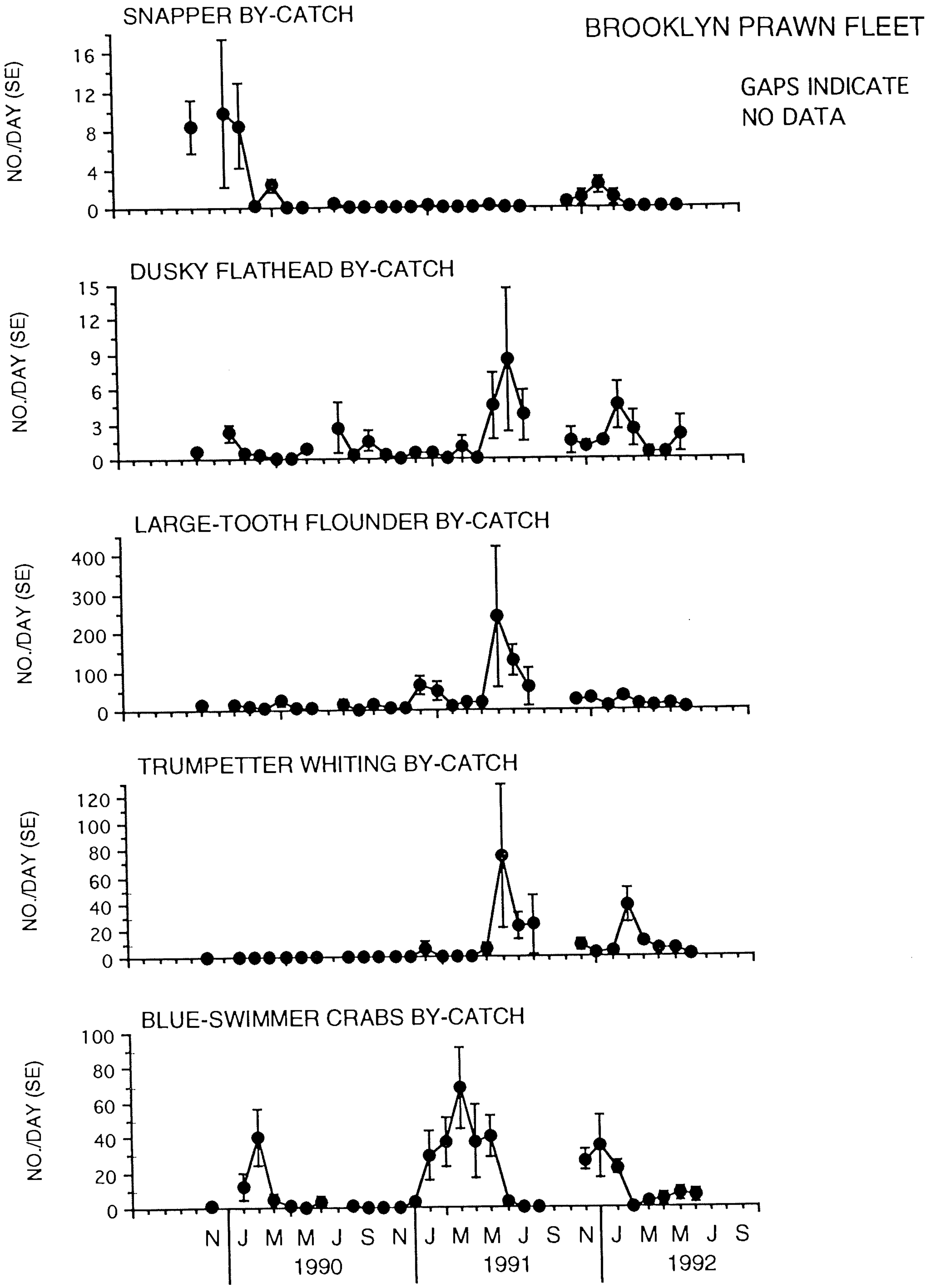
(on behalf of Geoff Liggins, Matt Broadhurst, Geoff Nemec, Keith Chilcott and Mark Bradley)

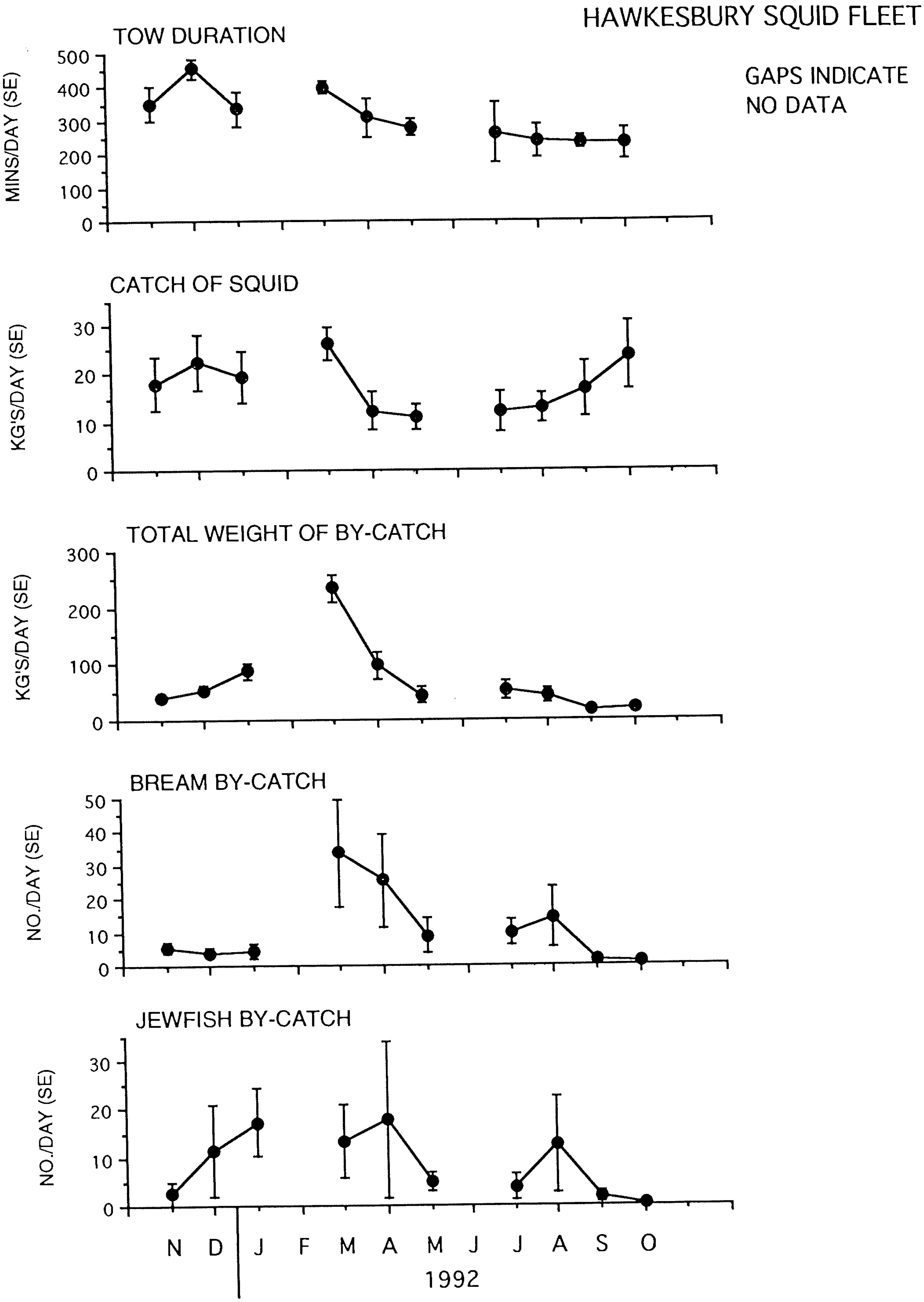

151° E
152° E
153° E
154° E
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE
RIVER
COFFS
HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY



BROOKLYN PRAWN FLEET
GAPS INDICATE NO DATA
TOW DURATION
MINS/DAY (SE)
0
200
400
600
800
CATCH OF PRAWNS
KG'S/DAY (SE)
0
30
60
90
120
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
0
20
40
60
80
BREAM BY-CATCH
NO./DAY (SE)
0
20
40
60
80
100
120
140
JEWFISH BY-CATCH
NO./DAY (SE)
0
200
400
600
800
1000
1200
N J M M J S N J M M J S N J M M J S
1990
1991
1992



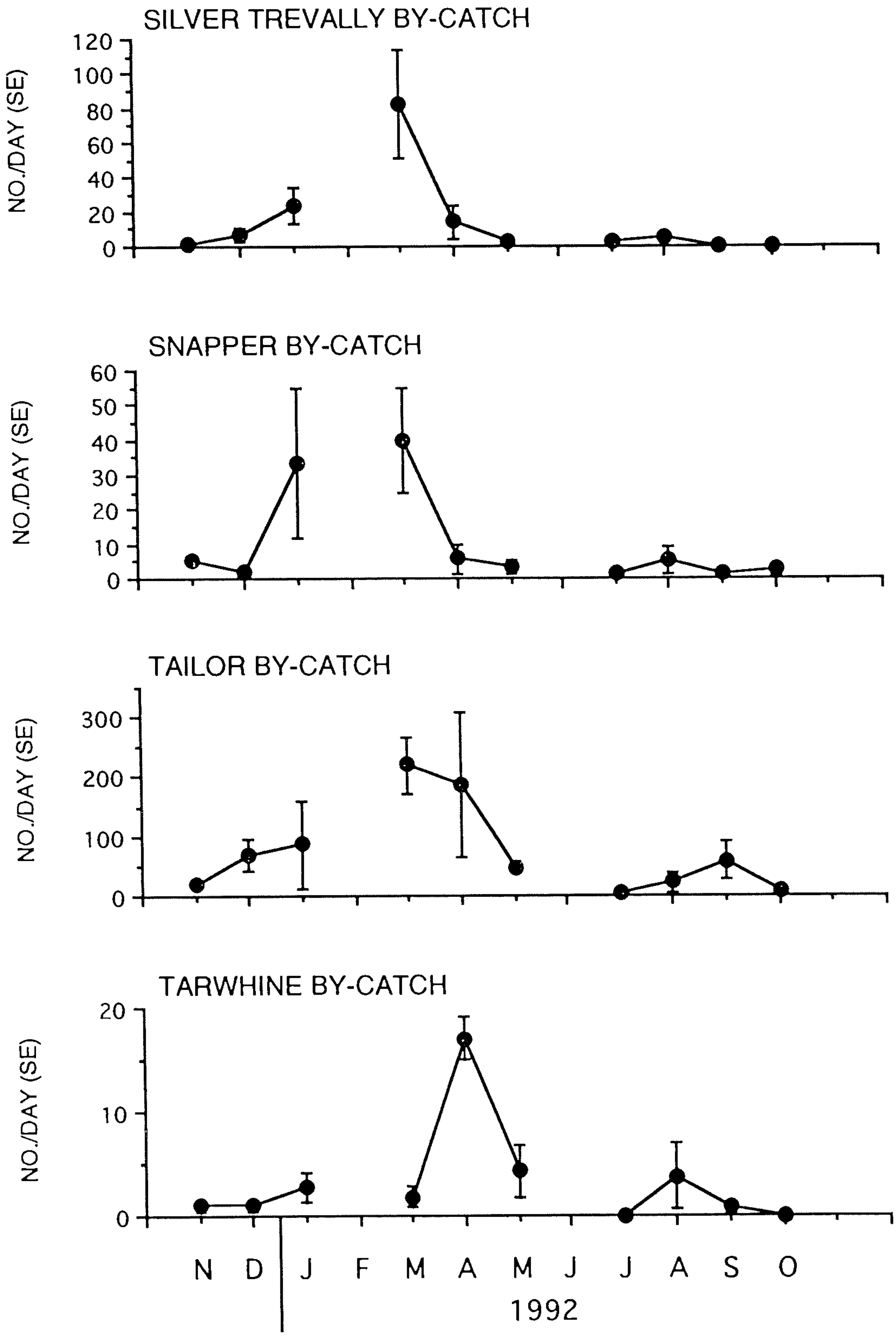
BROOKLYN PRAWN FLEET
GAPS INDICATE
NO DATA
SNAPPER BY-CATCH
DUSKY FLATHEAD BY-CATCH
LARGE-TOOTH FLOUNDER BY-CATCH
TRUMPETTER WHITING BY-CATCH
BLUE-SWIMMER CRABS BY-CATCH
NO./DAY (SE)
N J M M J S N J M M J S N J M M J S
1990
1991
1992



HAWKESBURY SQUID FLEET
GAPS INDICATE
NO DATA
TOW DURATION
MINS/DAY (SE)
0
100
200
300
400
500
CATCH OF SQUID
KG'S/DAY (SE)
0
10
20
30
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
0
100
200
300
BREAM BY-CATCH
NO./DAY (SE)
0
10
20
30
40
50
JEWFISH BY-CATCH
NO./DAY (SE)
0
10
20
30
N D J F M A M J J A S O
1992

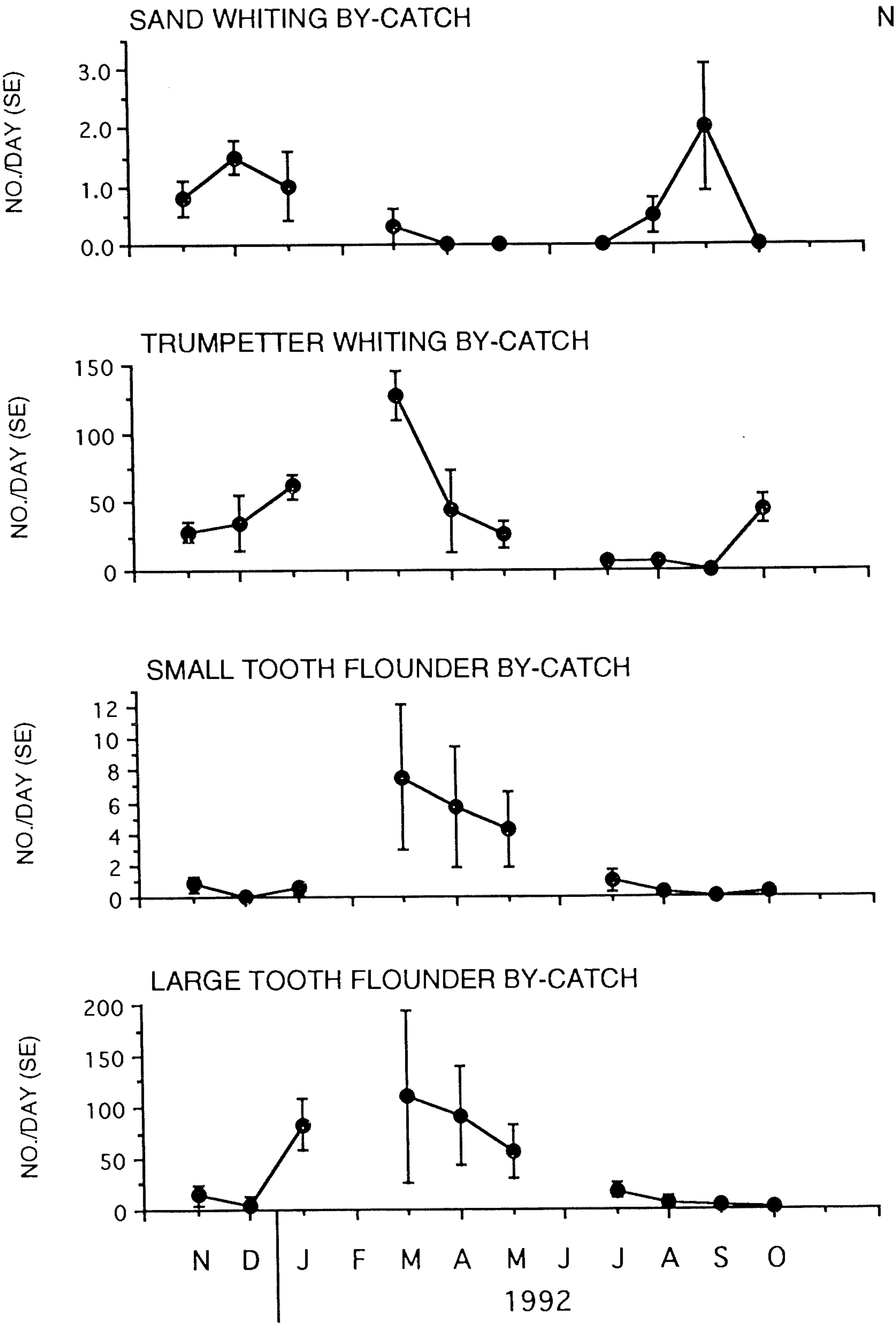
HAWKESBURY SQUID FLEET

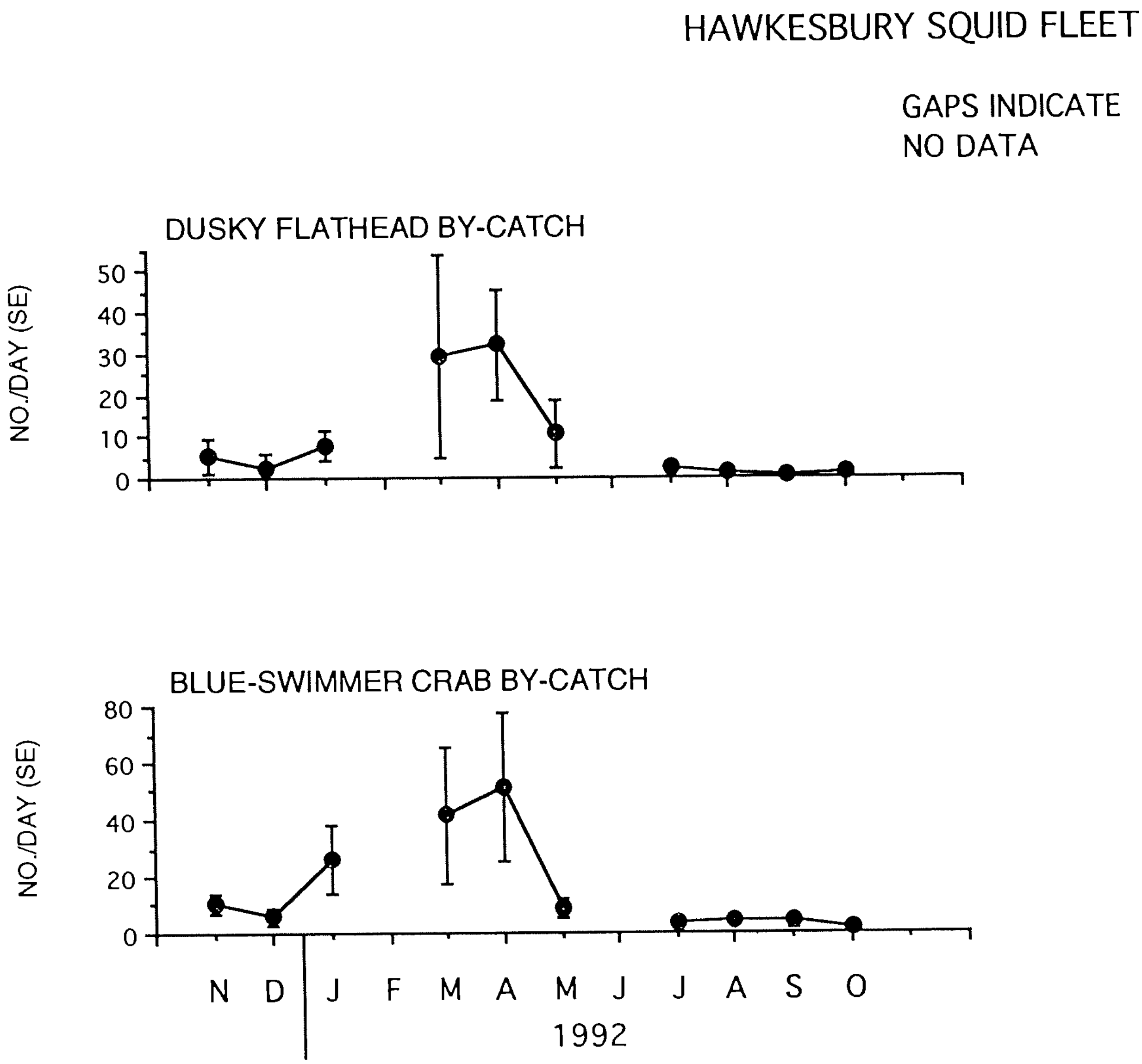
GAPS INDICATE NO DATA



HAWKESBURY SQUID FLEET

GAPS INDICATE NO DATA




HAWKESBURY SQUID FLEET
GAPS INDICATE
NO DATA
DUSKY FLATHEAD BY-CATCH
NO./DAY (SE)
50
40
30
20
10
0
BLUE-SWIMMER CRAB BY-CATCH
NO./DAY (SE)
80
60
40
20
0
N
D
J
F
M
A
M
J
J
A
S
O
1992

NSW FISHERIES

Mr

Fisheries Research Institute
P.O. Box 21, Cronulla, 2230

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FISHERIES RESEARCH INSTITUTE
202 Nicholson Parade — PO Box 21 Cronulla NSW Australia 2230
Telephone: (02) 527 8411 • **Facsimile:** (02) 527 8576

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The graphs show that the average time spent trawling on Port Jackson was around 250-400 minutes per night. The catch rates of prawns during the project varied between 5 and 25 kilos per night. The information on by-catches shows that some species are by-caught in quite large quantities (eg. trumpeter whiting, bream, snapper, large tooth flounder, dusky flathead and blue-swimmer crabs).

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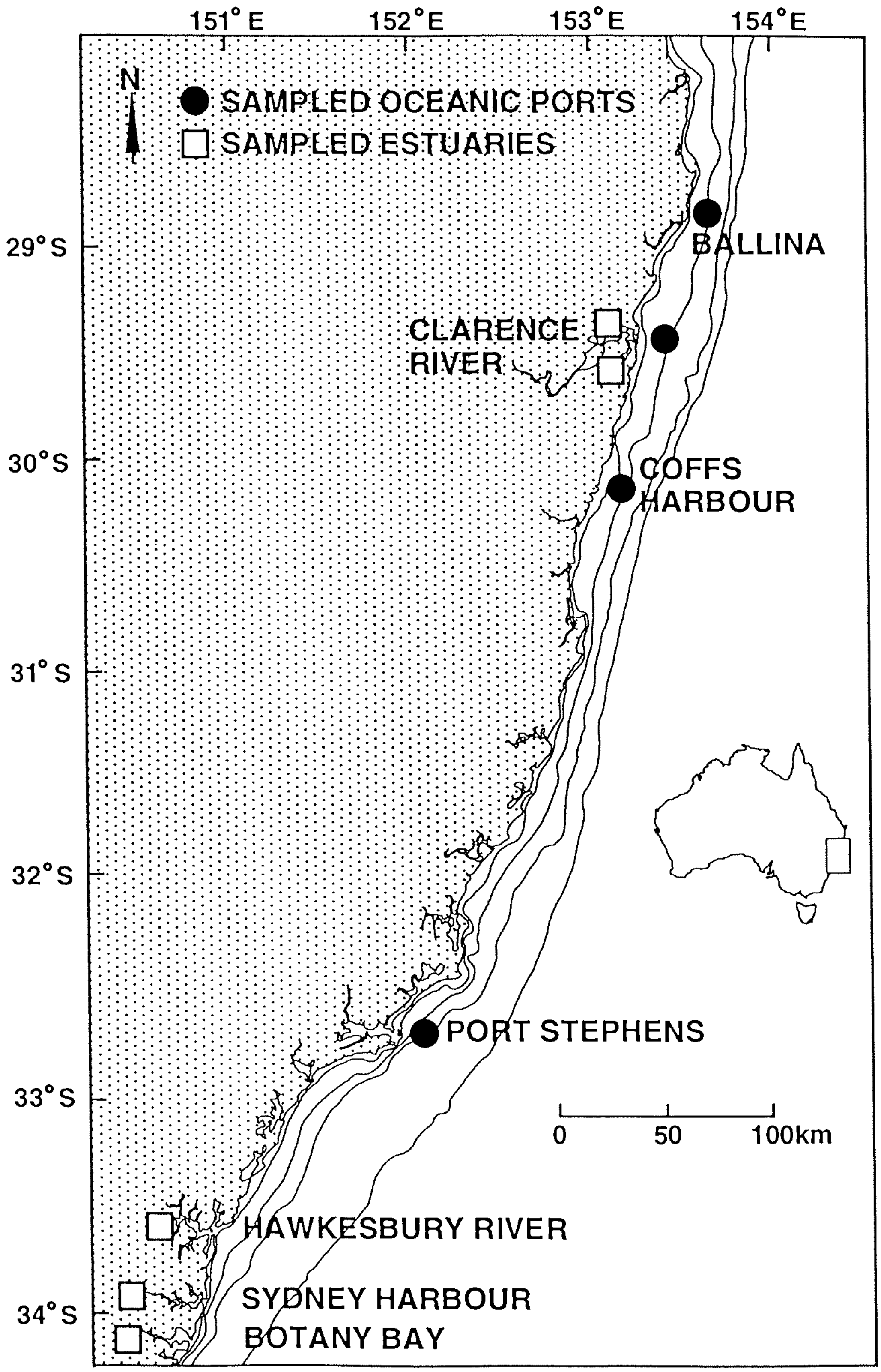
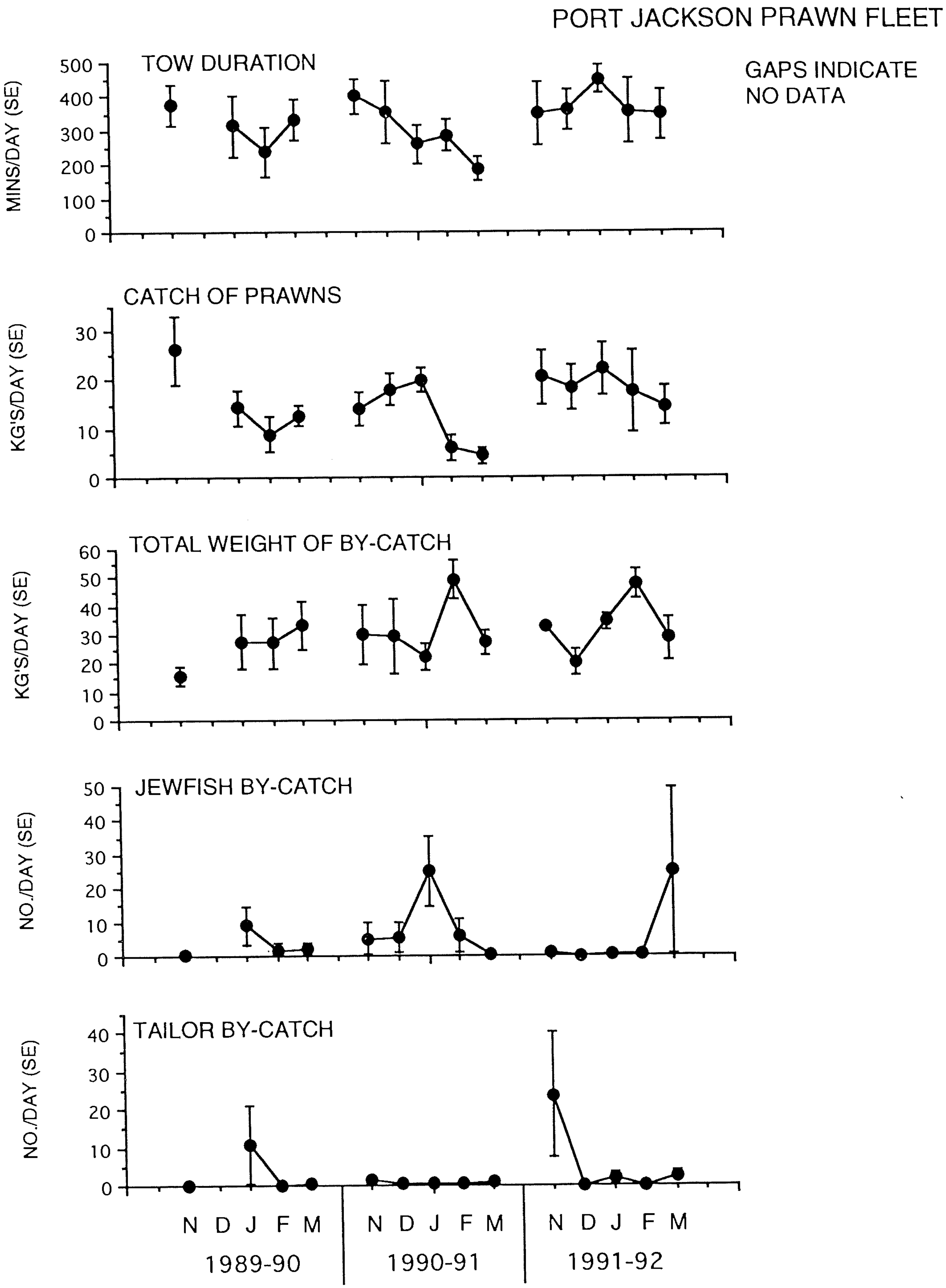
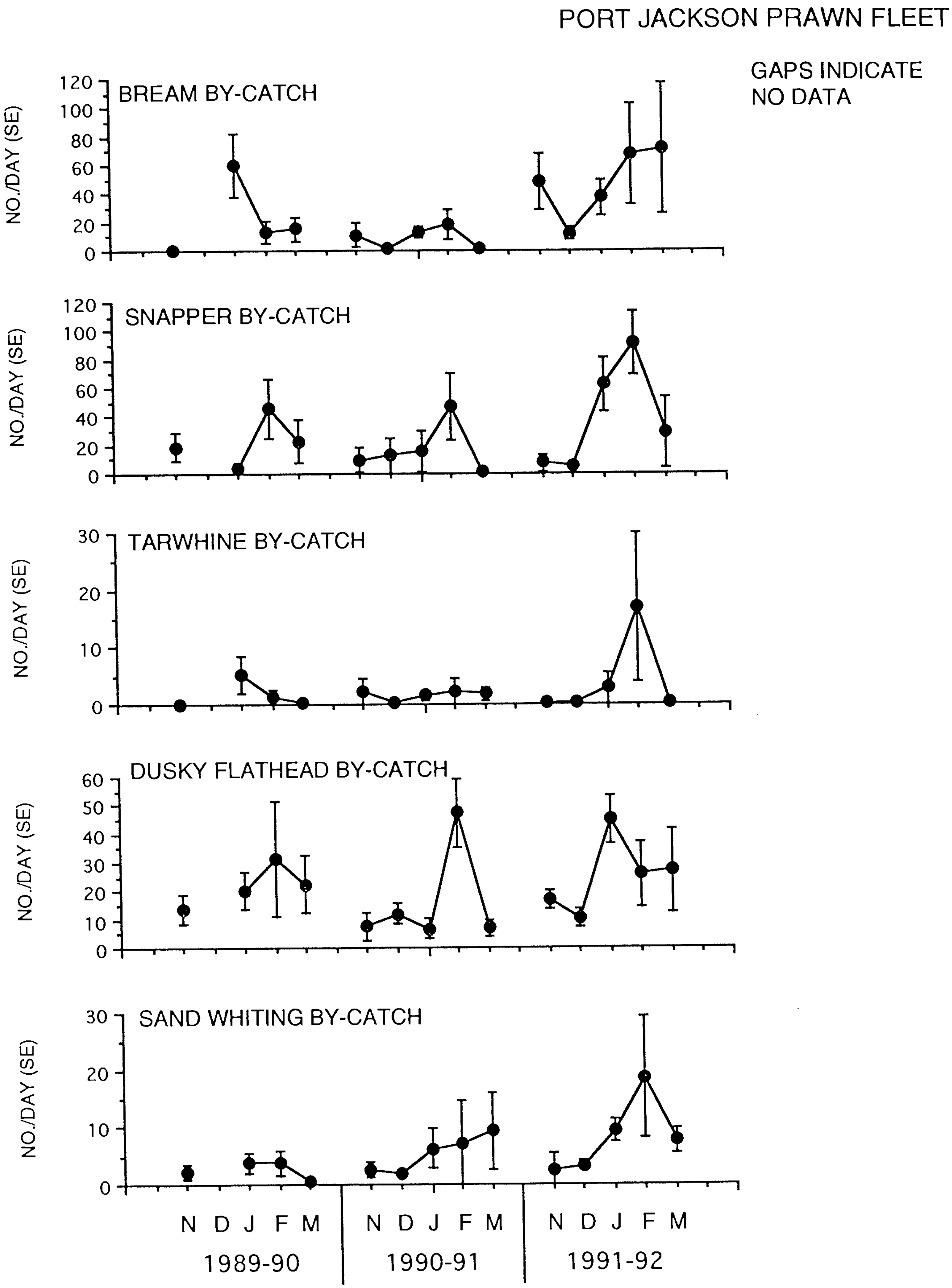
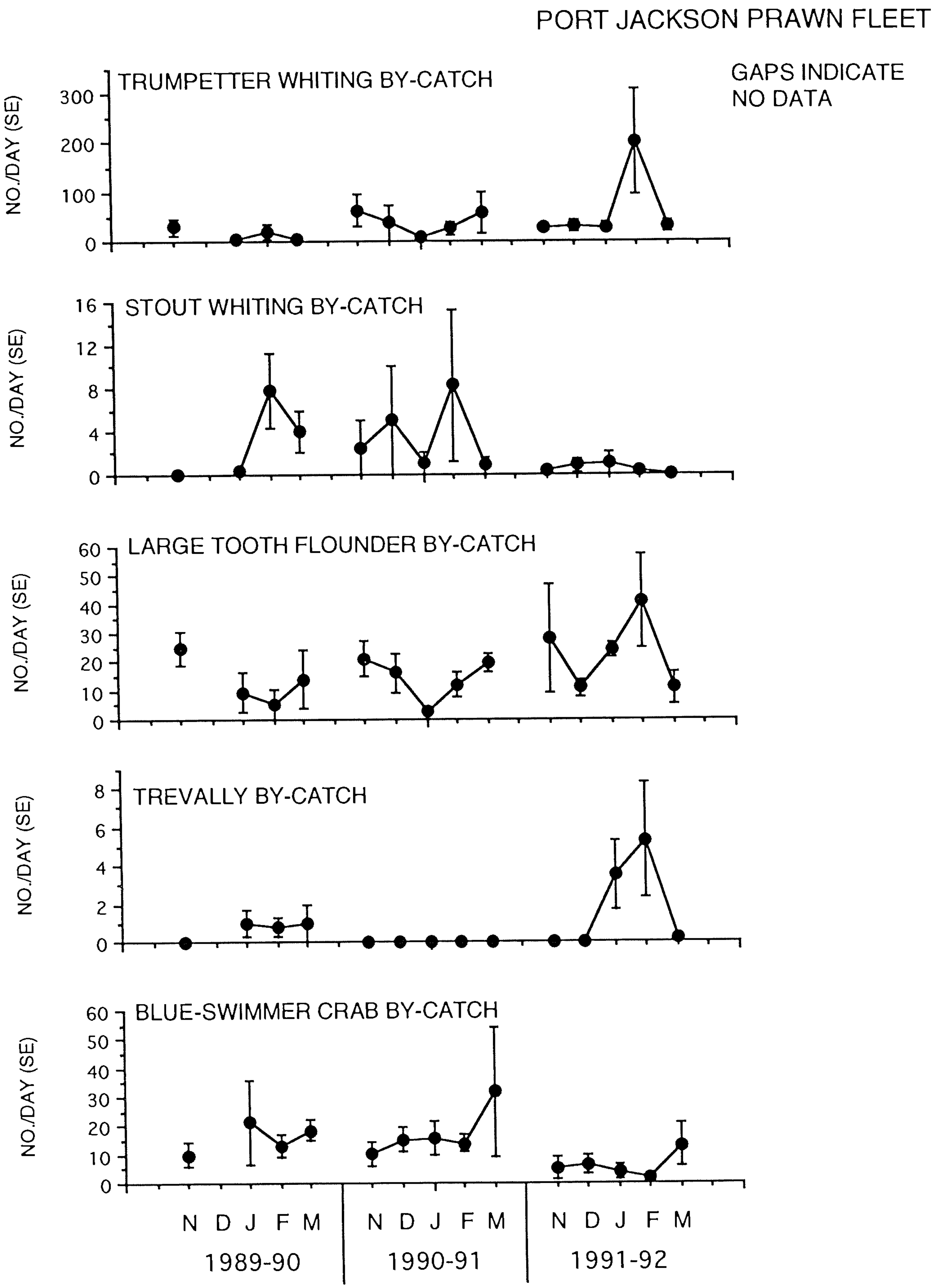
(on behalf of Geoff Liggins, Matt Broadhurst, Geoff Nemec, Keith Chilcott and Mark Bradley)


151° E
152° E
153° E
154° E
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE RIVER
COFFS HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY


PORT JACKSON PRAWN FLEET
GAPS INDICATE NO DATA
TOW DURATION
MINS/DAY (SE)
CATCH OF PRAWNS
KG'S/DAY (SE)
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
JEWFISH BY-CATCH
NO./DAY (SE)
TAILOR BY-CATCH
NO./DAY (SE)
N D J F M
1989-90
N D J F M
1990-91
N D J F M
1991-92



PORT JACKSON PRAWN FLEET
GAPS INDICATE NO DATA
BREAM BY-CATCH
SNAPPER BY-CATCH
TARWHINE BY-CATCH
DUSKY FLATHEAD BY-CATCH
SAND WHITING BY-CATCH
NO./DAY (SE)
0
20
40
60
80
100
120
0
10
20
30
40
50
60
N D J F M
1989-90
1990-91
1991-92



PORT JACKSON PRAWN FLEET
GAPS INDICATE NO DATA
TRUMPETTER WHITING BY-CATCH
STOUT WHITING BY-CATCH
LARGE TOOTH FLOUNDER BY-CATCH
TREVALLY BY-CATCH
BLUE-SWIMMER CRAB BY-CATCH
NO./DAY (SE)
0
100
200
300
4
8
12
16
10
20
30
40
50
60
2
6
N D J F M
1989-90
1990-91
1991-92

NSW FISHERIES

Mr

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The graphs show that the average time spent trawling on the Bay was around 250-350 minutes per night. The catch rates of prawns during the project varied between 15 and 35 kilos per night. The information on by-catches shows that many species are by-caught and a few species stand out as quite abundant (eg. snapper, stout, red spot and trumpeter whiting and blue-swimmer crabs).

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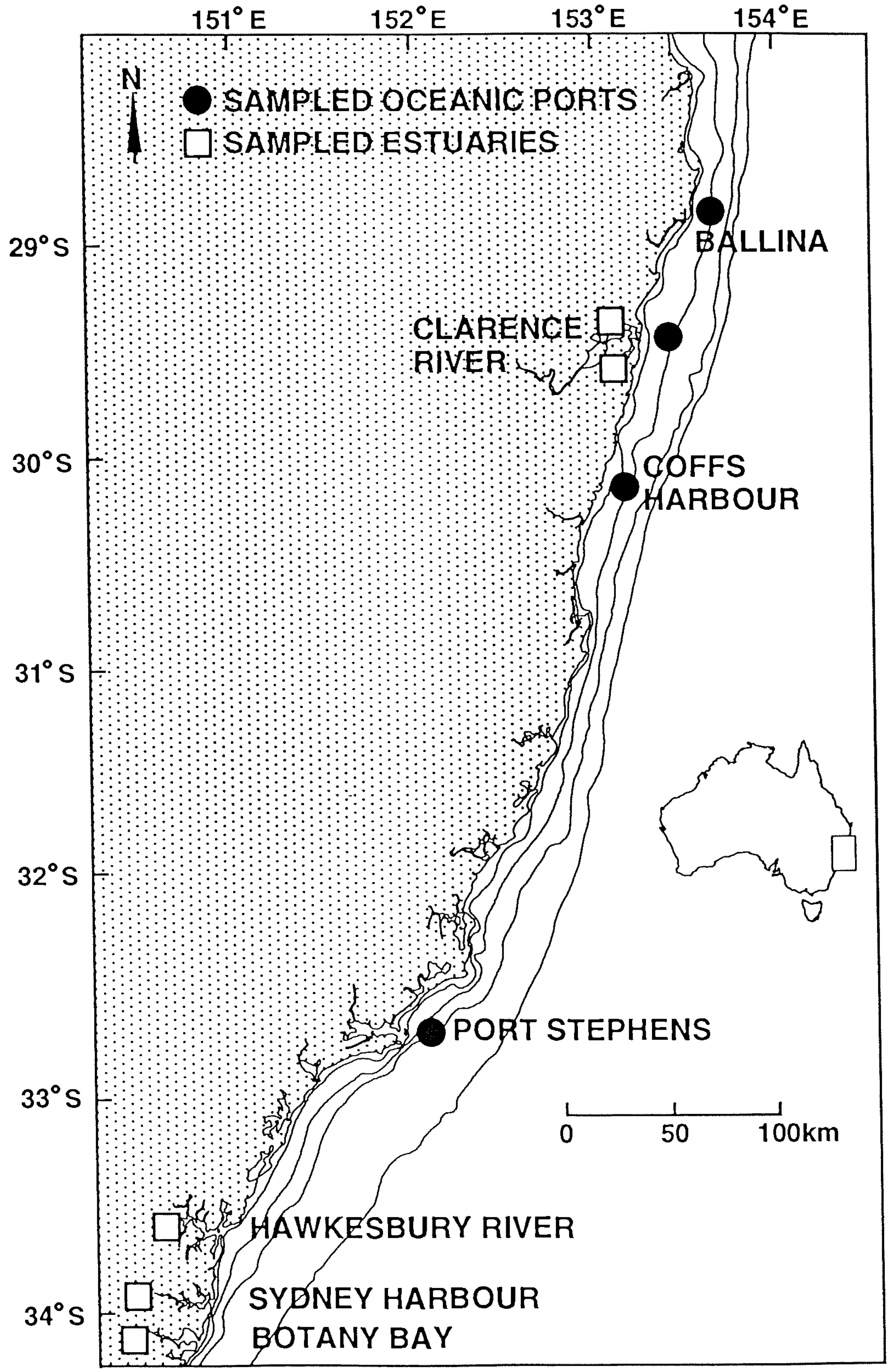
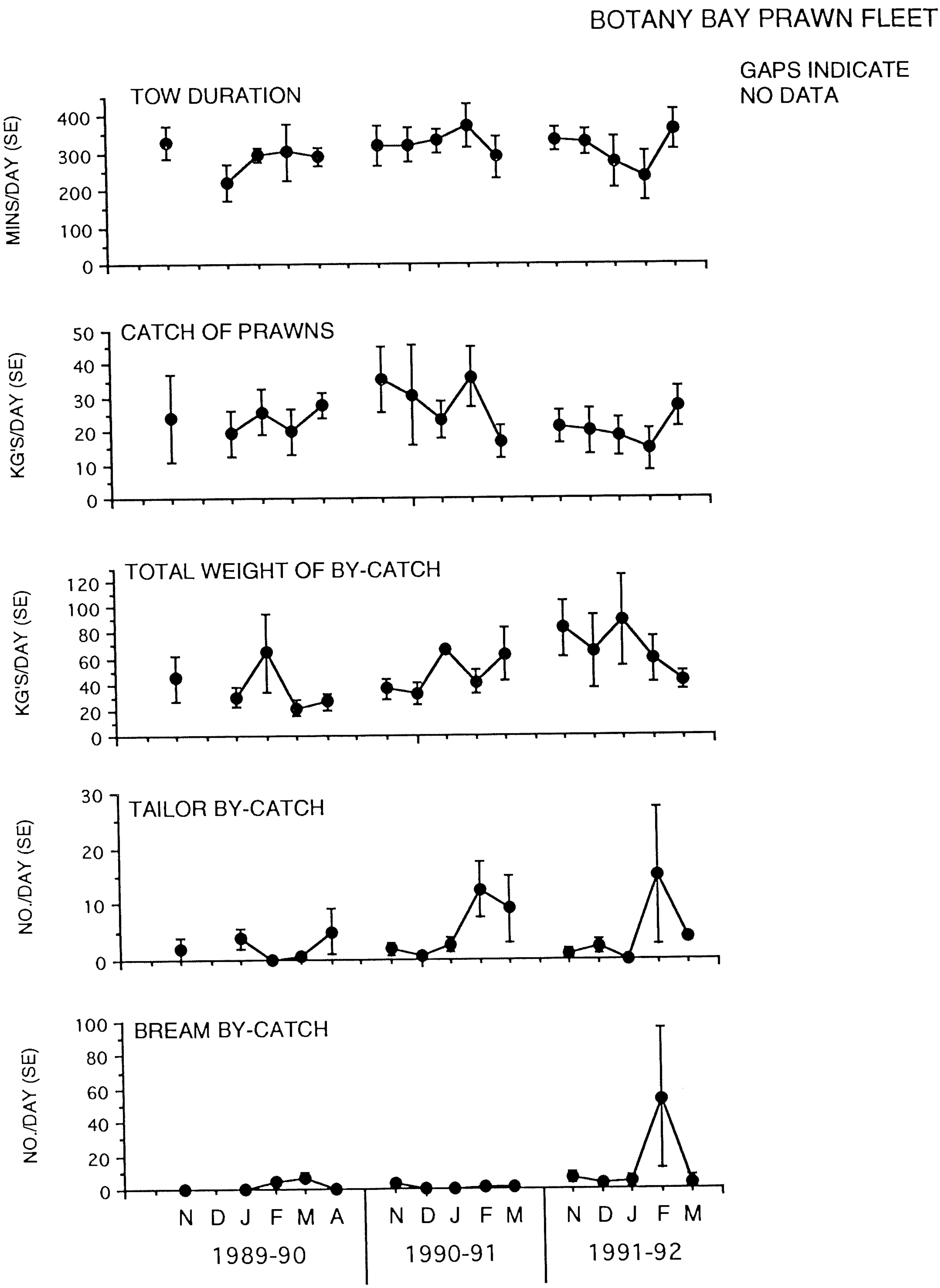
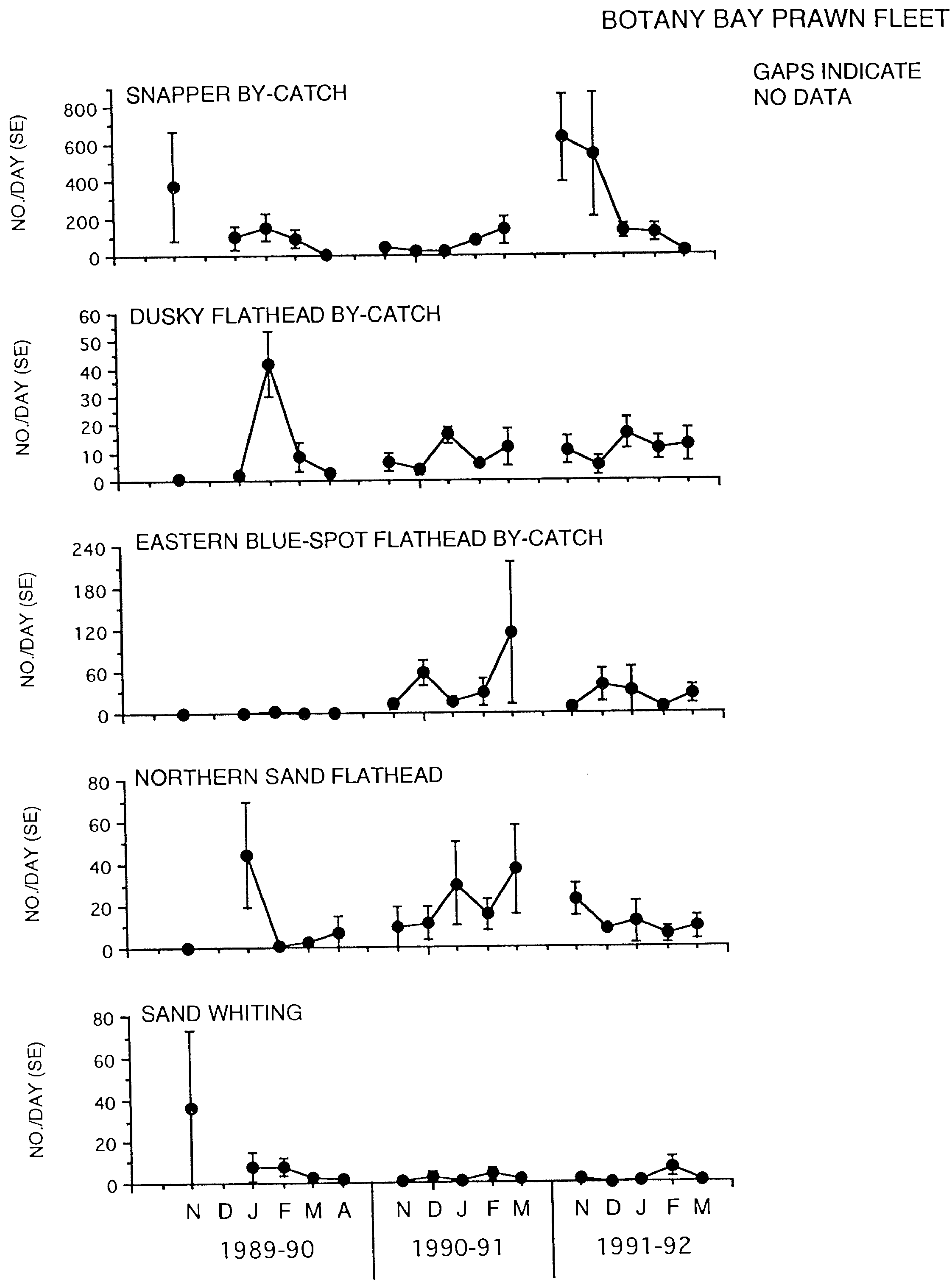


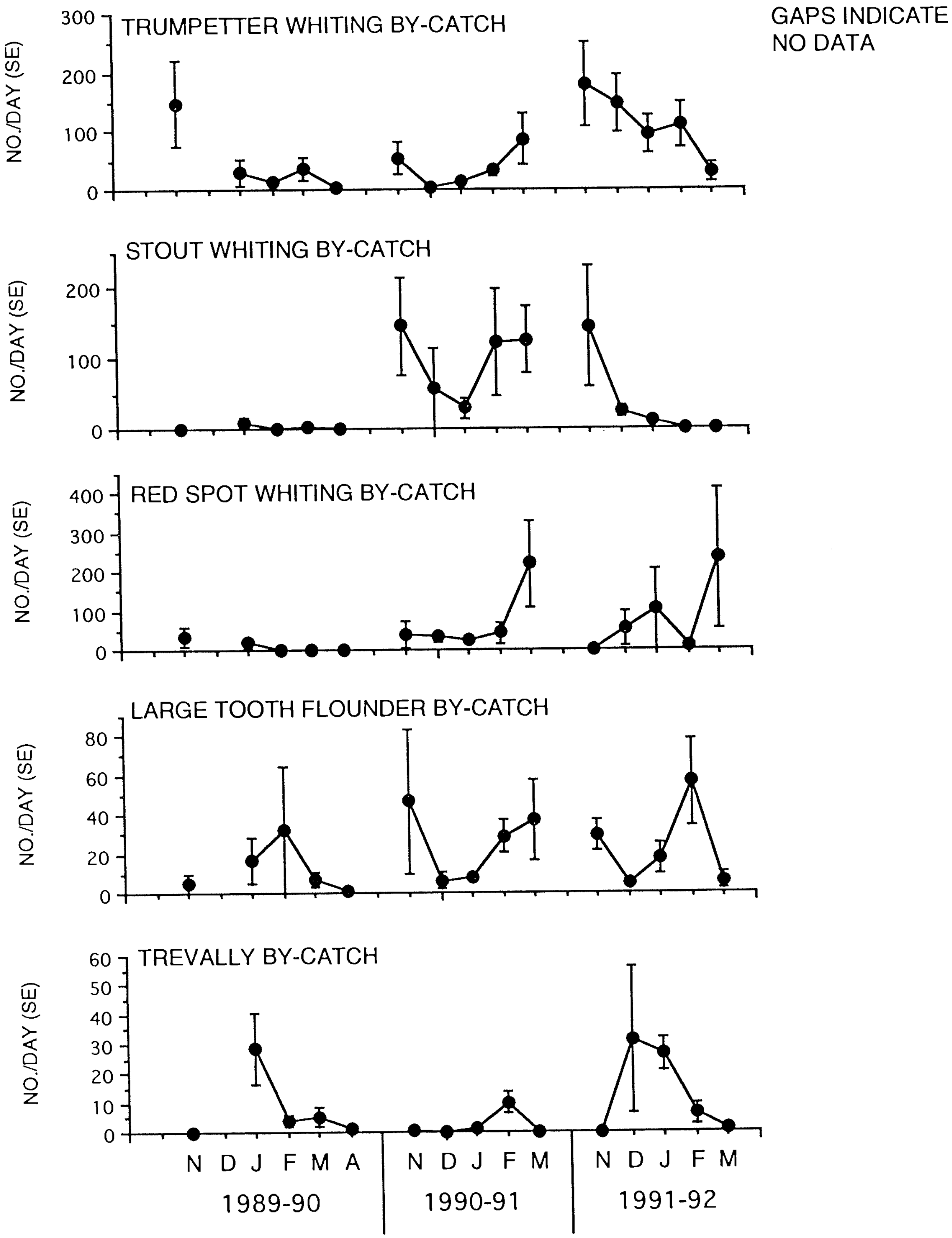
151° E
152° E
153° E
154° E
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE
RIVER
COFFS
HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY



BOTANY BAY PRAWN FLEET
GAPS INDICATE NO DATA
TOW DURATION
MINS/DAY (SE)
0
100
200
300
400
CATCH OF PRAWNS
KG'S/DAY (SE)
0
10
20
30
40
50
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
0
20
40
60
80
100
120
TAILOR BY-CATCH
NO./DAY (SE)
0
10
20
30
BREAM BY-CATCH
NO./DAY (SE)
0
20
40
60
80
100
N D J F M A
N D J F M
N D J F M
1989-90
1990-91
1991-92

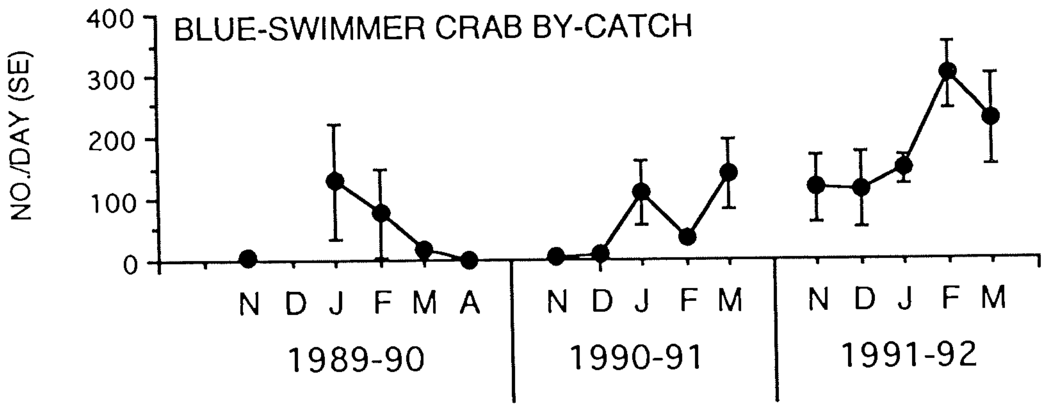

BOTANY BAY PRAWN FLEET
GAPS INDICATE
NO DATA
SNAPPER BY-CATCH
NO./DAY (SE)
0
200
400
600
800
DUSKY FLATHEAD BY-CATCH
0
10
20
30
40
50
60
EASTERN BLUE-SPOT FLATHEAD BY-CATCH
0
60
120
180
240
NORTHERN SAND FLATHEAD
0
20
40
60
80
SAND WHITING
N D J F M A
N D J F M
N D J F M
1989-90
1990-91
1991-92

BOTANY BAY PRAWN FLEET



BOTANY BAY PRAWN FLEET

GAPS INDICATE
NO DATA



NSW FISHERIES

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The graphs show that the average time spent trawling by vessels from Ballina was around 550 minutes per night. The catch rates of prawns during the project varied between 35 and 85 kilos per night, with highest catches occuring in the autumns of 1991 and 1992. The information on by-catches of different species represents total numbers (i.e retained and discarded commercial individuals) and shows that many species are by-caught in reasonable quantities, whilst a handful of species stand out as quite abundant (eg. stout and red spot whiting, octopus, bugs, red mullet, small tooth flounder and eastern blue spot flathead). We have only presented data on numbers of individuals for these by-caught species but also have estimates of their weights.

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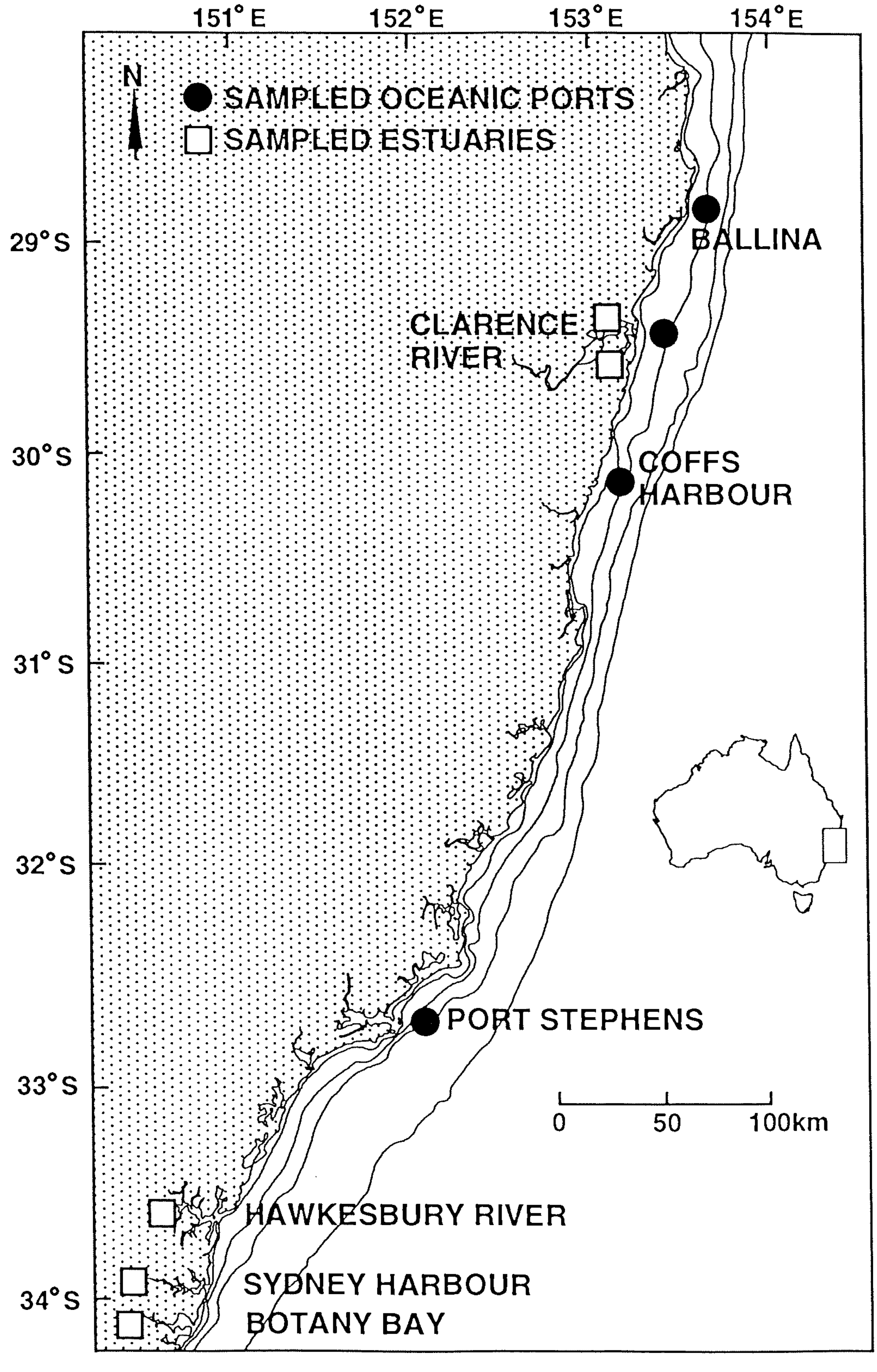

151° E
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SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE
RIVER
COFFS
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PORT STEPHENS
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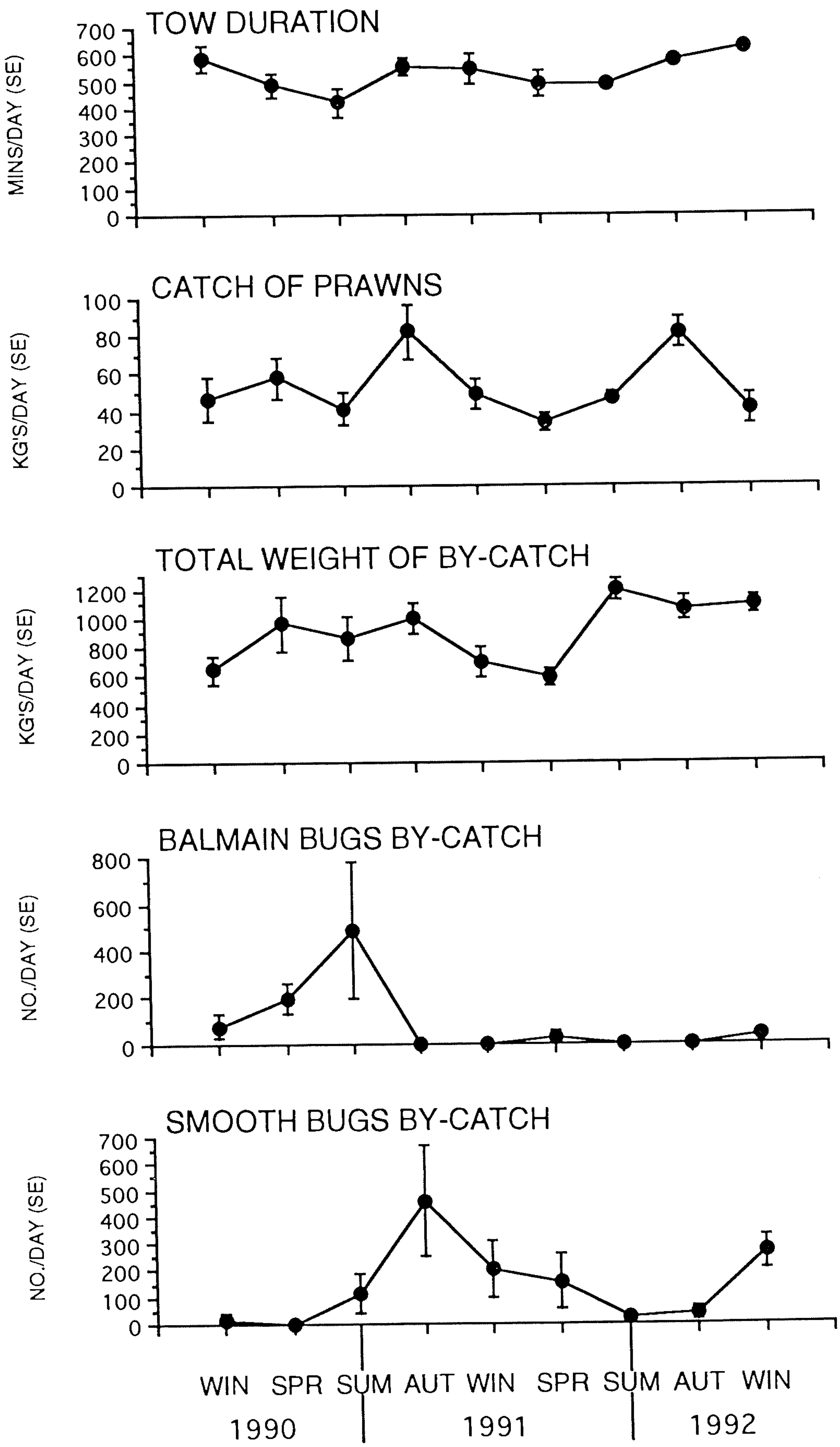
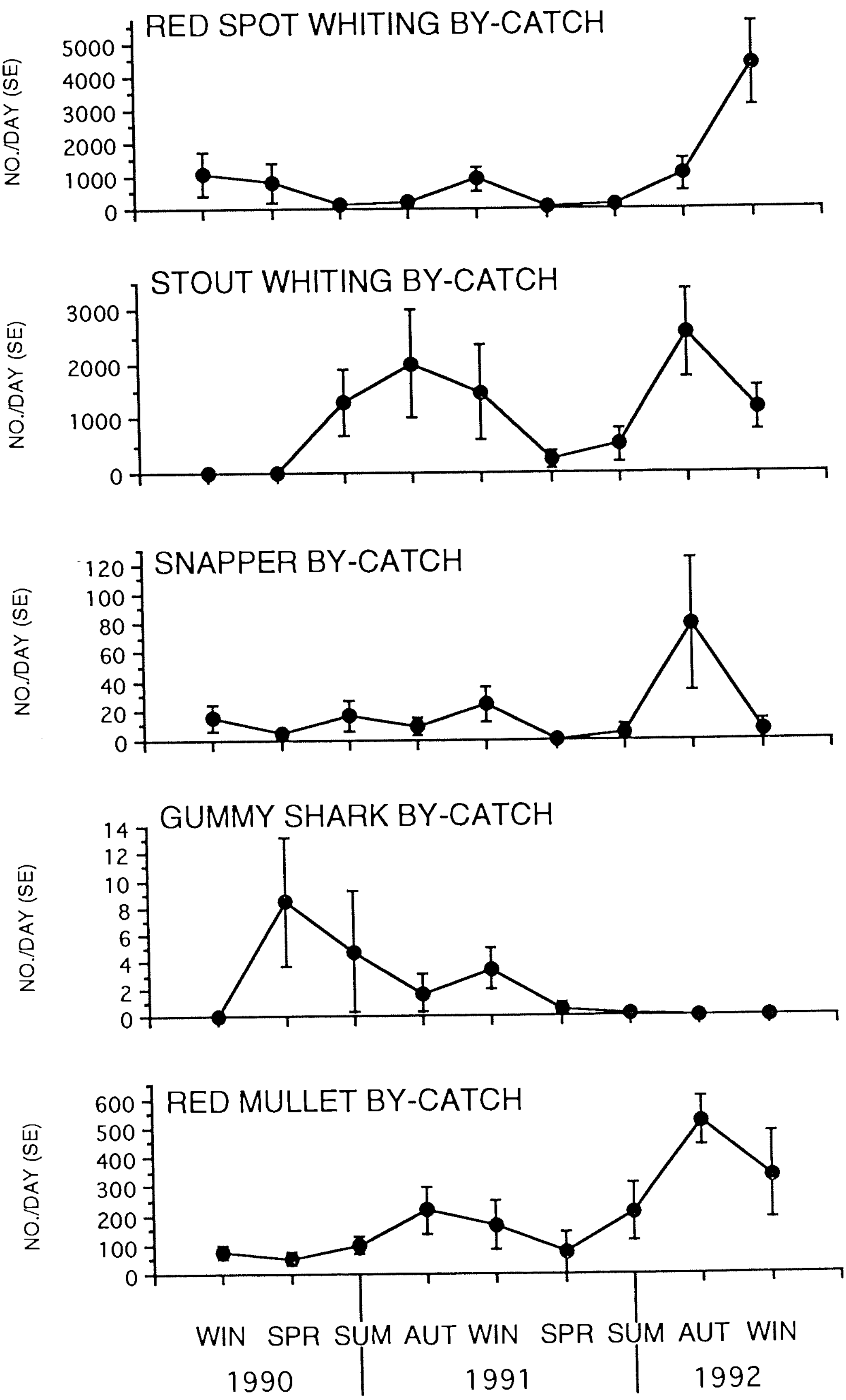
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY

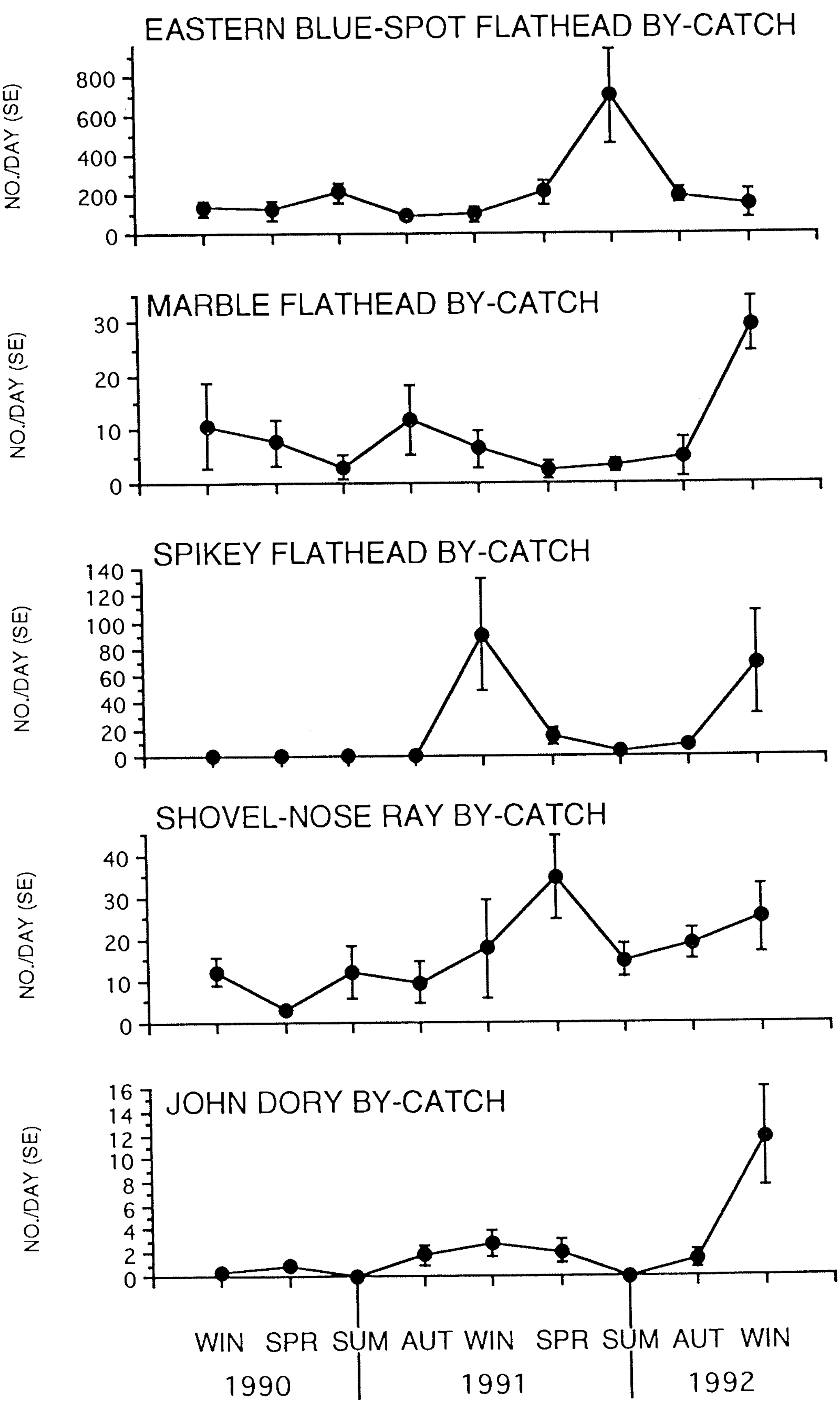
BALLINA PRAWN TRAWL FLEET



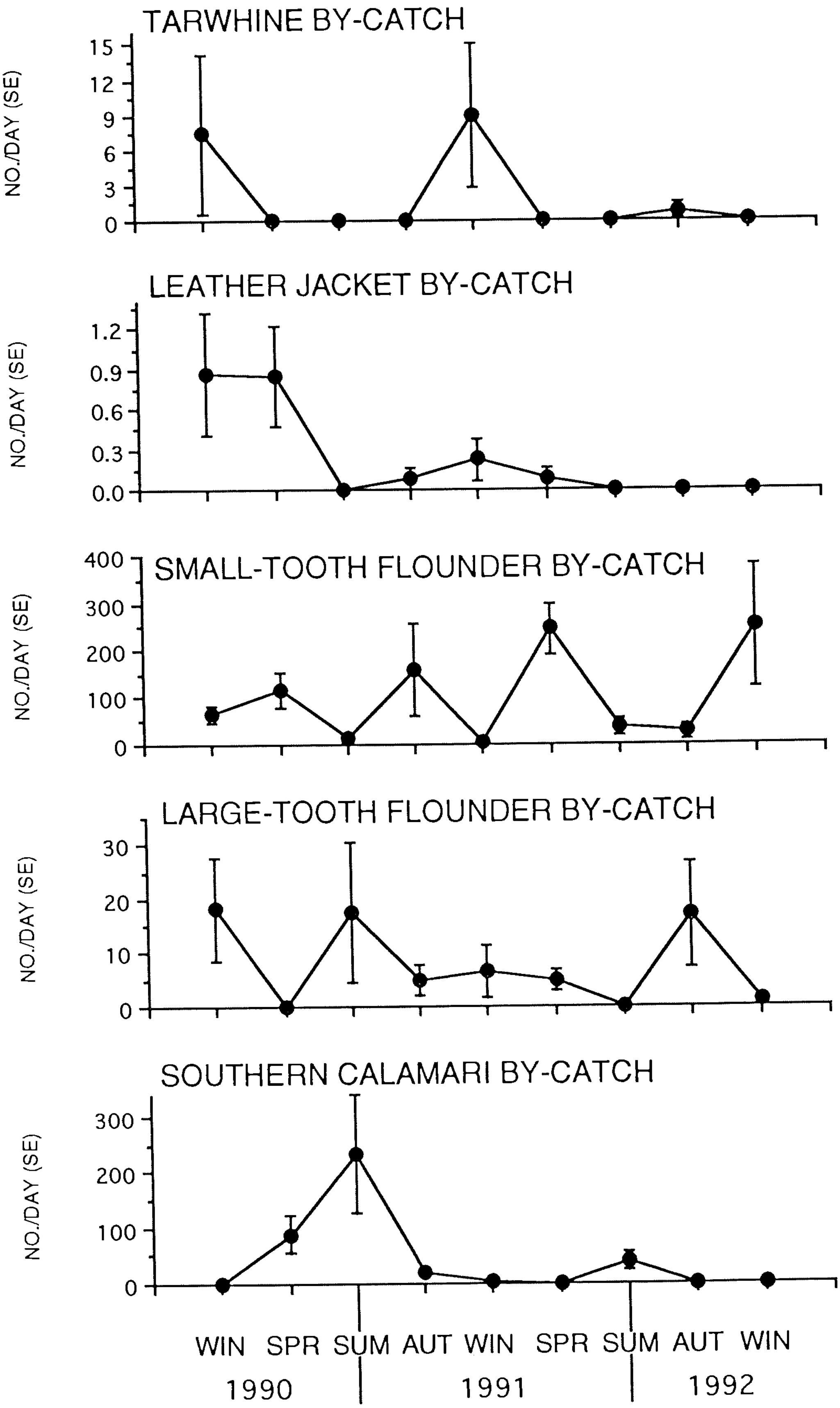
BALLINA PRAWN TRAWL FLEET



BALLINA PRAWN TRAWL FLEET



BALLINA PRAWN TRAWL FLEET



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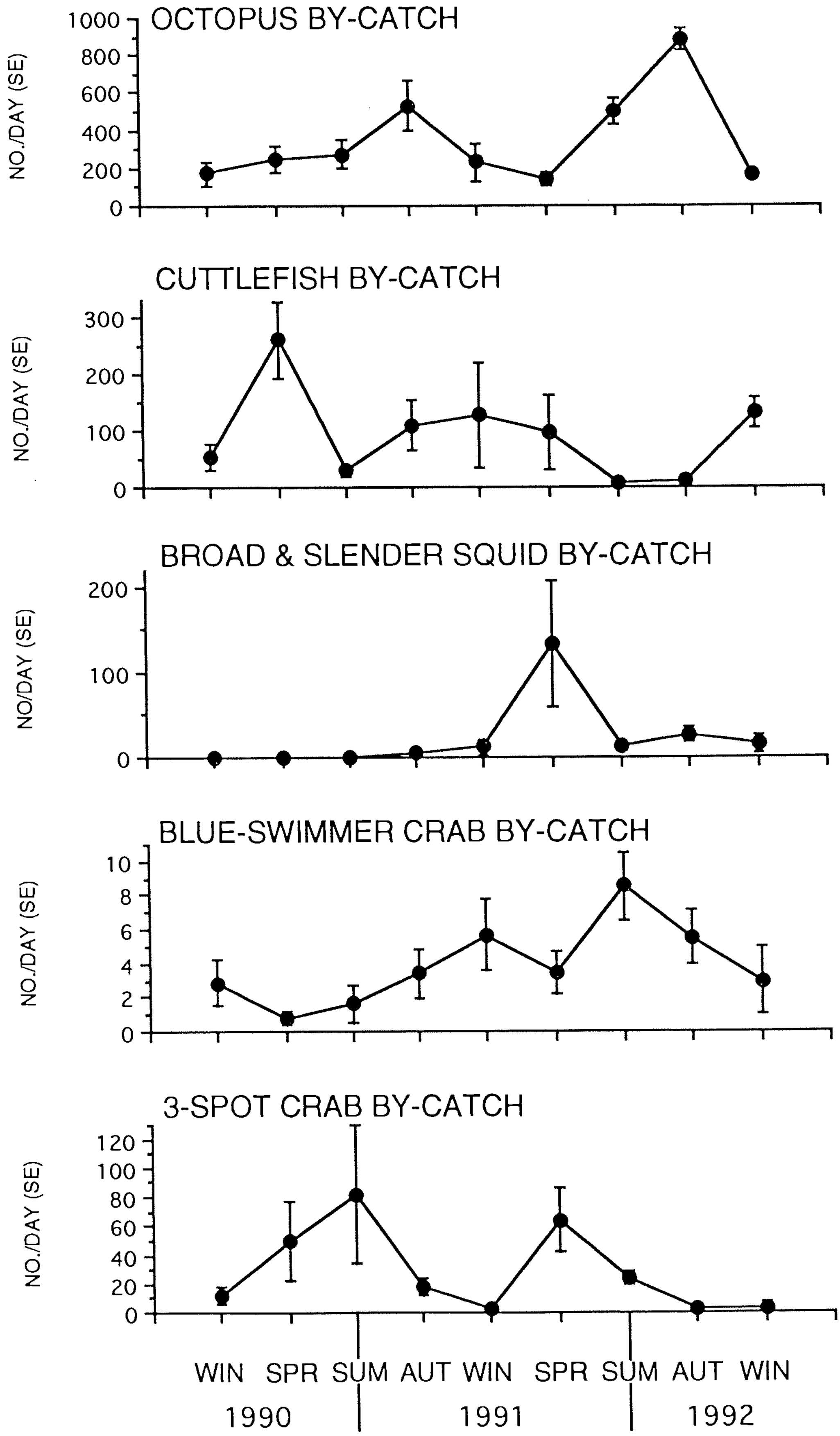

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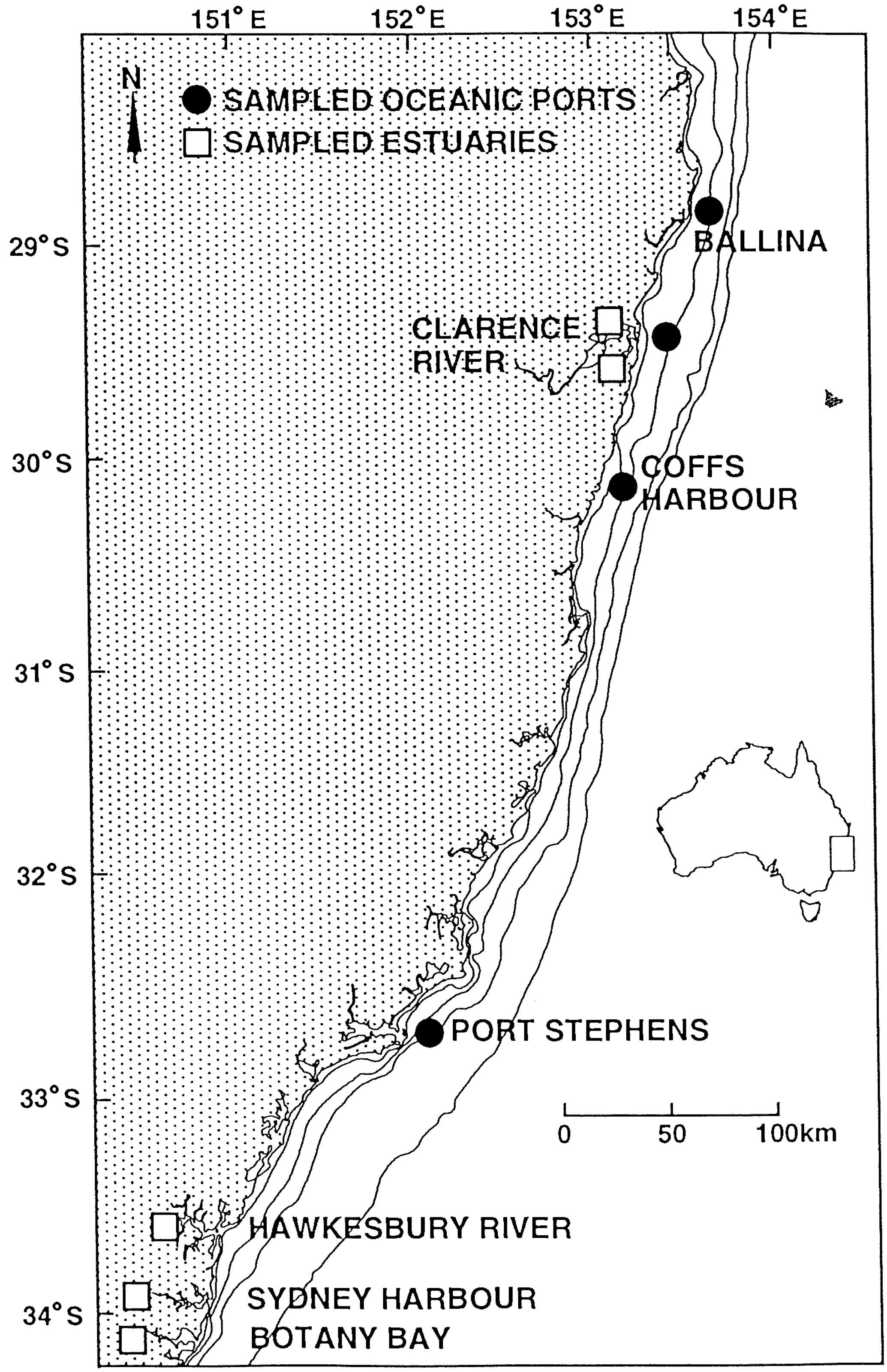
151° E
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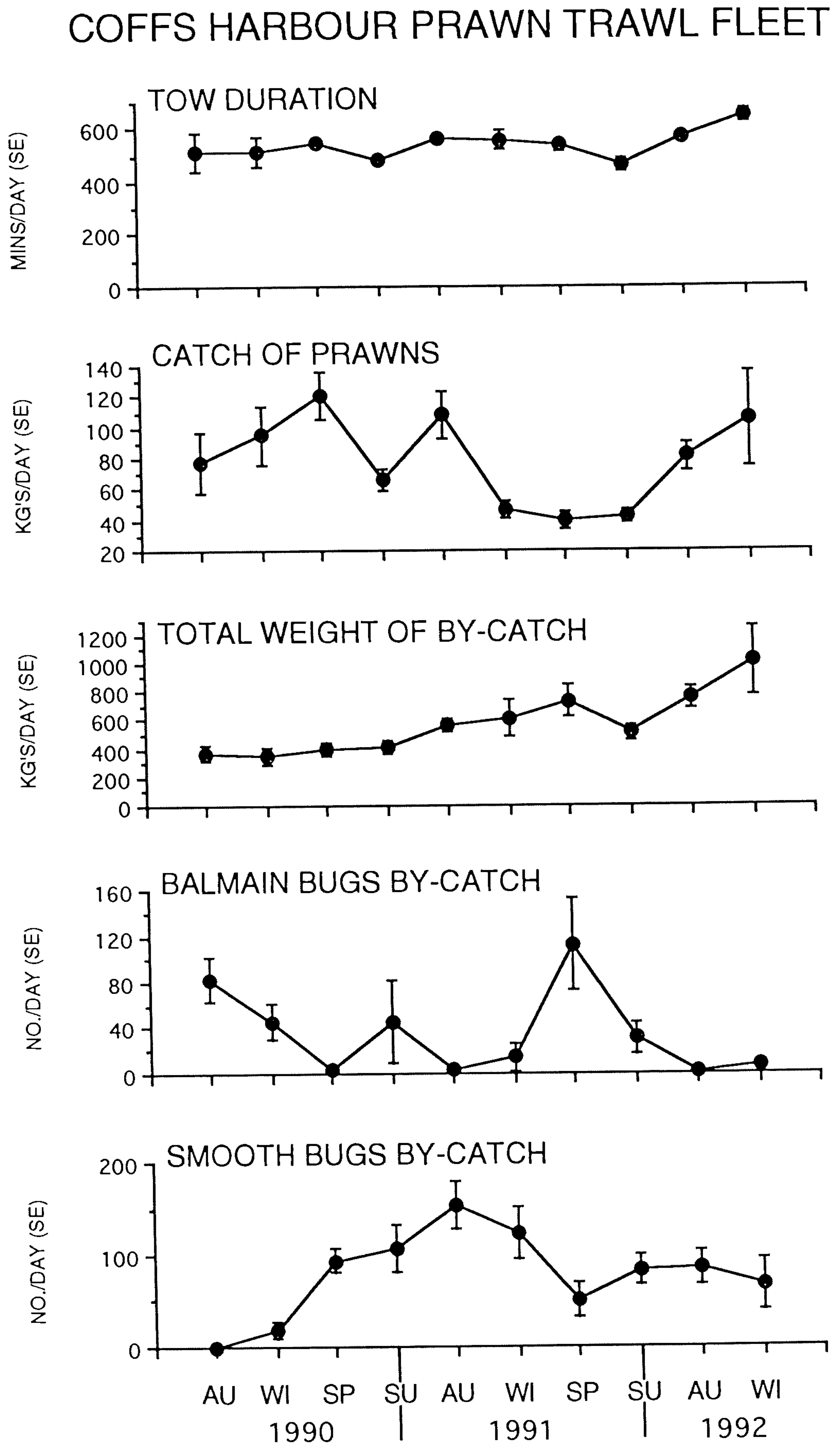
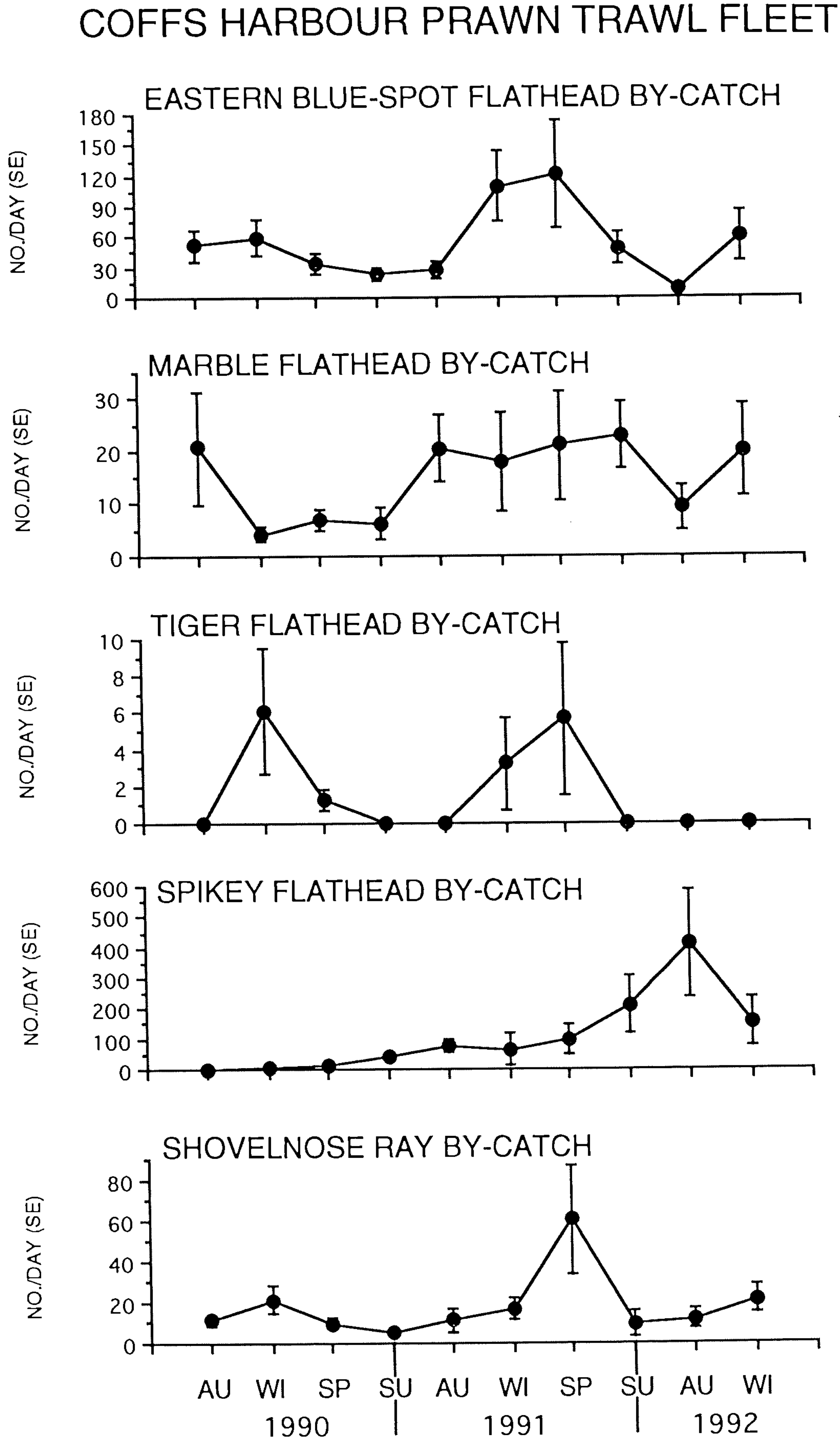
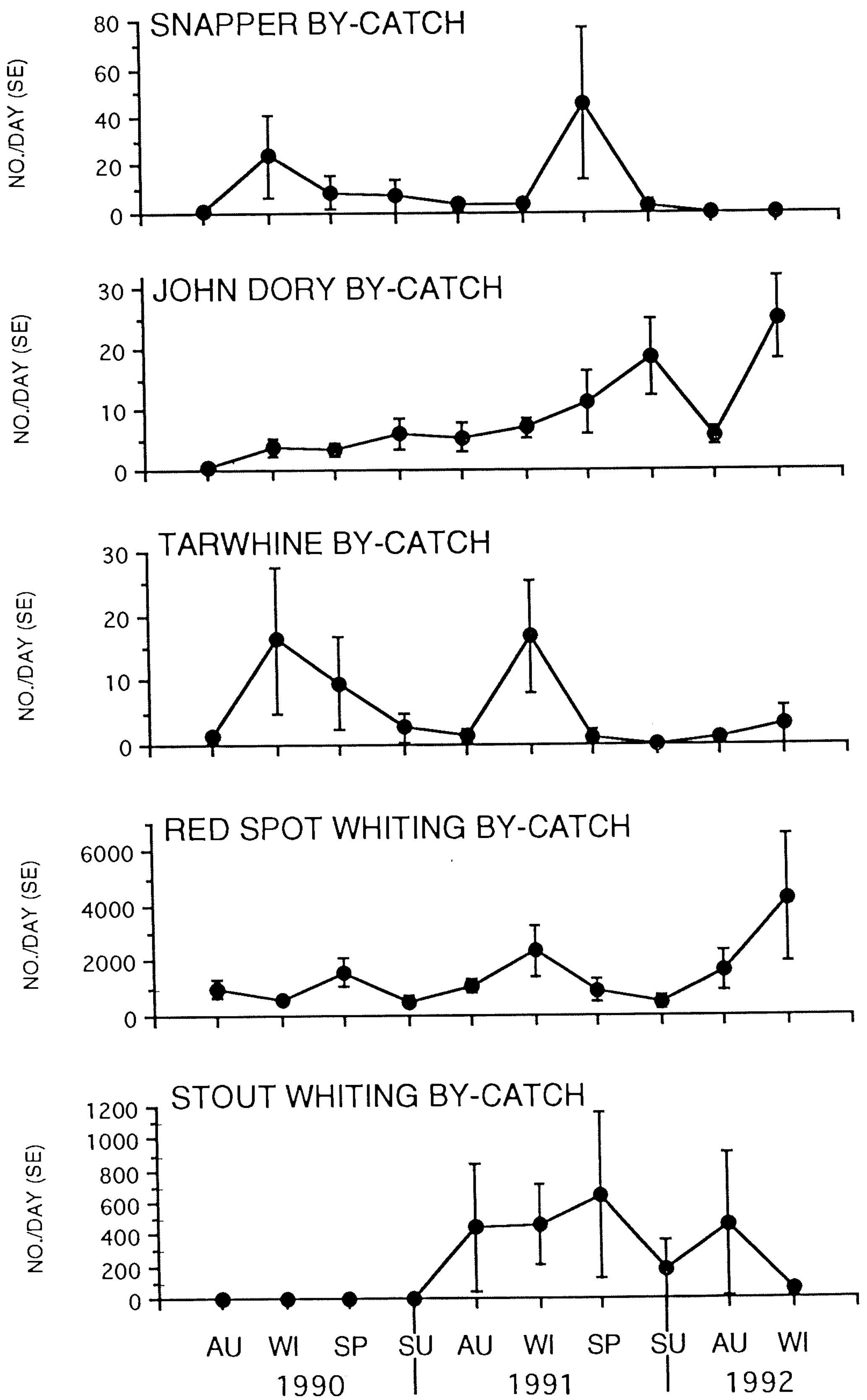
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE RIVER
COFFS HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY



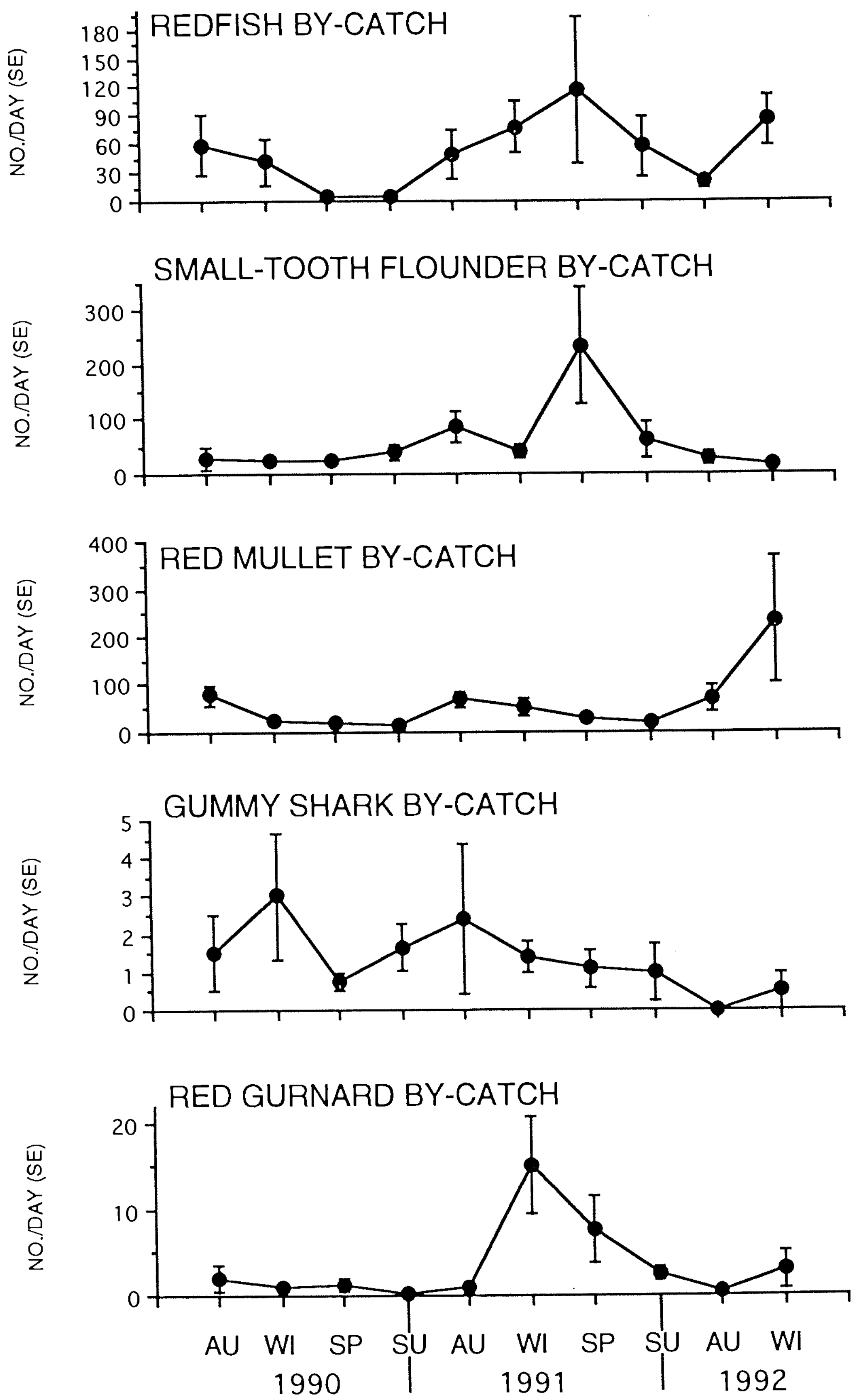
COFFS HARBOUR PRAWN TRAWL FLEET
TOW DURATION
MINS/DAY (SE)
0
200
400
600
CATCH OF PRAWNS
KG'S/DAY (SE)
20
40
60
80
100
120
140
TOTAL WEIGHT OF BY-CATCH
KG'S/DAY (SE)
0
200
400
600
800
1000
1200
BALMAIN BUGS BY-CATCH
NO./DAY (SE)
0
40
80
120
160
SMOOTH BUGS BY-CATCH
NO./DAY (SE)
0
100
200
AU WI SP SU AU WI SP SU AU WI
1990
1991
1992

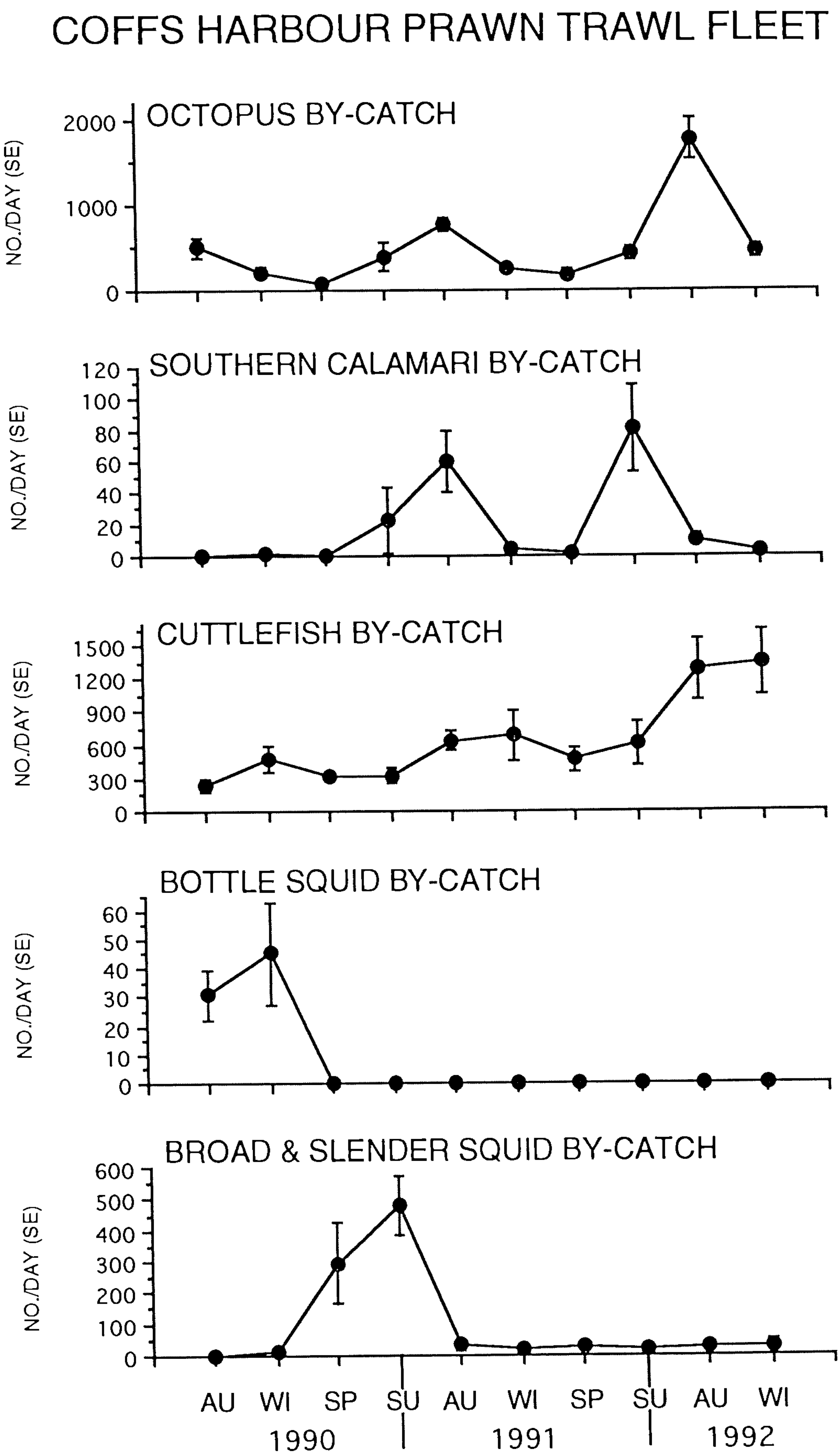

COFFS HARBOUR PRAWN TRAWL FLEET
EASTERN BLUE-SPOT FLATHEAD BY-CATCH
NO./DAY (SE)
180
150
120
90
60
30
0
MARBLE FLATHEAD BY-CATCH
NO./DAY (SE)
30
20
10
0
TIGER FLATHEAD BY-CATCH
NO./DAY (SE)
10
8
6
4
2
0
SPIKEY FLATHEAD BY-CATCH
NO./DAY (SE)
600
500
400
300
200
100
0
SHOVELNOSE RAY BY-CATCH
NO./DAY (SE)
80
60
40
20
0
AU WI SP SU AU WI SP SU AU WI
1990
1991
1992

COFFS HARBOUR PRAWN TRAWL FLEET

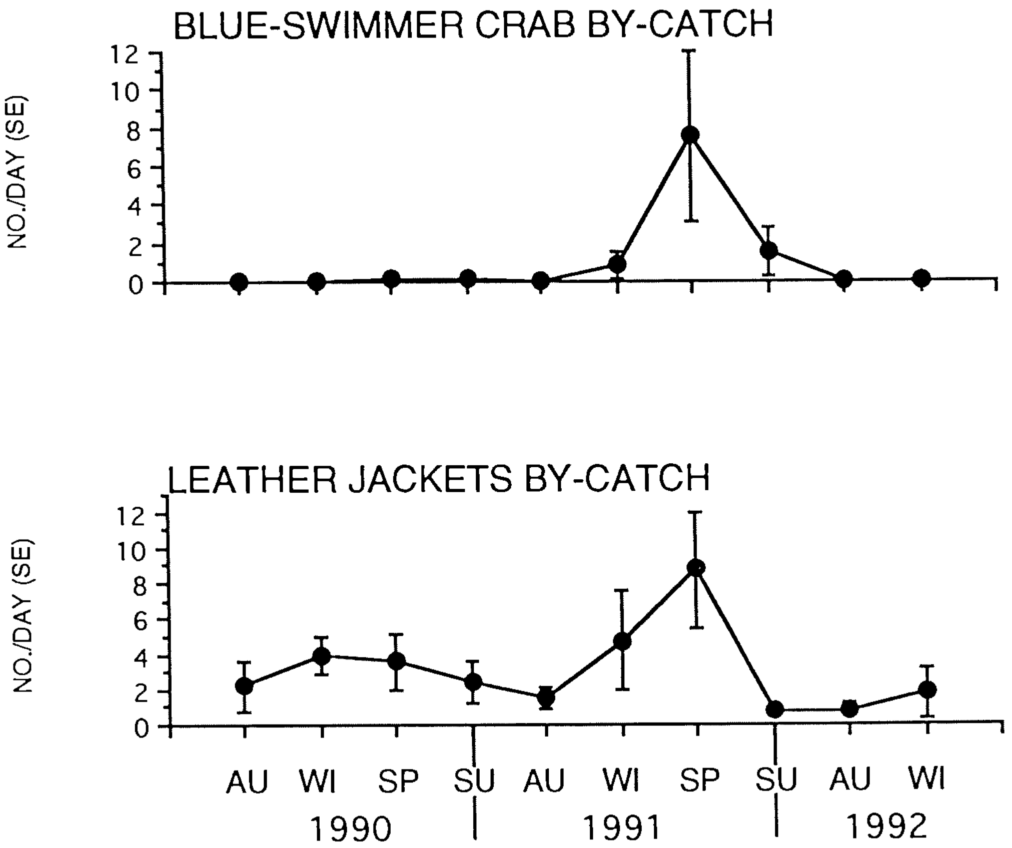


COFFS HARBOUR PRAWN TRAWL FLEET




COFFS HARBOUR PRAWN TRAWL FLEET
OCTOPUS BY-CATCH
NO./DAY (SE)
2000
1000
0
SOUTHERN CALAMARI BY-CATCH
120
100
80
60
40
20
0
CUTTLEFISH BY-CATCH
1500
1200
900
600
300
BOTTLE SQUID BY-CATCH
60
50
40
30
20
10
BROAD & SLENDER SQUID BY-CATCH
600
500
400
300
200
100
AU WI SP SU AU WI SP SU AU WI
1990
1991
1992

COFFS HARBOUR PRAWN TRAWL FLEET



NSW FISHERIES

Mr

Fisheries Research Institute
P.O. Box 21, Cronulla, 2230

Dear

You might remember that between late 1989 and mid 1992, scientists from the Fisheries Research Institute approached you asking permission for them to come on your trawler so they could record data on the catches of prawns and other species during a typical day or night's fishing. As explained to you at the time, the work those scientists were doing was part of our project (funded by the Fisheries Research and Development Corporation) which studied the catches of the estuarine prawn trawlers operating in Botany Bay, Port Jackson, the Hawkesbury and Clarence Rivers and Lake Woolooweyah and the oceanic prawn trawlers operating from Port Stephens, Coffs Harbour, Yamba/Iluka and Ballina. The aim of this work was to collect information on catch composition, abundances of species from individual shots, locations, depths, shot duration, etc. in order to complete the first logical step in the eventual provision of management recommendations for these fisheries.

We would like to take this opportunity to thank you most sincerely for the excellent co-operation that you and other fishermen gave us when we were doing this research. Quite simply, without your help over the past 3 years, we could not have done this work nor be in a position to present the data that is contained in this summary. At the International Conference on By-catch in the Shrimp Industry held in Florida last year the following point was made many times by fishermen, scientists and managers from all around the world: that our project enjoyed a level of industry-participation and good-will that is the equal of any such project in the world. We believe that this conclusion from this very high-level conference speaks volumes for the attitude and courtesy of NSW's prawn trawlermen.

The attached map shows the north coast of NSW, covering the range of the prawn-trawl fisheries in the state, and shows the places that we sampled during the project. As you know, these fisheries mainly target two species, the eastern king prawn at night and the school prawn during the day. Estuarine prawn trawling occurs in 5 estuaries during summer and all are closed during the winter, with the exception of the Hawkesbury River which is open to trawling all year. Oceanic prawn trawling mainly occurs out of 11 ports along the coast throughout the year.

During our project we promised to provide you, and all fishermen who helped us, a summary of the information we obtained during this research. As we mentioned at the time, we will only present data that are averages across all boats we sampled, not wishing to identify individuals. The attached information is the summary of data for your particular fishing area. All fishermen who permitted us on their vessels during the project have also received a summary for their particular fishing area. We have not sent summaries about fisheries to fishermen who were not in that area but we have given a copy of all the summaries for all fisheries to CFAC.

In each month that prawn trawling occurred between late 1989 and June 1992, we tried to have scientists on 4 randomly-selected trawler-trips from each fishery. During each trip from Port Stephens, the catch from each tow was sorted by the crew and our scientist, separating the prawns from the by-product. The weights of prawns and total by-catch (estimated from a sample) from each tow were recorded. All commercial species (landed by-product including octopus, squid, crabs, etc) were counted and weighed. A sample of the discarded trash was examined and all the commercially and recreationally important species (such as juvenile snapper, juvenile flathead, etc) were counted, weighed and measured. For each tow, we also recorded the time, depth, duration and location of the tow, as well as the basic gear configuration used.

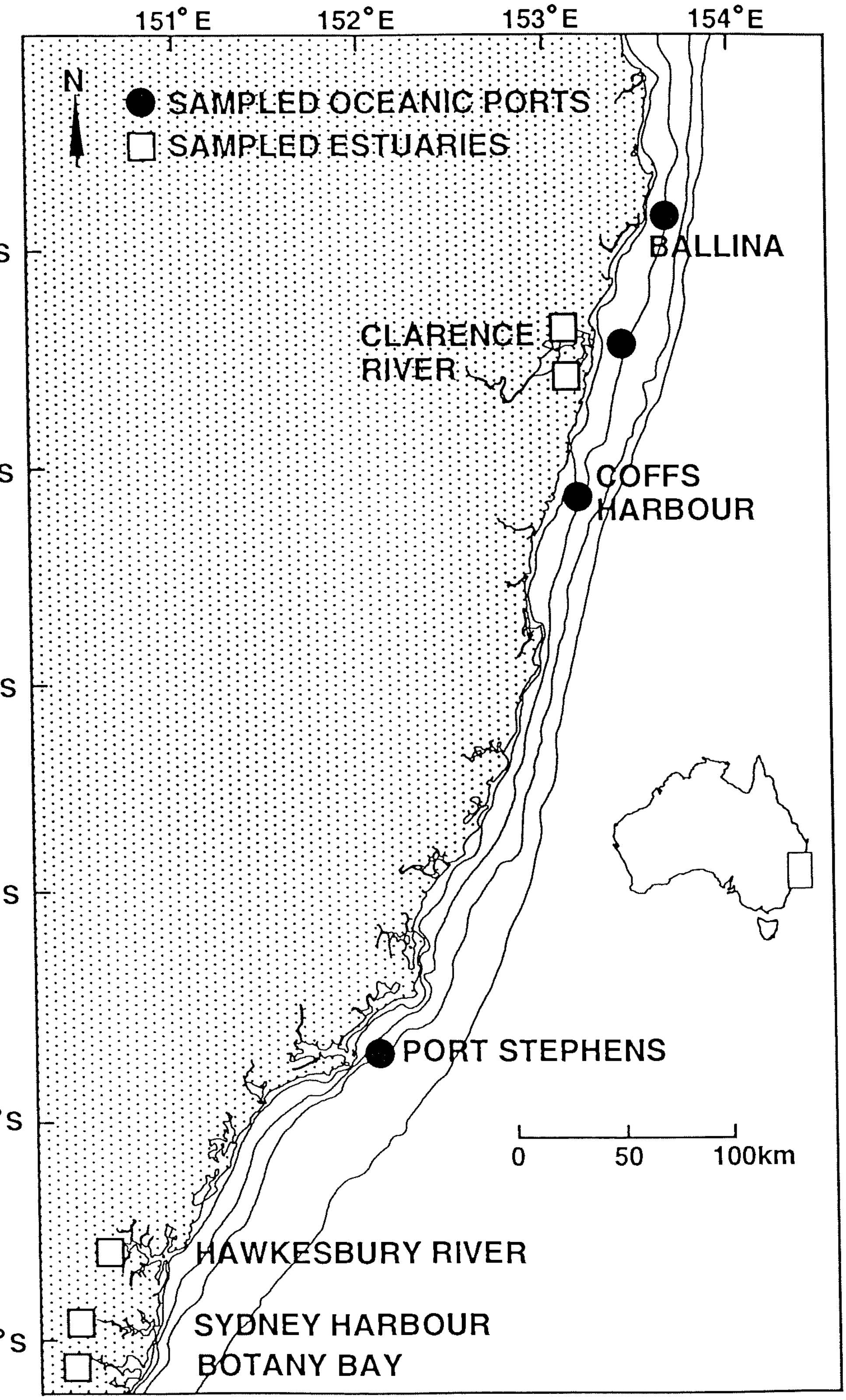
The catch of prawns and other species that may be of interest are shown in the attached figures. The graphs are pretty straightforward, showing the average tow times and catches per trip that occurred during each season of sampling. The vertical bars attached to each point (shown as SE in the graphs) is an estimate of the accuracy of that average - i.e. it shows you the slop around the average and the confidence that can be placed on that average.

The graphs show that the average time spent trawling by vessels from Port Stephens was around 400-600 minutes per trip. The catch rates of king prawns during the project averaged between 40 and 90 kilos per trip, with highest catches occurring in the autumn and winter of 1990 and 1991. The catch rates of racek prawns varied between 0 and 30 kilos per trip, with the highest catches occurring in summer. The information on by-catches of different species represents total numbers (i.e retained and discarded commercial individuals) and shows that red spot whiting, tiger flathead, redfish, ocean perch, squid and cuttlefish were caught in quite large quantities. We have only presented data on numbers of individuals for these by-caught species but also have estimates of their weights.

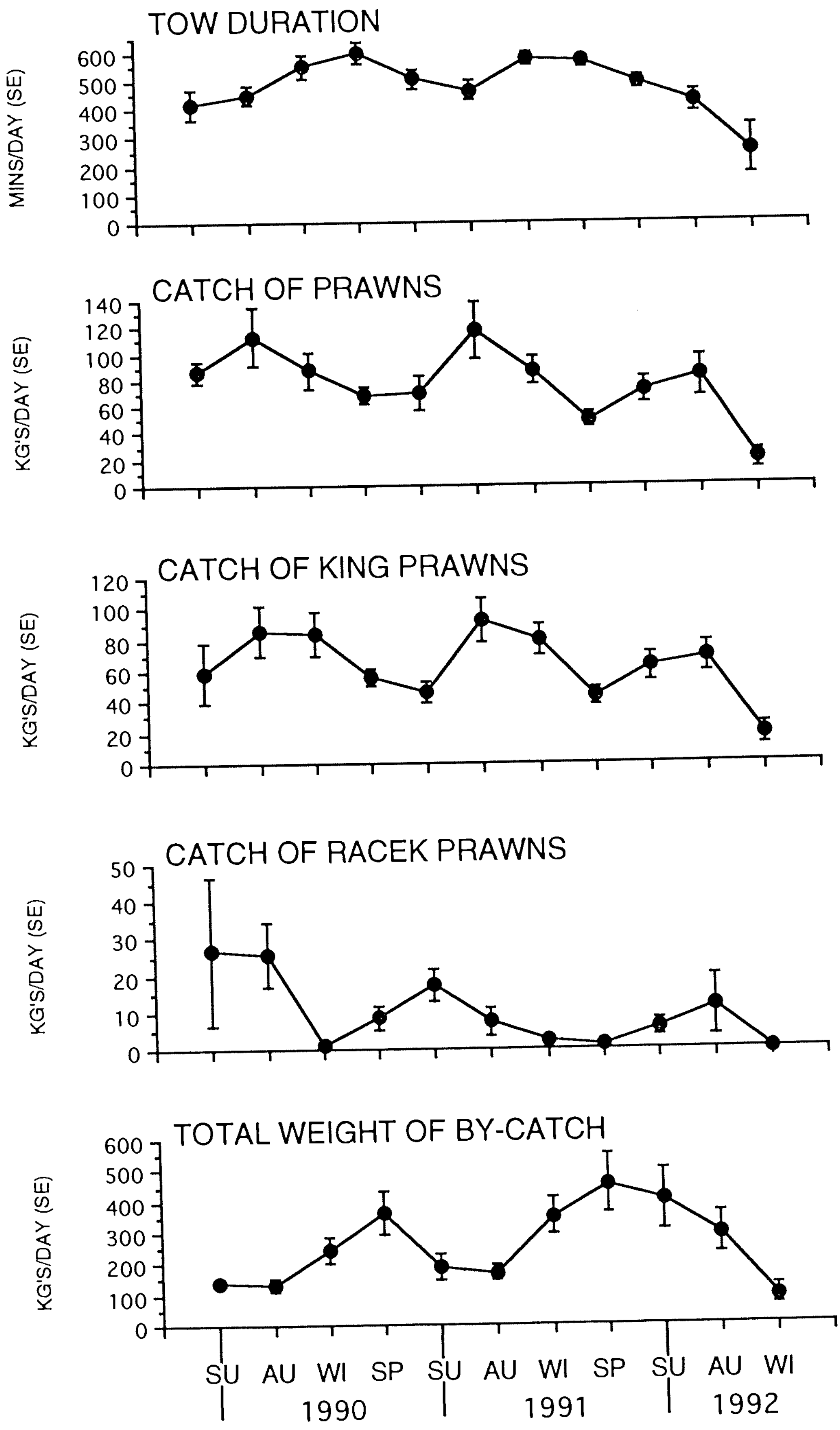
Thank you for your help over the past few years. To show our gratitude, we have enclosed a T-shirt as a small token of our appreciation. We look forward to working with you again in the future.

Yours sincerely,

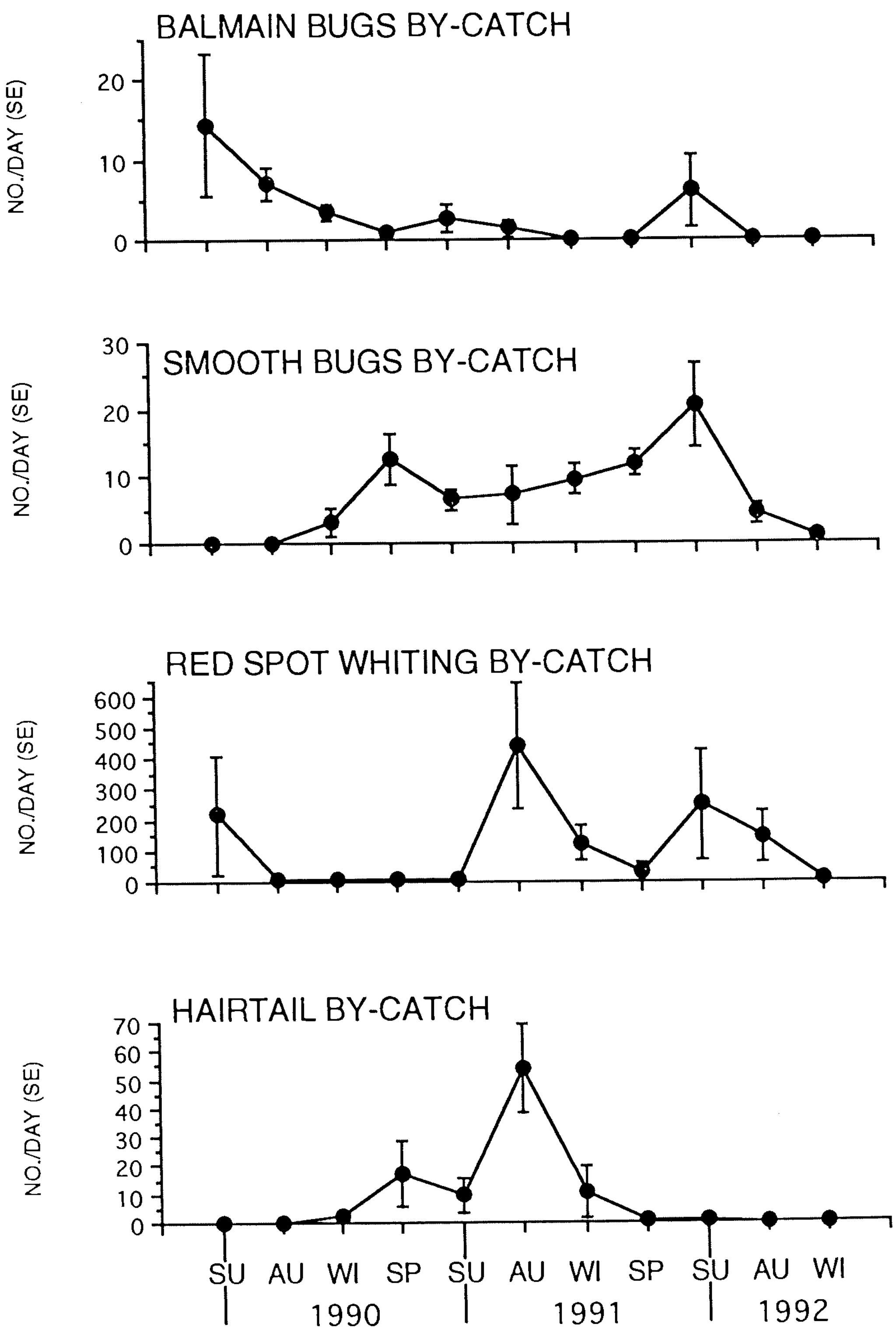
Steven J. Kennelly
(on behalf of Geoff Liggins, Matt Broadhurst, Geoff Nemec, Keith Chilcott and Mark Bradley)


151° E
152° E
153° E
154° E
N
SAMPLED OCEANIC PORTS
SAMPLED ESTUARIES
29° S
30° S
31° S
32° S
33° S
34° S
BALLINA
CLARENCE RIVER
COFFS HARBOUR
PORT STEPHENS
0
50
100km
HAWKESBURY RIVER
SYDNEY HARBOUR
BOTANY BAY

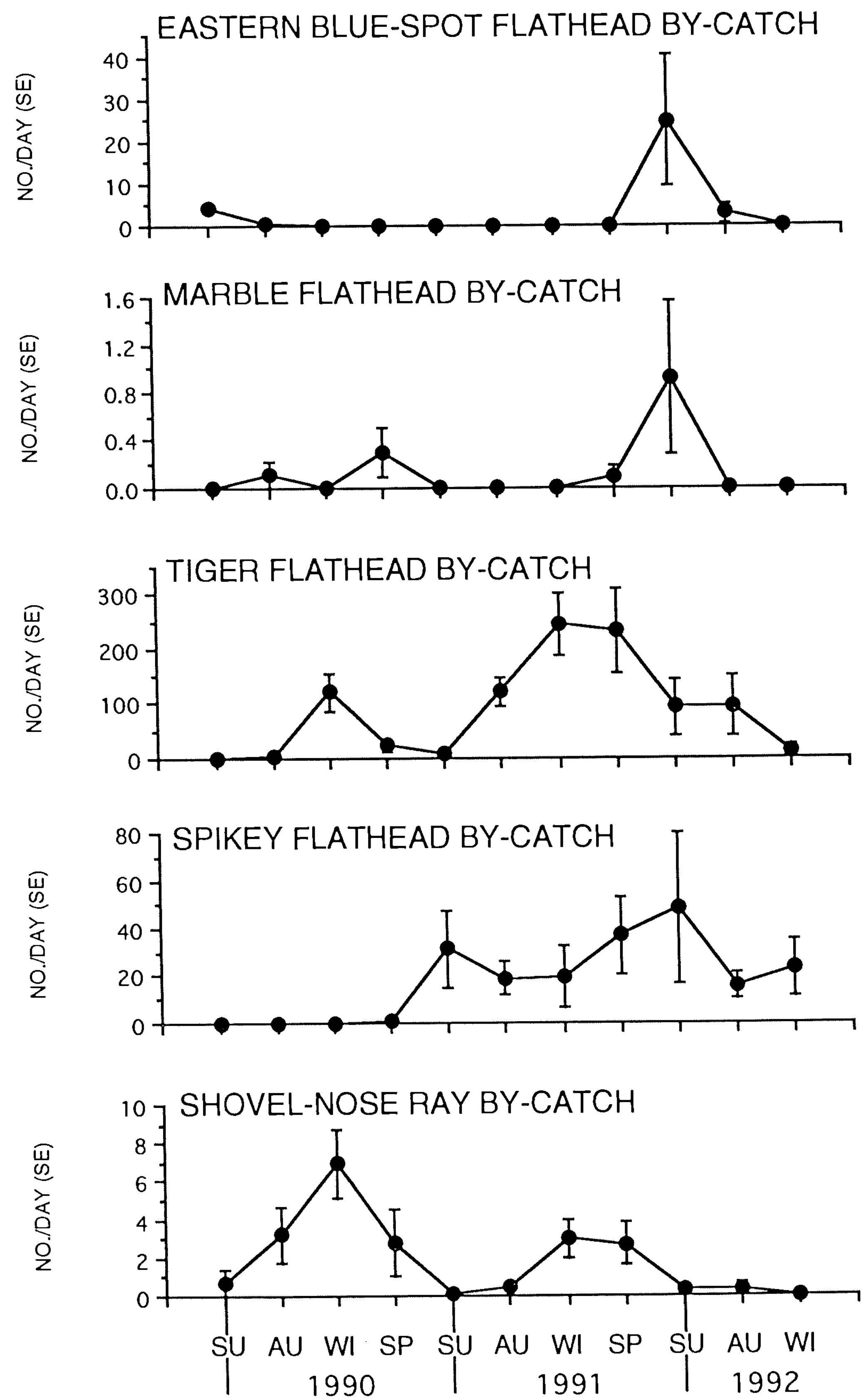
PORT STEPHENS PRAWN TRAWL FLEET



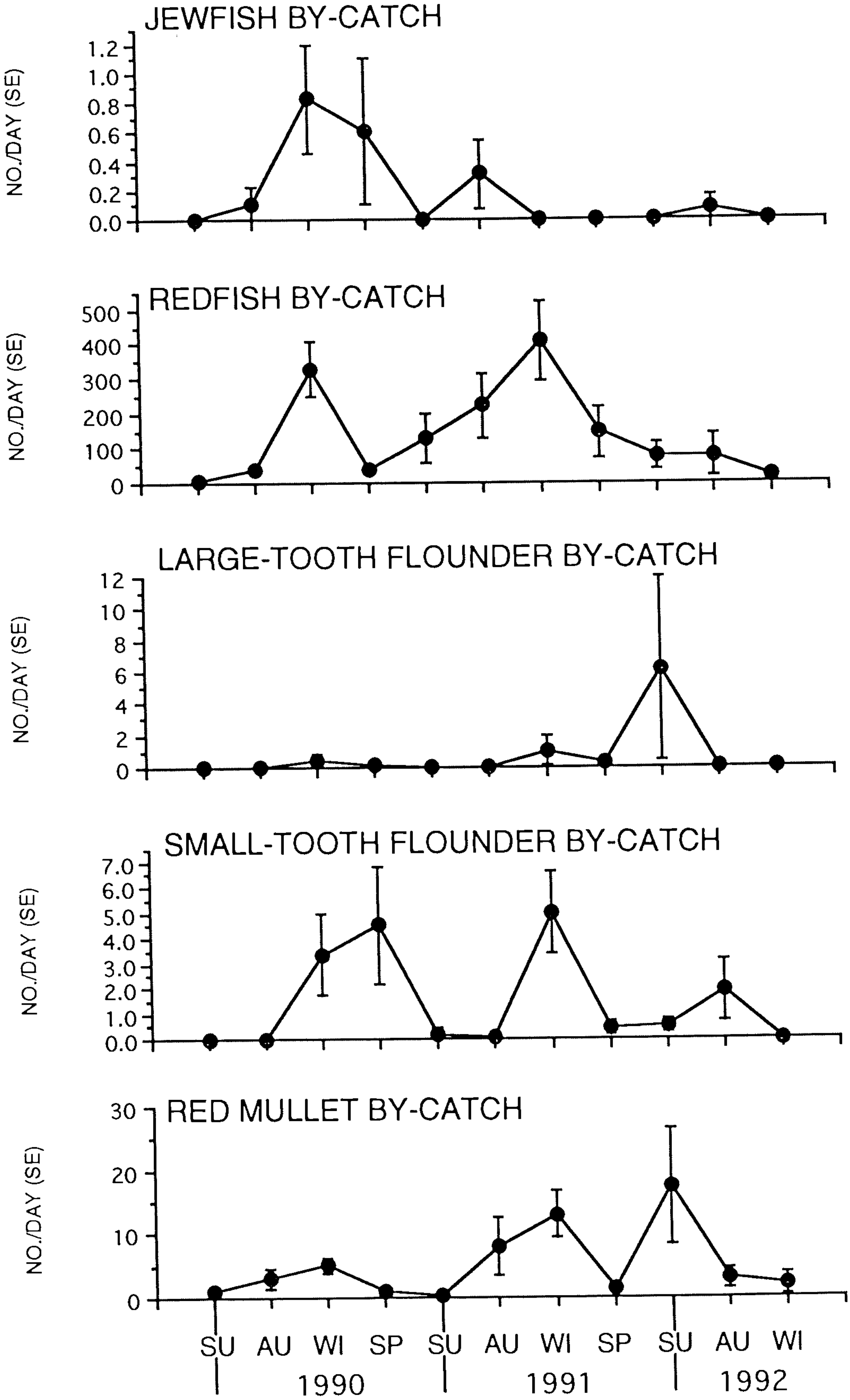
PORT STEPHENS PRAWN TRAWL FLEET



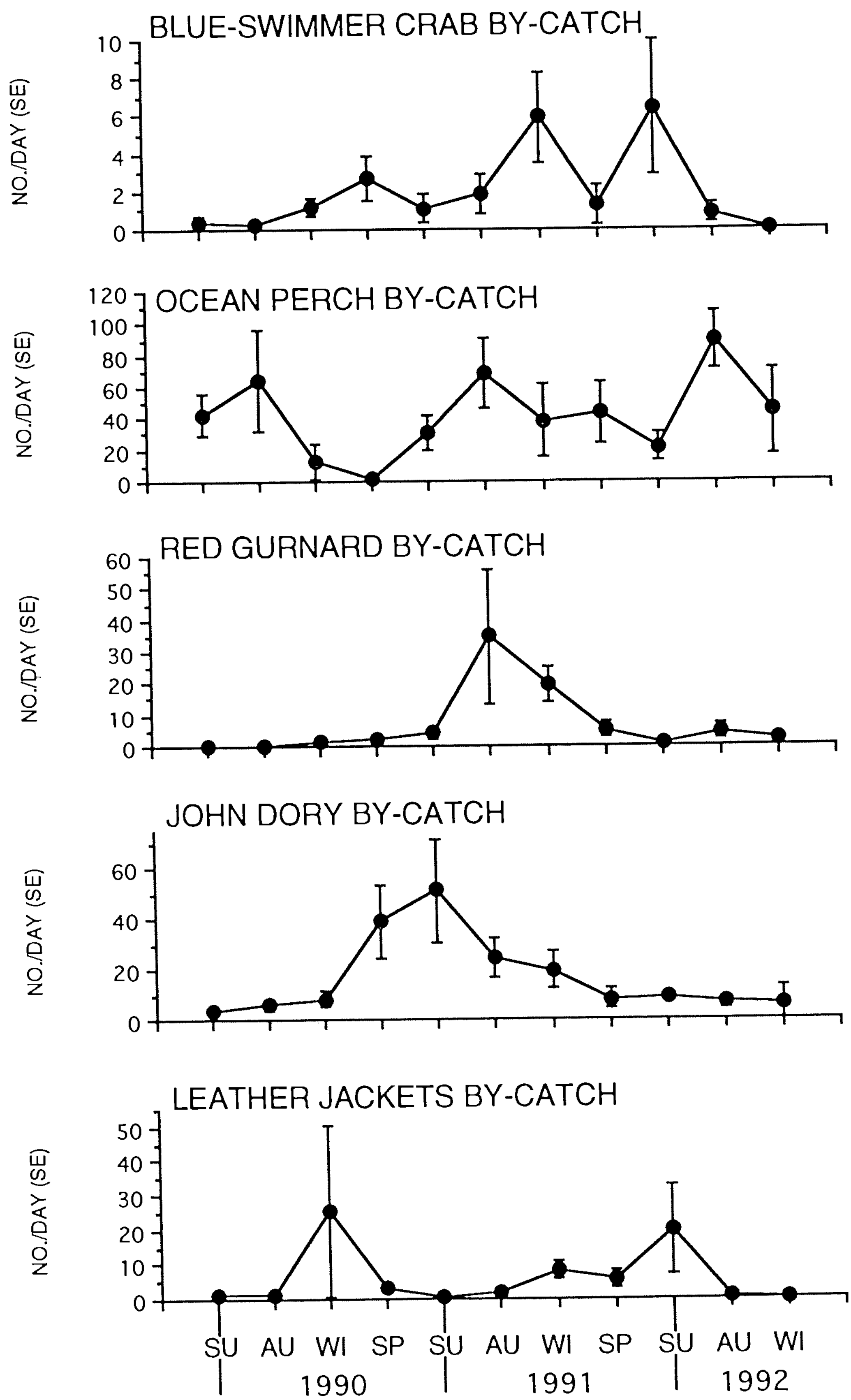
PORT STEPHENS PRAWN TRAWL FLEET



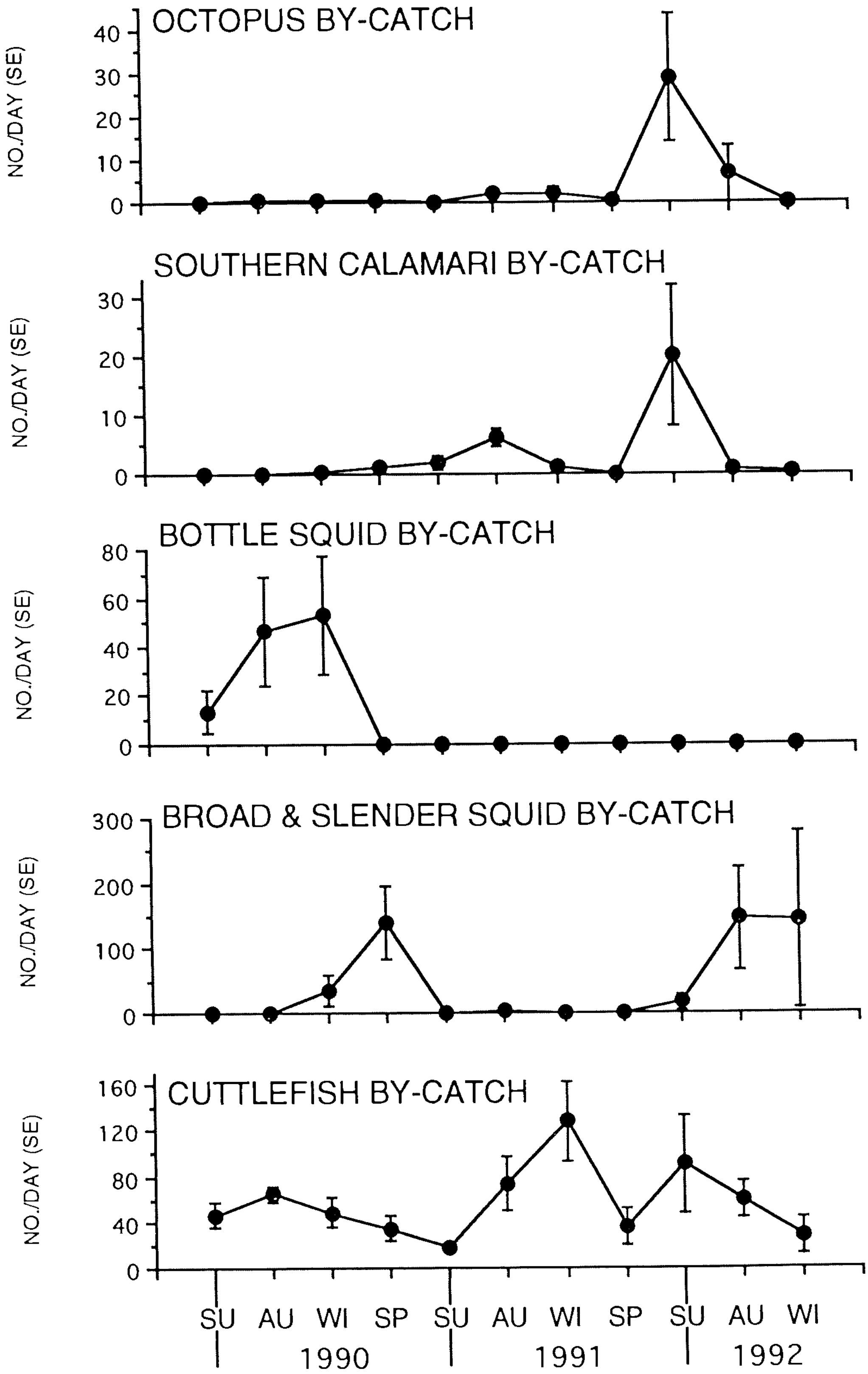
PORT STEPHENS PRAWN TRAWL FLEET



PORT STEPHENS PRAWN TRAWL FLEET



PORT STEPHENS PRAWN TRAWL FLEET



APPENDIX N

Lists of species recorded in all fisheries sampled.

List of by-catch taxa in the Clarence River

Family	Scientific name	Common name	Commercial ?
Finfishes:			
AMBASSIDAE	Ambassis jacksoniensis	Port jackson perchlet	
AMBASSIDAE	Ambassis marianus	Ramseys perchlet	
ANGUILLIDAE	Anguilla australis	Short finned eel	
ANGUILLIDAE	Anguilla reinhardtii	Long finned eel	
APOGONIDAE	Siphamia roseigaster	Pink breasted siphonfish	
ARIIDAE	Arius graeffei	Fork tailed catfish	
BOTHIDAE	Pseudorhombus arsius	Large toothed flounder	x
BOTHIDAE	Pseudorhombus jenynsii	Small toothed flounder	x
CALLIONYMIDAE	(unid. stinkfish)	Stinkfish	
CARANGIDAE	Gnathanodon speciosus	Golden trevally	x
CARCHARHINIDAE	Carcharhinus spp.	Whaler shark	x
CLUPEIDAE	(unid. herring)	Unid. herring	
CLUPEIDAE	Herklotsichthys castelnaui	Southern herring	
CLUPEIDAE	Hyperlophus vittatus	Sandy sprat	
CLUPEIDAE	Potamalosa richmondia	Freshwater herring	
DASYATIDIDAE / UROLOPHIDAE	Stingray/stingaree	Stingray/stingaree	
DIDONTIDAE	Dicotylichthys punctulatus	Porcupine fish	
DINOLESTIDAE	Dinolestes lewini	Long-finned pike	
ELEOTRIDAE	(unid. gudgeon)	Unid. gudgeon	
ELEOTRIDAE	Gobiomorphus australis	Striped gudgeon	
ELEOTRIDAE	Hypseleotris compressus	Empire gudgeon	
ELEOTRIDAE	Philypnodon grandiceps	Large-headed gudgeon	
ENGRAULIDIDAE	Engraulis australis	Australian anchovy	
EPHIPPIDAE	Platax tiera	Round faced batfish	
EXOCOETIDAE	Arrhamphus sclerolepis	Snub-nosed garfish	
GERREIDAE	Gerres subfasciatus	Common silver biddy	
GIRELLIDAE	Girella tricuspidata	Blackfish	x
GOBIIDAE	(unid. goby)	Unid. goby	
GOBIIDAE	Arenigobius bifrenatus	Bridled goby	
GOBIIDAE	Arenigobius frenatus	Half bridled goby	
GOBIIDAE	Brachyambloypus coecus	Blind goby	
GOBIIDAE	Favonigobius tamarensis	Tamar river goby	
GOBIIDAE	Redigobius macrostoma	Large mouth goby	
GOBIIDAE	Valenciennea longipinnis	Striped goby	
HEMIRAMPHIDAE	Hyporhamphus australis	Eastern sea garfish	x
HEMIRAMPHIDAE	Hyporhamphus regularis	River garfish	
MONACANTHIDAE	Meuschenia australis	Brown striped leatherjacket	
MONODACTYLIDAE	Monodactylus argenteus	Diamond fish	
MUGILIDAE	Liza argentea	Flat-tail mullet	x
MUGILIDAE	Mugil cephalus	Sea mullet	x
MUGILIDAE	Myxus elongatus	Sand mullet	
MURAENESOCIDAE	Muraenesox bagio	Common pike eel	
PERCICHTHYIDAE	Macquaria novemaculeata	Australian bass	x
PLATYCEPHALIDAE	Platycephalus arenarius	Northern sand flathead	x
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead	x
PLOTOSIDAE	Euristhmus lepturus	Long-tailed catfish	
PLOTOSIDAE	Plotosis lineatus	Striped catfish	

POMACENTRIDAE	(unid. damsel)	Damsel fish	
POMATOMIDAE	Pomatomus saltatrix	Tailor	x
PRIACANTHIDAE	Priacanthus macracanthus	Red bigeye	
SCATOPHAGIDAE	Selenotoca multifasciata	Old maid	
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish	x
SCORPAENIDAE	Notesthes robusta	Bullrout	
SCORPAENIDAE	Pterois volitans	Red firefish	
SILLAGINIDAE	Sillago ciliata	Sand whiting	x
SILLAGINIDAE	Sillago maculata	Trumpeter whiting	x
SOLEIDAE	Synclidopus macleayanus	Narrow banded sole	
SOLEIDAE	Synaptura nigra	Black sole	
SPARIDAE	Acanthopagrus australis	Bream	x
SPARIDAE	Rhabdosargus sarba	Tarwhine	x
TERAPONTIDAE	Pelates sexlineatus	Trumpeter	
TETRAODONTIDAE	(assorted toadfish/pufferfish)	Toadfish/pufferfish	
TRICHIURIDAE	Trichiurus lepturus	Hairtail	x
URANOSCOPIDAE	Ichthyscopus lebeck	Spotted stargazer	

Crustaceans:

GRAPSIDAE	Scylla serrata	Mud crab	x
PALAEMONIDAE	Macrobrachium sp.	Long armed prawn	
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab	x

List of by-catch taxa from Lake Woolooweyah

Family	Scientific name	Common name	Commercial ?
Finfishes			
AMBASSIDAE	Ambassis jacksoniensis	Port jackson perchlet	
AMBASSIDAE	Ambassis marianus	Ramseys perchlet	
ANGUILLIDAE	Anguilla australis	Short finned eel	
APOGONIDAE	Siphamia roseigaster	Pink breasted siphonfish	
ARIIDAE	Arius graeffei	Fork tailed catfish	
BOTHIDAE	Pseudorhombus arsius	Large toothed flounder	x
BOTHIDAE	Pseudorhombus jenynsii	Small toothed flounder	x
CARANGIDAE	Gnathanodon speciosus	Golden trevally	x
CARANGIDAE	Scomberoides commersonianus	Queenfish	
CARANGIDAE	Trachurus novaezelandiae	Yellowtail	
CLUPEIDAE	Herklotsichthys castelnaui	Southern herring	
CLUPEIDAE	Hyperlophus vittatus	Sandy sprat	
CLUPEIDAE	Potamalosa richmondia	Freshwater herring	
CONGRIDAE	Conger wilsoni	Congor eel	
DASYATIDIDAE / UROLOPHIDAE	Stingray/stingaree	Stingray/stingaree	
DINOLESTIDAE	Dinolestes lewini	Long-finned pike	
ELEOTRIDAE	Hypseleotris compressus	Empire gudgeon	
ELEOTRIDAE	Philypnodon grandiceps	Large-headed gudgeon	
ELOPIDAE	Elops machnata	Giant herring	
ENGRAULIDIDAE	Engraulis australis	Australian anchovy	
EXOCOETIDAE	Arrhamphus sclerolepis	Snub-nosed garfish	
GERREIDAE	Gerres subfasciatus	Common silver biddy	
GIRRELIDAE	Girella tricuspidata	Blackfish	x
GOBIIDAE	Arenigobius bifrenatus	Bridled goby	
GOBIIDAE	Arenigobius frenatus	Half bridled goby	
GOBIIDAE	Brachyambloypus coecus	Blind goby	
GOBIIDAE	Favonigobius tamarensis	Tamar river goby	
GOBIIDAE	Redigobius macrostoma	Large mouth goby	
HAEMULIIDAE	Pomadasys opercularis	Small spotted javelin fish	
HEMIRAMPHIDAE	Hyporhamphus australis	Eastern sea garfish	x
HEMIRAMPHIDAE	Hyporhamphus regularis	River garfish	
LUTJANIDAE	Lutjanus russelli	Moses perch	
MONACANTHIDAE	Eubalichthys mosaicus	Mosaic leatherjacket	x
MONODACTYLIDAE	Monodactylus argenteus	Diamond fish	
MUGILIDAE	Liza argentea	Flat-tail mullet	x
MUGILIDAE	Mugil cephalus	Sea mullet	x
MUGILIDAE	Myxus elongatus	Sand mullet	
MURAENESOCIDAE	Muraenesox bagio	Common pike eel	
PERCICHTHYIDAE	Macquaria colonorum	Estuary perch	x
PLATYCEPHALIDAE	Platycephalus arenarius	Northern sand flathead	x
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead	x
PLOTOSIDAE	Euristhmus lepturus	Long-tailed catfish	
PLOTOSIDAE	Plotosis lineatus	Striped catfish	
POMATOMIDAE	Pomatomus saltatrix	Tailor	x
PRIACANTHIDAE	Priacanthus macracanthus	Red bigeye	
SCATOPHAGIDAE	Selenotoca multifasciata	Old maid	
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish	x

SCORPAENIDAE	Notesthes robusta	Bullrout	
SILLAGINIDAE	Sillago ciliata	Sand whiting	x
SILLAGINIDAE	Sillago maculata	Trumpeter whiting	x
SOLEIDAE	Synclidopus macleayanus	Narrow banded sole	
SOLEIDAE	Synaptura nigra	Black sole	
SPARIDAE	Acanthopagrus australis	Bream	x
SPARIDAE	Pagrus auratus	Snapper	x
SPARIDAE	Rhabdosargus sarba	Tarwhine	x
TERAPONTIDAE	Pelates sexlineatus	Trumpeter	
TETRAODONTIDAE	(assorted toadfish/puferfish)	Toadfish/pufferfish	

Crustaceans:

GRAPSIDAE	Scylla serrata	Mud crab	x
PENAEIDAE	Penaeus esculentus	Tiger prawn	x
PENAEIDAE	Penaeus monodon	Leader prawn	x
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab	x
SQUILLIDAE	Squilla sp.	Mantis shrimp	

Molluscs:

LOLIGINIDAE	Loliolus sp.	Bottle squid	x

List of by-catch taxa in the Hawkesbury River (Brooklyn prawn trawl fleet)

Family	Scientific name	Common name	Commercial ?
Finfishes:			
AMBASSIDAE	Ambassis jacksoniensis	Port jackson perchlet	
AMBASSIDAE	Ambassis marianus	Ramseys perchlet	
ANGUILLIDAE	Anguilla australis	Short finned eel	
ANTENNARIIDAE	Antennarius striatus	Yellow anglerfish	
APOGONIDAE	Apogon sp.	Cardinal fish	
APOGONIDAE	Siphamia roseigaster	Pink breasted siphonfish	
BERYCIDAE	Centroberyx affinis	Redfish	x
BOTHIDAE	Pseudorhombus arsius	Large toothed flounder	x
BOTHIDAE	Pseudorhombus jenynsii	Small toothed flounder	x
CALLIONYMIDAE	(unid. stinkfish)	Stinkfish	
CARANGIDAE	Gnathanodon speciosus	Golden trevally	x
CARANGIDAE	Pseudocaranx dentex	Silver trevally	x
CARANGIDAE	Seriola hippos	Samson fish	x
CARANGIDAE	Trachurus novaezelandiae	Yellowtail	
CHEILODACTYLIDAE	Cheilodactylus douglasi	Blue morwong	x
CHIRONEMIDAE	Chironemus marmoratus	Eastern kelpfish	
CLUPEIDAE	Herklotsichthys castelnaui	Southern herring	
CLUPEIDAE	Hyperlophus vittatus	Sandy sprat	
CLUPEIDAE	Potamalosa richmondia	Freshwater herring	
CLUPEIDAE	Sardinops neopilchardus	Pilchard	
CONGRIDAE	Conger wilsoni	Congor eel	
CYNOGLOSSIDAE	Paraplagusia unicolor	Lemon tongue sole	
CYPRINIDAE	Cyprinus carpio	European carp	
DASYATIDIDAE / UROLOPHIDAE	Stingray/stingaree	Stingray/stingaree	
DIDONTIDAE	Dicotylichthys punctulatus	Porcupine fish	
DINOLESTIDAE	Dinolestes lewini	Long-finned pike	
ELEOTRIDAE	Gobiomorphus australis	Striped gudgeon	
ELEOTRIDAE	Philypnodon grandiceps	Large-headed gudgeon	
ENGRAULIDIDAE	Engraulis australis	Australian anchovy	
ENOPLOSIDAE	Enoplosus armatus	Old wife	
EPHIPPIDAE	Platax tiera	Round faced batfish	
GERREIDAE	Gerres subfasciatus	Common silver biddy	
GIRELLIDAE	Girella tricuspidata	Blackfish	x
GOBIIDAE	(unid. gobies)	Goby	
GOBIIDAE	Acanthogobius flavimanus	Oriental goby	
GOBIIDAE	Arenigobius bifrenatus	Bridled goby	
GOBIIDAE	Bathygobius cocosensis	Common goby	
GOBIIDAE	Bunaka herwerdenii	Mud gudgeon	
GOBIIDAE	Favonigobius exquisitus	Exquisite goby	
GOBIIDAE	Favonigobius tamarensis	Tamar river goby	
GOBIIDAE	Favonigobius lateralis	Long finned goby	
GOBIIDAE	Redigobius macrostoma	Large mouth goby	
GOBIIDAE	Tridentiger trigonocephalus	Japanese goby	
GOBIIDAE	Trimma sp.	Red and white goby	
GONORYNCHIDAE	Gonorynchus greyi	Beaked salmon	
HETERODONTIDAE	Heterodontos portjacksoni	Port jackson shark	
MONACANTHIDAE	Eubalichthys mosaicus	Mosaic leatherjacket	x

MONACANTHIDAE	Meuschenia trachylepis	Yellowfin leatherjacket	x
MONACANTHIDAE	Monacanthus chinensis	Fanbellied leatherjacket	
MONACANTHIDAE	Paramonacanthus filicauda	Threadfin leatherjacket	
MONODACTYLIDAE	Monodactylus argenteus	Diamond fish	
MORIDAE	Pseudophycis brevivsculus	Bearded cod	
MUGILIDAE	Liza argentea	Flat-tail mullet	x
MUGILIDAE	Mugil cephalus	Sea mullet	x
MUGILIDAE	Mugil georgii	Fantail mullet	
MUGILIDAE	Myxus elongatus	Sand mullet	
MURAENESOCIDAE	Muraenesox bagio	Common pike eel	
PERCICHTHYIDAE	Macquaria colonorum	Estuary perch	x
PERCICHTHYIDAE	Macquaria novemaculeata	Australian bass	x
PLATYCEPHALIDAE	Platycephalus arenarius	Northern sand flathead	x
PLATYCEPHALIDAE	Platycephalus caeruleopunctatus	Eastern blue spot flathead	x
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead	x
PLATYCEPHALIDAE	Platycephalus longispinus	Long spined flathead	
PLATYCEPHALIDAE	Suggrundus jugosis	Mud flathead	x
PLOTOSIDAE	Euristhmus lepturus	Long-tailed catfish	
PLOTOSIDAE	Plotosis lineatus	Striped catfish	
POMATOMIDAE	Pomatomus saltatrix	Tailor	x
PRIACANTHIDAE	Priacanthus macracanthus	Red bigeye	
RHINOBATIDAE	Aptychotrema rostrata	Shovelnose ray	x
SCATOPHAGIDAE	Selenotoca multifasciata	Old maid	
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish	x
SCIAENIDAE	Atractoscian aequidens	Teraglin	x
SCOMBRIDAE	Sardinella lemuru	Scaly mackeral	
SCORPAENIDAE	Centropogon australis	Eastern fortesque	
SCORPAENIDAE	Notesthes robusta	Bullrout	
SILLAGINIDAE	Sillago ciliata	Sand whiting	x
SILLAGINIDAE	Sillago flindersi	Red spot whiting	x
SILLAGINIDAE	Sillago maculata	Trumpeter whiting	x
SILLAGINIDAE	Sillago robusta	Stout whiting	x
SOLEIDAE	Synclidopus macleayanus	Narrow banded sole	
SOLEIDAE	Synaptura nigra	Black sole	
SPARIDAE	Acanthopagrus australis	Bream	x
SPARIDAE	Pagrus auratus	Snapper	x
SPARIDAE	Rhabdosargus sarba	Tarwhine	x
SYNGNATHIDAE	(unid. pipefish)	Pipefish	
TANIODIDAE	Taenioides mordax	Eel goby	
TERAPONTIDAE	Pelates quadrilineatus	Trumpeter	
TETRAODONTIDAE	(assorted toadfish/puferfish)	Toadfish/pufferfish	
TRICHIURIDAE	Trichiurus lepturus	Hairtail	x
TRIGLIDAE	Chelidonichthys kumu	Red gurnard	x
(UNID. EELS)	(unid. eels)	Eel	
(UNID. PERCHLET)	(unid. perchlet)	Unid. perchlet	

Reptiles:

(UNID. SEASNAKES)	(unid. seasnakes)	Seasnake

Crustaceans:

ALPHEIDAE	Alpheus spp.	Snapping shrimp

GRAPSIDAE	Scylla serrata	Mud crab
PALAEMONIDAE	Macrobrachium sp.	Long armed prawn
PORTUNIDAE	Charybdis cruciata	Coral crab
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab
PORTUNIDAE	Portunus sanguinolentus	3 spot crab
SQUILLIDAE	Squilla sp.	Mantis shrimp
(UNID. CRABS)	(unid. crabs)	Crab

Molluscs:

LOLIGINIDAE	Loligo chinensis	Broad squid
LOLIGINIDAE	Loligo sp.	Slender squid
LOLIGINIDAE	Loliolus sp.	Bottle squid
OCTOPODA (ORDER)	(unid. octopi)	Octopus
SEPIOLIDAE	Eupyrmna stenodactyla	Bubble squid
TEUTHOIDAE	Nototodarus gouldi	Arrow squid
(UNID. SQUID)	(unid. squid)	Unid. squid

List of by-catch taxa in the Hawkesbury River (squid trawl fleet)

Family	Scientific name	Common name	Commercial ?
Finfish:			
AMBASSIDAE	Ambassis jacksoniensis	Port jackson perchlet	
AMBASSIDAE	Ambassis marianus	Ramseys perchlet	
ANTENNARIIDAE	Antennarius striatus	Yellow anglerfish	
APOGONIDAE	Apogon sp.	Cardinal fish	
APOGONIDAE	Gronovichthys atripes	Two-eyed cardinal fish	
APOGONIDAE	Siphamia roseigaster	Pink breasted siphonfish	
ATHERINIDAE	Pranesus ogilbyi	Ogilby's hardy head	
BLENNIIDAE	Petroscirtes lupus	Sabretooth blenny	
BOTHIDAE	Pseudorhombus arsius	Large toothed flounder	x
BOTHIDAE	Pseudorhombus jenynsii	Small toothed flounder	x
CALLIONYMIDAE	(unid. stinkfish)	Stinkfish	
CARANGIDAE	Gnathanodon speciosus	Golden trevally	x
CARANGIDAE	Pseudocaranx dentex	Silver trevally	x
CARANGIDAE	Trachurus novaezelandiae	Yellowtail	
CENTROLOPHIDAE	Seriolella brama	Warehou	x
CLUPEIDAE	Herklotsichthys castelnaui	Southern herring	
CLUPEIDAE	Hyperlophus vittatus	Sandy sprat	
CLUPEIDAE	Sardinops neopilchardus	Pilchard	
CONGRIDAE	Conger wilsoni	Congor eel	
DASYATIDIDAE / UROLOPHIDAE	Stingray/stingaree	Stingray/stingaree	
DIDONTIDAE	Dicotylichthys punctulatus	Porcupine fish	
DINOLESTIDAE	Dinolestes lewini	Long-finned pike	
ENGRAULIDIDAE	Engraulis australis	Australian anchovy	
ENOPLOSIDAE	Enoplosus armatus	Old wife	
GERREIDAE	Gerres subfasciatus	Common silver biddy	
GIRELLIDAE	Girella tricuspidata	Blackfish	x
HETERODONTIDAE	Heterodontos portjacksoni	Port jackson shark	
LEIOGNATHIDAE	Leignathus sp.	Pony fish	
MONACANTHIDAE	Brachaluteres jacksonianus	Pygmy leatherjacket	
MONACANTHIDAE	Eubalichthys mosaicus	Mosaic leatherjacket	x
MONACANTHIDAE	Meuschenia freycineti	Six-spined leatherjacket	
MONACANTHIDAE	Meuschenia trachylepis	Yellowfin leatherjacket	x
MONACANTHIDAE	Monacanthus chinensis	Fanbellied leatherjacket	
MONACANTHIDAE	Paramonacanthus filicauda	Threadfin leatherjacket	
MONODACTYLIDAE	Monodactylus argenteus	Diamond fish	
MONODACTYLIDAE	Schuetta scalaripinnis	Ladder-finned pomfret	
MUGILIDAE	Liza argentea	Flat-tail mullet	x
MUGILIDAE	Mugil cephalus	Sea mullet	x
MUGILIDAE	Mugil georgii	Fantail mullet	
MULLIDAE	Upeneus tragula	Bartailed goatfish	x
MURAENESOCIDAE	Muraenesox bagio	Common pike eel	
MYLIOBATIDAE	Myliobatis australis	Eagle ray	
OSTRACIIDAE	(unid. boxfish)	Boxfish	
OSTRACIIDAE	Tetrosomus republicae	Turret fish	
PEMPHERIDIDAE	Pempheris analis	Bronze bullseye	
PEMPHERIDIDAE	Pempheris compressa	Deep bullseye	
PEMPHERIDIDAE	Pempheris multiradiatus	Common bullseye	

PLATYCEPHALIDAE	Platycephalus arenarius	Northern sand flathead	x
PLATYCEPHALIDAE	Platycephalus caeruleopunctatus	Eastern blue spot flatheac	x
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead	x
PLATYCEPHALIDAE	Platycephalus longispinus	Long spined flathead	
PLATYCEPHALIDAE	Suggrundus jugosis	Mud flathead	x
PLOTOSIDAE	Euristhmus lepturus	Long-tailed catfish	
PLOTOSIDAE	Plotosis lineatus	Striped catfish	
POMATOMIDAE	Pomatomus saltatrix	Tailor	x
PRIACANTHIDAE	Priacanthus macracanthus	Red bigeye	
RAJIDAE	Raja spp.	Skate	
RHINOBATIDAE	Aptychotrema rostrata	Shovelnose ray	x
RHINOBATIDAE	Trygonorrhina sp.	Banjo ray	x
SCATOPHAGIDAE	Selenotoca multifasciata	Old maid	
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish	x
SCIAENIDAE	Atractoscian aequidens	Teraglin	x
SCOMBRIDAE	Scomber australasicus	Blue mackerel	x
SCORPAENIDAE	Centropogon australis	Eastern fortesque	
SCORPAENIDAE	Notesthes robusta	Bullrout	
SCORPIDIDAE	Microcanthus strigatus	Stripey	
SCORPIDIDAE	Scorpis lineolatus	Sweep	
SILLAGINIDAE	Sillago ciliata	Sand whiting	x
SILLAGINIDAE	Sillago flindersi	Red spot whiting	x
SILLAGINIDAE	Sillago maculata	Trumpeter whiting	x
SILLAGINIDAE	Sillago robusta	Stout whiting	x
SOLEIDAE	Synclidopus macleayanus	Narrow banded sole	
SOLEIDAE	Synaptura nigra	Black sole	
SPARIDAE	Acanthopagrus australis	Bream	x
SPARIDAE	Pagrus auratus	Snapper	x
SPARIDAE	Rhabdosargus sarba	Tarwhine	x
SPHYRAENIDAE	Sphyraena africana	Snook	
SPYRNIDAE	Sphyrna lewini	Hammerhead shark	x
SYNODONTIDAE	Trachinocephalus myops	Painted grinner	
TERAPONTIDAE	Pelates quadrilineatus	Trumpeter	
TETRAODONTIDAE	(assorted toadfish/puferfish)	Toadfish/pufferfish	
TRACHICHTHYIDAE	Optivus elongatus	Slender roughy	
TRICHIURIDAE	Trichiurus lepturus	Hairtail	x
TRIGLIDAE	(unid. gurnard)	Unid. gurnard	
TRIGLIDAE	Chelidonichthys kumu	Red gurnard	x
ZEIDAE	Zeus faber	John dory	x

Reptiles:

(UNID. TURTLE)	(unid. turtle)	Turtle	

Crustaceans:

ALPHEIDAE	Alpheus spp.	Snapping shrimp	
GRAPSIDAE	Scylla serrata	Mud crab	x
PALINURIDAE	Jasus verreauxi	Eastern cray	x
PENAEIDAE	Metapenaeus bennettae	Greasyback prawn	x
PENAEIDAE	Metapenaeus macleayi	School prawn	x
PENAEIDAE	Penaeus esculentus	Tiger prawn	x
PENAEIDAE	Penaeus plebejus	King prawn	x

PORTUNIDAE	Charybdis cruciata	Coral crab	x
PORTUNIDAE	Ovalipes australiensis	2 spot crab	
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab	x
PORTUNIDAE	Portunus sanguinolentus	3 spot crab	x
SQUILLIDAE	Squilla sp.	Mantis shrimp	
(UNID. CRABS)	(unid. crabs)	Crab	

Molluscs:

LOLIGINIDAE	Loligo sp.	Slender squid	x
LOLIGINIDAE	Loliolus sp.	Bottle squid	x
OCTOPODA (ORDER)	(unid. octopi)	Octopus	x
SEPIIDAE	Sepia sp.	Cuttlefish	x
SEPIOLIDAE	Eupyrmna stenodactyla	Bubble squid	
SEPIOLIDAE	Sepioloida lineolata	Candy stripe squid	

List of by-catch taxa in Port Jackson

Family	Scientific name	Common name	Commercial ?
Finfishes:			
AMBASSIDAE	Ambassis jacksoniensis	Port jackson perchlet	
AMBASSIDAE	Ambassis marianus	Ramseys perchlet	
ANTENNARIIDAE	Antennarius striatus	Yellow anglerfish	
APOGONIDAE	Apogon cooki	Cooks soldier fish	
APOGONIDAE	Apogon sp.	Cardinal fish	
APOGONIDAE	Gronovichthys atripes	Two-eyed cardinal fish	
APOGONIDAE	Siphamia cephalotes	Woods siphonfish	
APOGONIDAE	Siphamia roseigaster	Pink breasted siphonfish	
BATRACHOIDIDAE	Batrachomoeus dubius	Eastern frogfish	
BERYCIDAE	Centroberyx affinis	Redfish	x
BOTHIDAE	Engyprosodon grandisquamma	Spiny-headed flounder	
BOTHIDAE	Pseudorhombus arsius	Large toothed flounder	x
BOTHIDAE	Pseudorhombus jenynsii	Small toothed flounder	x
CALLIONYMIDAE	(unid. stinkfish)	Stinkfish	
CARANGIDAE	Pseudocaranx dentex	Silver trevally	x
CARANGIDAE	Trachurus novaezelandiae	Yellowtail	
CENTROLOPHIDAE	Seriolella brama	Warehou	x
CLUPEIDAE	Hyperlophus vittatus	Sandy sprat	
CONGRIDAE	Conger wilsoni	Congor eel	
DASYATIDIDAE / UROLOPHIDAE	Stingray/stingaree	Stingray/stingaree	
DIDONTIDAE	Dicotylichthys punctulatus	Porcupine fish	
DINOLESTIDAE	Dinolestes lewini	Long-finned pike	
ENGRAULIDIDAE	Engraulis australis	Australian anchovy	
ENOPLOSIDAE	Enoplosus armatus	Old wife	
GERREIDAE	Gerres subfasciatus	Common silver biddy	
GOBIIDAE	(unid. gobies)	Goby	
GOBIIDAE	Acanthogobius flavimanus	Oriental goby	
GOBIIDAE	Arenigobius bifrenatus	Bridled goby	
GOBIIDAE	Favonigobius exquisitus	Exquisite goby	
GOBIIDAE	Favonigobius tamarensis	Tamar river goby	
GOBIIDAE	Favonigobius lateralis	Long finned goby	
GOBIIDAE	Tridentiger trigonocephalus	Japanese goby	
HETERODONTIDAE	Heterodontos portjacksoni	Port jackson shark	
LEIOGNATHIDAE	Leignathus sp.	Pony fish	
MONACANTHIDAE	(unid. leatherjackets)	Unid. leatherjacket	x
MONACANTHIDAE	Brachaluteres jacksonianus	Pygmy leatherjacket	
MONACANTHIDAE	Meuschenia australis	Brown striped leatherjacket	
MONACANTHIDAE	Meuschenia freycineti	Six-spined leatherjacket	
MONACANTHIDAE	Meuschenia trachylepis	Yellowfin leatherjacket	x
MONACANTHIDAE	Monacanthus chinensis	Fanbellied leatherjacket	
MONACANTHIDAE	Nelusetta ayraudi	Chinaman leatherjacket	x
MONACANTHIDAE	Parika scaber	Velvet leatherjacket	x
MONACANTHIDAE	Scobinichthys granulatus	Rough skin leatherjacket	
MORIDAE	Pseudophycis brevivsculus	Bearded cod	
MUGILIDAE	Mugil cephalus	Sea mullet	x
MUGILIDAE	Myxus elongatus	Sand mullet	
MUGILIDAE	Myxus petardi	Pink-eye mullet	

MULLIDAE	(unid. goatfish)	Goatfish	
MULLIDAE	Upeneichthys lineates	Red mullet	x
MULLIDAE	Upeneus tragula	Bartailed goatfish	x
MURAENIDAE	Enchelycore ramosa	Mosaic moray	
OPICHTHIDAE	Ophisurus serpens	Serpent eel	
ORECTOLOBIDAE	(unid. wobbegongs)	Wobbegong	x
OSTRACIIDAE	(unid. boxfish)	Boxfish	
PEMPHERIDIDAE	Pempheris multiradiatus	Common bullseye	
PLATYCEPHALIDAE	Platycephalus arenarius	Northern sand flathead	x
PLATYCEPHALIDAE	Platycephalus caeruleopunctatus	Eastern blue spot flathead	x
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead	x
PLATYCEPHALIDAE	Platycephalus longispinus	Long spined flathead	
PLATYCEPHALIDAE	Ratabulus diversidens	Spikey flathead	x
PLATYCEPHALIDAE	Suggrundus jugosis	Mud flathead	x
PLEURONECTIDAE	Ammotretis rostratus	Long snouted flounder	
PLOTOSIDAE	Euristhmus lepturus	Long-tailed catfish	
PLOTOSIDAE	Plotosis lineatus	Striped catfish	
POMATOMIDAE	Pomatomus saltatrix	Tailor	x
PRIACANTHIDAE	Priacanthus macracanthus	Red bigeye	
SCATOPHAGIDAE	Selenotoca multifasciata	Old maid	
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish	x
SCIAENIDAE	Atractoscian aequidens	Teraglin	x
SCORPAENIDAE	Centropogon australis	Eastern fortesque	
SCORPAENIDAE	Notesthes robusta	Bullrout	
SCORPAENIDAE	Scorpaena cardinalis	Red rock cod	x
SCORPIDIDAE	Atypichthys strigatus	Mado	
SCORPIDIDAE	Microcanthus strigatus	Stripey	
SERRANIDAE	Ellerkeldia mccullochi	Half-banded seaperch	
SERRANIDAE	Epinephelus undulatostriatus	Maori cod	
SILLAGINIDAE	Sillago ciliata	Sand whiting	x
SILLAGINIDAE	Sillago flindersi	Red spot whiting	x
SILLAGINIDAE	Sillago maculata	Trumpeter whiting	x
SILLAGINIDAE	Sillago robusta	Stout whiting	x
SOLEIDAE	Synaptura nigra	Black sole	
SPARIDAE	Acanthopagrus australis	Bream	x
SPARIDAE	Pagrus auratus	Snapper	x
SPARIDAE	Rhabdosargus sarba	Tarwhine	x
SPHYRAENIDAE	Sphyraena africana	Snook	
SPHYRAENIDAE	Sphyraena obtusata	Striped sea pike	
SYNODONTIDAE	Trachinocephalus myops	Painted grinner	
TERAPONTIDAE	Pelates quadrilineatus	Trumpeter	
TETRAODONTIDAE	(assorted toadfish/puferfish)	Toadfish/pufferfish	
TRACHICHTHYIDAE	Optivus elongatus	Slender roughy	
TRACHICHTHYIDAE	Trachichthys australis	Pig faced roughy	
TRIGLIDAE	Chelidonichthys kumu	Red gurnard	x
ZEIDAE	Zeus faber	John dory	x
(UNID. EELS)	(unid. eels)	Eel	
(UNID. PERCHLET)	(unid. perchlet)	Unid. perchlet	
?	?	Red barred grubfish	

Crustaceans:

ALPHEIDAE	Alpheus spp.	Snapping shrimp

GRAPSIDAE	Scylla serrata	Mud crab	x
PAGURIDAE	Paguristes spp.	Hermit crab	
PALAEMONIDAE	Macrobrachium sp.	Long armed prawn	
PORTUNIDAE	Charybdis cruciata	Coral crab	x
PORTUNIDAE	Ovalipes australiensis	2 spot crab	
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab	x
PORTUNIDAE	Portunus sanguinolentus	3 spot crab	x
SCYLLARIDAE	Ibacus peronii	Balmain bug	x
SQUILLIDAE	Squilla sp.	Mantis shrimp	
(UNID. CRABS)	(unid. crabs)	Crab	

Molluscs:

LOLIGINIDAE	Loligo chinensis	Broad squid	x
LOLIGINIDAE	Loligo sp.	Slender squid	x
LOLIGINIDAE	Loliolus sp.	Bottle squid	x
LOLIGINIDAE	Sepioteuthis australis	Southern calamary	x
OCTOPODA (ORDER)	(unid. octopi)	Octopus	x
SEPIIDAE	Sepia sp.	Cuttlefish	x
SEPIOLIDAE	Eupyrmna stenodactyla	Bubble squid	
SEPIOLIDAE	Sepioloida lineolata	Candy stripe squid	
TEUTHOIDAE	Nototodarus gouldi	Arrow squid	x
(UNID. NUDIBRANCH)	(unid. nudibranch)	Nudibranch	

List of by-catch taxa from Botany Bay

Finfishes:

Family	Scientific name	Common name	Commercial ?
AMBASSIDAE	Ambassis jacksoniensis	Port Jackson perchlet	
AMBASSIDAE	Ambassis marianus	Ramsey's perchlet	
ANTENNARIIDAE	Antennarius striatus	Yellow anglerfish	
APOGONIDAE	Apogon sp.	Cardinal fish	
APOGONIDAE	Gronovichthys atripes	Two-eyed cardinal fish	
APOGONIDAE	Siphamia roseigaster	Pink-breasted siphonfish	
ATHERINIDAE	Pranesus ogilbyi	Ogilby's hardy head	
BATRACHOIDIDAE	Batrachomoeus dubius	Eastern frogfish	
BERYCIDAE	Centroberyx affinis	Redfish	x
BLENNIIDAE	Petroscirtes lupus	Sabretooth blenny	
BOTHIDAE	Engyprosodon grandisquamma	Spiny-headed flounder	
BOTHIDAE	Pseudorhombus arsius	Large-toothed flounder	x
BOTHIDAE	Pseudorhombus jenynsii	Small-toothed flounder	x
CALLIONYMIDAE	(unid. stinkfish)	Stinkfish	
CARANGIDAE	Pseudocaranx dentex	Silver trevally	x
CARANGIDAE	Seriola hippos	Samson fish	x
CARANGIDAE	Trachurus novaezelandiae	Yellowtail	
CENTROLOPHIDAE	Seriolella brama	Warehou	x
CHEILODACTYLIDAE	Cheilodactylus fuscus	Red morwong	x
CHEILODACTYLIDAE	Cheilodactylus vestitus	Magpie morwong	x
CLUPEIDAE	Herklotsichthys castelnaui	Southern herring	
CLUPEIDAE	Hyperlophus vittatus	Sandy sprat	
CONGRIDAE	Conger wilsoni	Congor eel	
CYNOGLOSSIDAE	Paraplagusia unicolor	Lemon tongue sole	
DASYATIDIDAE/UROLOPHIDAE	Stingray/stingaree	Stingray/stingaree	
DIDONTIDAE	Dicotylichthys punctulatus	Porcupine fish	
DINOLESTIDAE	Dinolestes lewini	Long-finned pike	
ECHENEIDIDAE	Remora remora	Remora	
ENGRAULIDIDAE	Engraulis australis	Australian anchovy	
ENOPLOSIDAE	Enoplosus armatus	Old wife	
FISTULARIIDAE	Fistularia spp.	Flutemouth	
GEMPYLIDAE	Thyristes atun	Barracouta	x
GERREIDAE	Gerres subfasciatus	Common silver biddy	
GIRELLIDAE	Girella tricuspidata	Blackfish	x
GOBIIDAE	Arenigobius bifrenatus	Bridled goby	
GOBIIDAE	Favonigobius exquisitus	Exquisite goby	
GOBIIDAE	Favonigobius tamarensis	Tamar river goby	
GOBIIDAE	Favonigobius lateralis	Long finned goby	
GOBIIDAE	Tridentiger trigonocephalus	Japanese goby	
GONORYNCHIDAE	Gonorynchus greyi	Beaked salmon	
HEMIRAMPHIDAE	Hyporhamphus australis	Eastern sea garfish	x
HETERODONTIDAE	Heterodontos portjacksoni	Port jackson shark	
LABRIDAE	Achoerodus viridis	Eastern blue groper	x
LEIOGNATHIDAE	Leignathus sp.	Pony fish	
LETHRINIDAE	Lethrinus nebulosis	Spangled emperor	x
MONACANTHIDAE	(unid. leatherjackets)	Unid. leatherjacket	x
MONACANTHIDAE	Acanthaluteres spilomelanurus	Bridled leatherjacket	

MONACANTHIDAE	Brachaluteres jacksonianus	Pygmy leatherjacket	
MONACANTHIDAE	Eubalichthys mosaicus	Mosaic leatherjacket	x
MONACANTHIDAE	Meuschenia australis	Brown-striped leatherjacket	
MONACANTHIDAE	Meuschenia freycineti	Six-spined leatherjacket	
MONACANTHIDAE	Meuschenia trachylepis	Yellowfin leatherjacket	x
MONACANTHIDAE	Monacanthus chinensis	Fanbellied leatherjacket	
MONACANTHIDAE	Nelusetta ayraudi	Chinaman leatherjacket	x
MONACANTHIDAE	Paramonacanthus otisensis	Dusky leatherjacket	
MONACANTHIDAE	Parika scaber	Velvet leatherjacket	x
MONACANTHIDAE	Scobinichthys granulatus	Rough skin leatherjacket	
MORIDAE	Pseudophycis brevivsculus	Bearded cod	
MUGILIDAE	Mugil cephalus	Sea mullet	x
MUGILIDAE	Myxus elongatus	Sand mullet	
MULLIDAE	(unid. goatfish)	Goatfish	
MULLIDAE	Parupeneus signatus	Blackspot goatfish	
MULLIDAE	Upeneichthys lineates	Red mullet	x
MULLIDAE	Upeneus tragula	Bar-tailed goatfish	x
MYLIOBATIDAE	Myliobatis australis	Eagle ray	
OPHIDIIDAE	Genypterus tigerinus	Rock ling	
OPICHTHIDAE	Ophisurus serpens	Serpent eel	
OSTRACIIDAE	(unid. boxfish)	Boxfish	
OSTRACIIDAE	Lactoria spp	Cowfish	
OSTRACIIDAE	Tetrosomus reipublicae	Turret fish	
PEGASIDAE	Parapegasus natans	Slender sea moth	
PEMPHERIDIDAE	Pempheris compressa	Deep bullseye	
PEMPHERIDIDAE	Pempheris multiradiatus	Common bullseye	
PENTACEROTIDAE	Paristiopterus labiosis	Giant boar fish	x
PENTACEROTIDAE	Pentaceropsis recurivirostris	Long-snouted boarfish	x
PLATYCEPHALIDAE	Platycephalus arenarius	Northern sand flathead	x
PLATYCEPHALIDAE	Platycephalus caeruleopunctatus	Eastern blue spot flathead	x
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead	x
PLATYCEPHALIDAE	Platycephalus longispinus	Long spined flathead	
PLATYCEPHALIDAE	Platycephalus marmoratus	Marble flathead	x
PLATYCEPHALIDAE	Platycephalus richardsoni	Tiger flathead	x
PLATYCEPHALIDAE	Ratabulus diversidens	Spikey flathead	x
PLATYCEPHALIDAE	Suggrundus jugosis	Mud flathead	x
PLEURONECTIDAE	Ammotretis rostratus	Long snouted flounder	
PLEURONECTIDAE	Rhombosolea tapirina	Greenback flounder	
PLOTOSIDAE	Euristhmus lepturus	Long-tailed catfish	
PLOTOSIDAE	Plotosis lineatus	Striped catfish	
POMATOMIDAE	Pomatomus saltatrix	Tailor	x
PRIACANTHIDAE	Priacanthus macracanthus	Red bigeye	
PSYCHROLUTIDAE	Psychrolutes marcidus	Blob fish	
RAJIDAE	Raja spp.	Skate	
RHINOBATIDAE	Aptychotrema rostrata	Shovelnose ray	x
RHINOBATIDAE	Trygonorrhina sp.	Banjo ray	x
SCARIDAE	(unid. parrotfish)	Parrot fish	x
SCARIDAE	Scarus sordidus	Green-finned parrot fish	
SCATOPHAGIDAE	Selenotoca multifasciata	Old maid	
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish	x
SCOMBRIDAE	Scomber australasicus	Blue mackerel	x
SCORPAENIDAE	Centropogon australis	Eastern fortesque	
SCORPAENIDAE	Notesthes robusta	Bullrout	

SCORPAENIDAE	Pterois volitans	Red firefish	
SCORPAENIDAE	Scorpaena cardinalis	Red rock cod	x
SCORPIDIDAE	Atypichthys strigatus	Mado	
SCORPIDIDAE	Microcanthus strigatus	Stripey	
SERRANIDAE	Callanthias allporti	Splendid perch	
SERRANIDAE	Epinephelus septemfasciatus	Bar cod	x
SIGANIDAE	Siganus fuscescens	Black spinefoot	
SILLAGINIDAE	Sillago ciliata	Sand whiting	x
SILLAGINIDAE	Sillago flindersi	Red spot whiting	x
SILLAGINIDAE	Sillago maculata	Trumpeter whiting	x
SILLAGINIDAE	Sillago robusta	Stout whiting	x
SOLEIDAE	Pardachirus hedleyi	Peacock sole	
SOLEIDAE	Synaptura nigra	Black sole	
SOLEIDAE	Synclidopus macleayanus	Narrow banded sole	
SPARIDAE	Acanthopagrus australis	Bream	x
SPARIDAE	Pagrus auratus	Snapper	x
SPARIDAE	Rhabdosargus sarba	Tarwhine	x
SPHYRAENIDAE	Sphyraena africana	Snook	
SPHYRAENIDAE	Sphyraena obtusata	Striped sea pike	
SYNGNATHIDAE	(unid. pipefish)	Pipefish	
SYNGNATHIDAE	Hippocampus spp.	Seahorse	
SYNODONTIDAE	Trachinocephalus myops	Painted grinner	
TERAPONTIDAE	Pelates quadrilineatus	Trumpeter	
TETRAODONTIDAE	(assorted toadfish/puferfish)	Toadfish/pufferfish	
TRACHICHTHYIDAE	Optivus elongatus	Slender roughy	
TRIGLIDAE	(unid. gurnard)	Unid. gurnard	
TRIGLIDAE	Chelidonichthys kumu	Red gurnard	x
TRIGLIDAE	Pterygotrigla polyommata	Sharp-beaked gurnard	
URANOSCOPIDAE	Ichthyscopus lebeck	Spotted stargazer	
ZEIDAE	Zeus faber	John dory	x
(UNID. EELS)	(unid. eels)	Eel	
(UNID. PERCHLET)	(unid. perchlet)	Unid. perchlet	

Crustaceans:

ALPHEIDAE	Alpheus spp.	Snapping shrimp	
PAGURIDAE	Paguristes spp.	Hermit crab	
PALINURIDAE	Jasus lalandii	Southern cray	x
PALINURIDAE	Jasus verreauxi	Eastern cray	x
PORTUNIDAE	Charybdis cruciata	Coral crab	x
PORTUNIDAE	Ovalipes australiensis	2 spot crab	
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab	x
PORTUNIDAE	Portunus sanguinolentus	3 spot crab	x
(UNID. CRABS)	(unid. crabs)	Crab	
SCYLLARIDAE	Ibacus peronii	Balmain bug	x
SQUILLIDAE	Squilla sp.	Mantis shrimp	

Molluscs:

LOLIGINIDAE	Loligo chinensis	Broad squid	x
LOLIGINIDAE	Loligo sp.	Slender squid	x
LOLIGINIDAE	Loliolus sp.	Bottle squid	x
LOLIGINIDAE	Sepioteuthis australis	Southern calamary	x

OCTOPODA (ORDER)	(unid. octopi)	Octopus	x
OCTOPODA (ORDER)	Hapalochaena maculosa	Blue ringed octopus	
PECTINIDAE	Pecten fumatus	Tasmanian scallop	x
SEPIIDAE	Sepia sp.	Cuttlefish	x
SEPIOLIDAE	Eupyrmna stenodactyla	Bubble squid	
SEPIOLIDAE	Sepioloida lineolata	Candy stripe squid	
TEUTHOIDAE	Nototodarus gouldi	Arrow squid	x
(UNID. SQUID)	(unid. squid)	Unid. squid	x

Echinoderms:

(UNID. STARFISH)	(unid. starfish)	Starfish	

List of by-catch taxa from Ballina (oceanic fleet)

Family	Scientific name	Common name
Finfishes:		
BERYCIDAE	Centroberyx affinis	Redfish
BOTHIDAE	Pseudorhombus arsius	Large-toothed flounder
BOTHIDAE	Pseudorhombus jenynsii	Small-toothed flounder
CARCHARHINIDAE	Carcharhinus melanopterus	Black-tip shark
CARCHARHINIDAE	Carcharhinus spp.	Whaler shark
CHEILODACTYLIDAE	Cheilodactylus douglasi	Blue morwong
GLAUCOSOMIDAE	Glaucosoma scapulare	Pearl perch
MONACANTHIDAE	(unid. leatherjackets)	unid. Leatherjacket
MONACANTHIDAE	Eubalichthys mosaicus	Mosaic leatherjacket
MONACANTHIDAE	Meuschenia trachylepis	Yellowfin leatherjacket
MONACANTHIDAE	Nelusetta ayraudi	Chinaman leatherjacket
MULLIDAE	Upeneichthys lineates	Red mullet
PENTACEROTIDAE	Paristiopterus labiosis	Giant boar fish
PENTACEROTIDAE	Zanclistus elevates	Black-spotted boarfish
PLATYCEPHALIDAE	Platycephalus arenarius	Northern sand flathead
PLATYCEPHALIDAE	Platycephalus caeruleopun	Eastern blue spot flathead
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead
PLATYCEPHALIDAE	Platycephalus marmoratus	Marble flathead
PLATYCEPHALIDAE	Platycephalus richardsoni	Tiger flathead
PLATYCEPHALIDAE	Ratabulus diversidens	Spikey flathead
PLATYCEPHALIDAE	Suggrundus jugosis	Mud flathead
RACHYCENTRIDAE	Rachycentron canadus	Cobia
RHINOBATIDAE	Aptychotrema rostrata	Shovelnose ray
RHYNCHOBATIDAE	Rhynchobatus djiddensis	White-spotted shovelnose ray
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish
SCIAENIDAE	Atractoscian aequidens	Teraglin
SCOMBRIDAE	Scomber australasicus	Blue mackerel
SCORPAENIDAE	(unid. scorpaenid)	Popeye cod
SCORPAENIDAE	Scorpaena cardinalis	Red rock cod
SERRANIDAE	Epinephelus septemfasciat	Bar cod
SILLAGINIDAE	Sillago ciliata	Sand whiting
SILLAGINIDAE	Sillago flindersi	Red spot whiting
SILLAGINIDAE	Sillago robusta	Stout whiting
SPARIDAE	Pagrus auratus	Snapper
SPARIDAE	Rhabdosargus sarba	Tarwhine
SQUATINIDAE	Squatina spp.	Angel shark
TRIAKIDAE	Mustelus antarcticus	Gummy shark
TRICHIURIDAE	Trichiurus lepturus	Hairtail
TRIGLIDAE	Chelidonichthys kumu	Red gurnard
ZEIDAE	Zenopsis nebulosis	Mirror dory
ZEIDAE	Zeus faber	John dory
Crustaceans:		
PALINURIDAE	Jasus verreauxi	Eastern cray
PALINURIDAE	Panulirus ornatus	Painted cray
PORTUNIDAE	Charybdis cruciata	Coral crab

PORTUNIDAE	Portunus pelagicus	Blue swimmer crab
PORTUNIDAE	Portunus sanguinolentus	3 spot crab
RANINIDAE	Ranina ranina	Spanner crab
SCYLLARIDAE	Ibacus brucei	Bruce's bug
SCYLLARIDAE	Ibacus peronii	Balmain bug
SCYLLARIDAE	Ibacus sp.	Smooth bug
SCYLLARIDAE	Scyllarides squammosus	Slipper lobster

Molluscs:

LOLIGINIDAE	Loligo sp.	Slender squid
LOLIGINIDAE	Loliolus sp.	Bottle squid
LOLIGINIDAE	Sepioteuthis australis	Southern calamary
OCTOPODA (ORDER)	(unid. octopi)	Octopus
SEPIIDAE	Sepia sp.	Cuttlefish
TEUTHOIDAE	Nototodarus gouldi	Arrow squid

List of by-catch taxa from Yamba/Iluka (oceanic fl

Family	Scientific name	Common name
Finfishes:		
BERYCIDAE	Centroberyx affinis	Redfish
BOTHIDAE	Pseudorhombus arsius	Large-toothed flounder
BOTHIDAE	Pseudorhombus jenynsii	Small-toothed flounder
CARANGIDAE	Pseudocaranx dentex	Silver trevally
CARCHARHINIDAE	Carcharhinus melanopterus	Black-tip shark
CARCHARHINIDAE	Carcharhinus spp.	Whaler shark
CHEILODACTYLIDAE	Cheilodactylus douglasi	Blue morwong
GLAUCOSOMIDAE	Glaucosoma scapulare	Pearl perch
MONACANTHIDAE	(unid. leatherjackets)	unid. Leatherjacket
MONACANTHIDAE	Eubalichthys mosaicus	Mosaic leatherjacket
MONACANTHIDAE	Meuschenia trachylepis	Yellowfin leatherjacket
MONACANTHIDAE	Nelusetta ayraudi	Chinaman leatherjacket
MULLIDAE	Upeneichthys lineates	Red mullet
MULLIDAE	Upeneus tragula	Bar-tailed goatfish
ORECTOLOBIDAE	(unid. wobbegongs)	Wobbegong
PENTACEROTIDAE	Paristiopterus labiosis	Giant boar fish
PENTACEROTIDAE	Zanclistus elevates	Black-spotted boarfish
PLATYCEPHALIDAE	Platycephalus arenarius	Northern sand flathead
PLATYCEPHALIDAE	Platycephalus caeruleopunctatus	Eastern blue spot flathead
PLATYCEPHALIDAE	Platycephalus endrachtens	Bar-tailed flathead
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead
PLATYCEPHALIDAE	Platycephalus marmoratus	Marble flathead
PLATYCEPHALIDAE	Platycephalus richardsoni	Tiger flathead
PLATYCEPHALIDAE	Ratabulus diversidens	Spikey flathead
PLATYCEPHALIDAE	Suggrundus jugosis	Mud flathead
POMATOMIDAE	Pomatomus saltatrix	Tailor
RHINOBATIDAE	Aptychotrema rostrata	Shovelnose ray
RHINOBATIDAE	Trygonorrhina sp.	Banjo ray
RHYNCHOBATIDAE	Rhynchobatus djiddensis	White-spotted shovelnose ray
SCARIDAE	(unid. parrotfish)	unid. Parrot fish
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish
SCIAENIDAE	Atractoscian aequidens	Teraglin
SCOMBRIDAE	Scomber australasicus	Blue mackerel
SCORPAENIDAE	Scorpaena cardinalis	Red rock cod
SERRANIDAE	Epinephelus septemfasciat	Bar cod
SILLAGINIDAE	Sillago ciliata	Sand whiting
SILLAGINIDAE	Sillago flindersi	Red spot whiting
SILLAGINIDAE	Sillago robusta	Stout whiting
SPARIDAE	Acanthopagrus australis	Bream
SPARIDAE	Pagrus auratus	Snapper
SPARIDAE	Rhabdosargus sarba	Tarwhine
TRIAKIDAE	Galeorhinus galeus	School shark
TRIAKIDAE	Mustelus antarcticus	Gummy shark
TRICHIURIDAE	Trichiurus lepturus	Hairtail
TRIGLIDAE	Chelidonichthys kumu	Red gurnard
ZEIDAE	Zeus faber	John dory

Crustaceans:

PALINURIDAE	Jasus verreauxi	Eastern cray
PORTUNIDAE	Charybdis cruciata	Coral crab
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab
PORTUNIDAE	Portunus sanguinolentus	3 spot crab
RANINIDAE	Ranina ranina	Spanner crab
SCYLLARIDAE	Ibacus brucei	Bruce's bug
SCYLLARIDAE	Ibacus peronii	Balmain bug
SCYLLARIDAE	Ibacus sp.	Smooth bug

Molluscs:

LOLIGINIDAE	Loligo chinensis	Broad squid
LOLIGINIDAE	Loligo sp.	Slender squid
LOLIGINIDAE	Loliolus sp.	Bottle squid
LOLIGINIDAE	Sepioteuthis australis	Southern calamary
OCTOPODA (ORDER)	(unid. octopi)	Octopus
SEPIIDAE	Sepia sp.	Cuttlefish
TEUTHOIDAE	Nototodarus gouldi	Arrow squid
(UNID. SQUID)	(unid. squid)	Unid. squid

List of by-catch taxa from Coffs Harbour (oceanic fleet)

Family	Scientific name	Common name
Finfishes:		
BERYCIDAE	Centroberyx affinis	Redfish
BOTHIDAE	Pseudorhombus arsius	Large-toothed flounder
BOTHIDAE	Pseudorhombus jenynsii	Small-toothed flounder
CARCHARHINIDAE	Carcharhinus spp.	Whaler shark
CHEILODACTYLIDAE	Cheilodactylus douglasi	Blue morwong
CHEILODACTYLIDAE	Nemadactylus macropterus	Jackass morwong
MONACANTHIDAE	(unid. leatherjackets)	unid. Leatherjacket
MONACANTHIDAE	Eubalichthys bucephalus	Black reef leatherjacket
MONACANTHIDAE	Eubalichthys mosaicus	Mosaic leatherjacket
MONACANTHIDAE	Meuschenia trachylepis	Yellowfin leatherjacket
MONACANTHIDAE	Nelusetta ayraudi	Chinaman leatherjacket
MULLIDAE	Upeneichthys lineates	Red mullet
ORECTOLOBIDAE	(unid. wobbegongs)	Wobbegong
ORECTOLOBIDAE	Orectolobus maculatus	Spotted wobbegong
PARASCYLLIDAE	Parascyllium sp	Catshark
PENTACEROTIDAE	Paristiopterus labiosis	Giant boar fish
PENTACEROTIDAE	Zanclistus elevates	Black-spotted boarfish
PLATYCEPHALIDAE	Platycephalus caeruleopun	Eastern blue spot flathead
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead
PLATYCEPHALIDAE	Platycephalus marmoratus	Marble flathead
PLATYCEPHALIDAE	Platycephalus richardsoni	Tiger flathead
PLATYCEPHALIDAE	Ratabulus diversidens	Spikey flathead
RHINOBATIDAE	Aptychotrema rostrata	Shovelnose ray
RHINOBATIDAE	Trygonorrhina sp.	Banjo ray
RHYNCHOBATIDAE	Rhynchobatus djiddensis	White-spotted shovelnose ray
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish
SCIAENIDAE	Atractoscian aequidens	Teraglin
SCOMBRIDAE	Sarda australis	Bonito
SCORPAENIDAE	Helicolenus percoides	Ocean perch
SCORPAENIDAE	Scorpaena cardinalis	Red rock cod
SERRANIDAE	Epinephelus septemfasciat	Bar cod
SILLAGINIDAE	Sillago flindersi	Red spot whiting
SILLAGINIDAE	Sillago robusta	Stout whiting
SPARIDAE	Pagrus auratus	Snapper
SPARIDAE	Rhabdosargus sarba	Tarwhine
SQUATINIDAE	Squatina spp.	Angel shark
TRIAKIDAE	Galeorhinus galeus	School shark
TRIAKIDAE	Mustelus antarcticus	Gummy shark
TRICHIURIDAE	Trichiurus lepturus	Hairtail
TRIGLIDAE	Chelidonichthys kumu	Red gurnard
ZEIDAE	Zeus faber	John dory
Crustaceans:		
PALINURIDAE	Jasus verreauxi	Eastern cray
PORTUNIDAE	Charybdis cruciata	Coral crab
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab

PORTUNIDAE	Portunus sanguinolentus	3 spot crab
RANINIDAE	Ranina ranina	Spanner crab
SCYLLARIDAE	Ibacus brucei	Bruce's bug
SCYLLARIDAE	Ibacus peronii	Balmain bug
SCYLLARIDAE	Ibacus sp.	Smooth bug

Molluscs:

LOLIGINIDAE	Loligo chinensis	Broad squid
LOLIGINIDAE	Loligo sp.	Slender squid
LOLIGINIDAE	Loliolus sp.	Bottle squid
LOLIGINIDAE	Sepioteuthis australis	Southern calamary
OCTOPODA (ORDER)	(unid. octopi)	Octopus
SEPIIDAE	Sepia sp.	Cuttlefish
TEUTHOIDAE	Nototodarus gouldi	Arrow squid

List of by-catch taxa from Port Stephens (oceanic fl

Family	Scientific name	Common name
Finfishes:		
AULOPIDAE	Aulopus purpurissatus	Sergeant baker
BERYCIDAE	Centroberyx affinis	Redfish
BOTHIDAE	Pseudorhombus arsius	Large-toothed flounder
BOTHIDAE	Pseudorhombus jenynsii	Small-toothed flounder
BRANCHIOSTEGIDAE	Branchiostegus wardi	Tilefish
CARANGIDAE	Pseudocaranx dentex	Silver trevally
CARANGIDAE	Trachurus declivis	Jack mackeral
CARCHARHINIDAE	Carcharhinus spp.	Whaler shark
CENTROLOPHIDAE	Seriolella brama	Warehou
CENTROLOPHIDAE	Seriolella punctata	Spotted trevalla
CHEILODACTYLIDAE	Cheilodactylus douglasi	Blue morwong
GEMPYLIDAE	Rexea solandri	Gemfish
HEMIRAMPHIDAE	Hyporhamphus australis	Eastern sea garfish
MONACANTHIDAE	(unid. leatherjackets)	unid. Leatherjacket
MONACANTHIDAE	Eubalichthys mosaicus	Mosaic leatherjacket
MONACANTHIDAE	Meuschenia trachylepis	Yellowfin leatherjacket
MONACANTHIDAE	Nelusetta ayraudi	Chinaman leatherjacket
MONACANTHIDAE	Parika scaber	Velvet leatherjacket
MULLIDAE	Upeneichthys lineates	Red mullet
MULLIDAE	Upeneus tragula	Bar-tailed goatfish
ORECTOLOBIDAE	(unid. wobbegongs)	Wobbegong
ORECTOLOBIDAE	Orectolobus maculatus	Spotted wobbegong
PARASCYLLIDAE	Parascyllium sp	Catshark
PENTACEROTIDAE	Paristiopterus labiosis	Giant boar fish
PENTACEROTIDAE	Pentaceropsis recuriviros	Long-snouted boarfish
PENTACEROTIDAE	Zanclistus elevates	Black-spotted boarfish
PLATYCEPHALIDAE	Platycephalus caeruleopun	Eastern blue spot flathead
PLATYCEPHALIDAE	Platycephalus fuscus	Dusky flathead
PLATYCEPHALIDAE	Platycephalus marmoratus	Marble flathead
PLATYCEPHALIDAE	Platycephalus richardsoni	Tiger flathead
PLATYCEPHALIDAE	Ratabulus diversidens	Spikey flathead
PLATYCEPHALIDAE	Suggrundus jugosis	Mud flathead
POMATOMIDAE	Pomatomus saltatrix	Tailor
PRISTIOPHORIDAE	Pristiophorus sp.	Saw shark
RHINOBATIDAE	Aptychotrema rostrata	Shovelnose ray
RHINOBATIDAE	Trygonorrhina sp.	Banjo ray
SCIAENIDAE	Argyrosomus hololepidotus	Jewfish
SCOMBRIDAE	Scomber australasicus	Blue mackerel
SCORPAENIDAE	Helicolenus percoides	Ocean perch
SERRANIDAE	Epinephelus septemfasciat	Bar cod
SILLAGINIDAE	Sillago flindersi	Red spot whiting
SPARIDAE	Pagrus auratus	Snapper
SPYRNIDAE	Sphyrna lewini	Hammerhead shark
SQUATINIDAE	Squatina spp.	Angel shark
TRIAKIDAE	Galeorhinus galeus	School shark
TRIAKIDAE	Mustelus antarcticus	Gummy shark
TRICHIURIDAE	Trichiurus lepturus	Hairtail

TRIGLIDAE	Chelidonichthys kumu	Red gurnard
ZEIDAE	Cyttus australis	Silver dory
ZEIDAE	Zenopsis nebulosis	Mirror dory
ZEIDAE	Zeus faber	John dory

Crustaceans:

GRAPSIDAE	Scylla serrata	Mud crab
PALINURIDAE	Jasus verreauxi	Eastern cray
PALINURIDAE	Linuparis trigonus	Barking cray
PENAEIDAE	Penaeus plebejus	King prawn
PORTUNIDAE	Charybdis cruciata	Coral crab
PORTUNIDAE	Portunus pelagicus	Blue swimmer crab
SCYLLARIDAE	Ibacus peronii	Balmain bug
SCYLLARIDAE	Ibacus sp.	Smooth bug

Molluscs:

LOLIGINIDAE	Loligo chinensis	Broad squid
LOLIGINIDAE	Loligo sp.	Slender squid
LOLIGINIDAE	Loliolus sp.	Bottle squid
LOLIGINIDAE	Sepioteuthis australis	Southern calamary
OCTOPODA (ORDER)	(unid. octopi)	Octopus
PECTINIDAE	Pecten fumatus	Tasmanian scallop
SEPIIDAE	Sepia sp.	Cuttlefish
TEUTHOIDAE	Nototodarus gouldi	Arrow squid

APPENDIX J

Kapala Cruise Report No. 112. Fisheries Research Institute, NSW Fisheries, 1993, 74 pp.

Graham, K.J., G.W. Liggins, J. Wildforster and S.J. Kennelly.

KAPALA CRUISE REPORT NO. 112

RELATIVE ABUNDANCES AND SIZE COMPOSITIONS OF PRAWNS AND BY-CATCH SPECIES ON NEW SOUTH WALES PRAWN GROUNDS DURING SURVEYS V-VIII (MAY 1991-MAY 1992).

by

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KAPALA CRUISE REPORT NO. 112

Report for Cruises 91-08 to 92-05 conducted between
May 1991 and May 1992.

OBJECTIVES

* To survey selected prawn grounds off northern and central New South Wales to obtain data on the relative abundances and size compositions of prawns and associated by-catch species on these grounds.

* To collect samples of king prawns for studies of their reproductive biology.

* To conduct exploratory trawling for prawns on grounds outside the survey areas.

* To tag and release king prawns on grounds south of Newcastle and off South West Rocks.

INTRODUCTION

During the period 1990-92, Fisheries Research Institute conducted a major study of the New South Wales prawn fishery. The study included an independent assessment of the relative abundances and size compositions of prawns and by-catch species on selected prawn grounds off central and northern New South Wales by FRV *Kapala.* At the same time, an observer-based survey of the catch and by-catch taken by estuarine and ocean prawn trawlers was completed.

Kapala's sampling gear was described in Kapala Cruise Report No.108 (Graham et al. 1991) and Andrew et al. (1991). Kennelly et al. (1993) and Kapala Cruise Report No.109 (Graham et al. 1992) discussed the development of the experimental design, and Kapala Cruise Report No.110 (Graham et al. 1993) detailed the survey sites and summarised the catch and size data collected during the first year of this two year project.

This report summarises the catch and size data collected during Surveys V-VIII (the second year of the program); the relative abundances (catch rates) of prawns and important by-catch species over the two year's sampling are also presented and discussed. No statistical analyses of the results are presented as these will be contained in a detailed journal publication. Also included in this report are operational and catch data for exploratory trawling and prawn tagging carried out during the period of Surveys V-VIII.

GEAR AND SAMPLING METHODS

Trawling was conducted with three 22 m headline length Florida Flyer prawn nets towed in a triple-rig arrangement.

The grounds (Fig.1) were surveyed four times in the year. Each survey comprised four 30 minute tows made during each of three days (on inshore school prawn grounds) and three nights (on offshore king prawn grounds). Trawling speed was approximately 2.75 knots. Between tows, *Kapala* travelled at 5 knots for 5 minutes in a randomly selected direction to provide independence between replicate tows.

A number of tows were also made at night on the inshore grounds and during the day on the offshore grounds to provide comparative data.

After each tow, the catches from the three codends were combined for sorting. The numbers and total weights of each commercial species of fish, crustacean and cephalopod were recorded. Length measurements of all commercial species of fish, squids and crustaceans, or subsamples of large catches, were recorded; fish and most species of squids were measured to the half cm below, bottle squid and crustaceans to the mm below. Up to four of the main trash (non-commercial) species were separated and weighed, and the total trash was weighed.

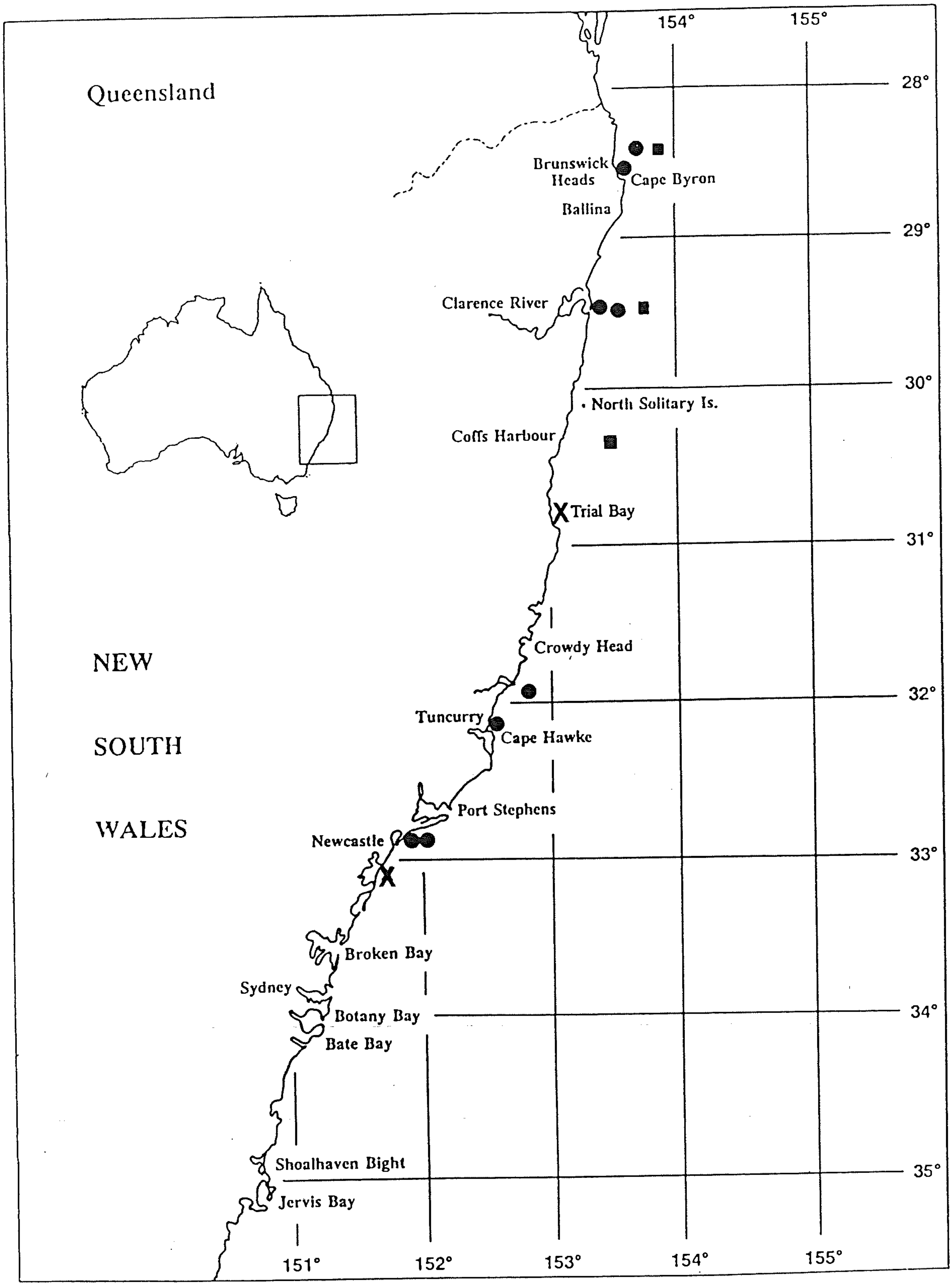

Figure 1: Map of northern and central NSW showing the survey grounds (●) off Brunswick Heads, the Clarence River, Tuncurry and Newcastle. Tagging sites (X) and the areas where exploratory trawling was conducted (■) are also indicated.

Samples of prawns were collected from all grounds and forwarded to FRI to provide data on their size composition and reproductive biology. Gonad samples from female king prawns were preserved onboard and also forwarded to FRI for histological examination. The results of these studies will be reported separately.

A species list of all fishes, crustaceans, and cephalopods was compiled for all tows. Most taxa have been identified to species level; unfamiliar species were referred to taxonomists at the Australian Museum in Sydney, the CSIRO Division of Fisheries in Hobart and a number of other institutions. Voucher specimens were retained by those institutions. Common names used in the text and their associated taxonomic names are listed in Appendix 1.

DATA ENTRY AND ANALYSIS

Data for each tow were entered onto a database with facilities for data verification, processing and statistical analyses. For this report, mean numbers and/or weights of commercial species, trash fish, total by-catch and numbers of species were generated for each area and each survey, and length-frequency histograms were produced for key species. By-catch was defined as all species except prawns.

RESULTS

Operational and total catch data for each 30 minute tow are presented in Appendix 2.

Tables 1 to 4 and 6 to 9 summarise the catch data for each survey. Shown are the number of tows from which each commercial species was recorded, and the mean catch numbers and/or weights of the composite by-catch components and those species caught in four or more tows per survey. The means were calculated for the total number of tows completed in each survey; catches referred to in the results are the survey means.

INSHORE GROUNDS

Operational problems were encountered during Survey VI on the Brunswick Heads ground and Survey V on the Newcastle grounds. On each occasion, damage to gear prevented the completion of the fourth tow of the day.

Prawn catches

On the Brunswick Heads ground, relatively large catches of school prawns were taken during Surveys V and VIII with mean catch rates of 6.3 and 3.7 kg/tow (Table 1). During both surveys most prawns were caught in the southern half of the ground close to Byron Bay with individual catches as high as 15 kg/tow (see Appendix 2a). Two night tows during Survey V caught 20.7 kg of school prawns for a total of one hour's trawling.

Very few prawns were present on the Clarence River ground during Surveys V, VI and VII; catches during Survey VIII averaged 5.2 kg/tow (Table 2). Most prawns were caught on the first day of the survey when the mean catch rate was 11.0 kg/tow (see Appendix 2g).

Almost no prawns were caught off Tuncurry during any of the surveys and on the Newcastle ground during Surveys V and VI; mean catch rates on the Newcastle ground for Surveys VII and VIII were 1.5 and 3.3 kg/tow (Tables 3 and 4). During Survey VII, almost the total prawn catch (17.4 kg of the total of 17.7 kg) was taken in three tows at the Newcastle Harbour end of the ground whereas during Survey VIII, substantial catches were taken in both halves of the ground (see Appendices 2f and 2h).

Large numbers of small king prawns were caught on the Clarence River ground during Survey VII (37.1/tow) and on the Newcastle ground during Survey VII (40.5/tow). Other species caught in small numbers were banana prawns (Brunswick Heads, Clarence River and Newcastle), leader and tiger prawns (Brunswick Heads and Clarence River) and greasyback prawns (Clarence River).

Crabs

Six species of commercial crabs were caught although few were of marketable size. Three-spotted crabs were common on the Brunswick Heads ground (Surveys V, VII and VIII), the Clarence River ground (Surveys VII and VIII), and off Newcastle (Survey VIII). Mean catch rates of two-spotted crabs ranged between 34 and 119 crabs/tow during the four surveys off Newcastle; very few were caught on the other grounds apart from Survey VII off the Clarence River (97/tow) and Survey VI off Tuncurry (26/tow). Blue-swimmer crabs were taken on all grounds but were more common off Tuncurry and Newcastle than on the two northern grounds. Small numbers of coral crabs (all grounds), spanner crabs (Brunswick Heads, Clarence River and Newcastle) and mud crabs (Newcastle) were also caught.

Squid and Octopus

Five species of squids were recorded from the four inshore grounds. Most common was the small bottle squid which was caught in large numbers on all grounds except Tuncurry. The highest mean catch rates were made off Brunswick Heads during Survey VIII (120 squid weighing 1.7 kg), off the Clarence River during Surveys VII and VIII (316 squid/4.2 kg and 386 squid/5.2 kg) and off Newcastle in Surveys V and VIII (176 squid/2.0 kg and 274 squid/3.4 kg). Broad squid was the only other species with catches in excess of 1.0 kg/tow and then only on the Tuncurry ground in Survey VIII. Southern calamary and slender squid were frequently caught but rarely in large numbers.

During Survey VIII on the Brunswick Heads ground, very large catches of octopus (mainly southern octopus) were taken (mean: 101 octopus weighing 11.4 kg/tow). Only small numbers of octopus were caught during other surveys and on the other grounds.

Fish

Forty-seven species of commercial and/or angling fishes were caught on the inshore grounds although only 10 species were taken in large numbers. Catch details for all significant commercial species are shown in Tables 1 to 4; data were not collected for incidentally-caught pelagic species (e.g. pilchard, common mackerel) which are sometimes marketed in small quantities.

Brunswick Heads (Table 1): During the four surveys, the average by-catch of commercial fish ranged from 40 to 70 kg per tow and comprised between about 40% and 70% of the total fish catch. Stout whiting was the dominant species: during Surveys V and VI, stout whiting comprised 77% and 92% of the mean total commercial catch weights of 45 and 48 kg/tow, and in Survey VIII, 53% of the 43 kg/tow mean. During Survey VII, the mean commercial catch of 70 kg/tow comprised mainly shovelnose rays (28 kg/tow) and stout whiting (26 kg/tow). Large numbers of sand flathead were caught in all surveys, especially Surveys VII and VIII (160/tow and 132/tow). Large numbers of juvenile red gurnard were also taken in Survey VII (72/tow).

The main trash fish species were stingarees, yellowtail and small toadfishes. The mean number of fish species ranged from 21/tow (Survey VI, August) to 38/tow (Survey VIII, February).

Clarence River (Table 2): Average total commercial fish catches ranged from 3.7 kg/tow (Survey V) to 53.5 kg/tow (Survey VII). During all surveys, stout whiting was the main catch with a maximum mean of 25.4 kg/tow during Survey VII. Caught in large numbers were small sand flathead (Survey VII: 95/tow and Survey VIII: 108/tow), small red gurnard (Survey VII: 155/tow) and small snapper (Survey VII; 64/tow). The trash component of the by-catch ranged from 7.7 kg/tow (Survey V) to 38.8 kg/tow (Survey VIII) and consisted mainly of stingarees and small pelagic species such as yellowtail and seapike.

Tuncurry (Table 3): Apart from Survey VIII when overall catch rates were low, commercial fish species made up a small proportion of the total by-catch. By weight, only banjo rays and shovelnose rays (Surveys VI and VII), and sand flathead (Survey VII) exceeded 10 kg/tow; large numbers of stout whiting and small snapper were caught during Survey VIII. Trash fish catches were relatively large with the means ranging from 126 kg/tow (Survey V) to 242 kg/tow (Survey VII); the main trash species were stingarees and smooth boxfish

Newcastle (Table 4): Catches of commercial and trash fish were very small off Newcastle. The mean total commercial fish catch and mean trash catch was less than 15 kg/tow for any survey. Significant numbers of small red gurnard (Survey VII), juvenile mulloway (Survey VIII), tailor (Survey VIII) and redspot whiting (Surveys V and VI) were caught.

Total by-catch
The range of means of total by-catch per tow for the four surveys were: Brunswick Heads 68-162 kg; Clarence River 13-94 kg; Tuncurry 68-275 kg; Newcastle 18-44 kg. On four of the occasions when prawn catch rates exceeded 1.0 kg/tow (Brunswick Heads, Surveys V; Clarence River, Survey VIII; and Newcastle, Surveys VII and VIII), the prawn catch to by-catch ratios were about 1:14; the ratio was 1:33 for the catches on the Brunswick Heads ground during Survey VIII.

Night-time Trawling on Inshore Grounds

Two 30 minute night-time tows were made on each of the Brunswick Heads ground and the Tuncurry ground during Survey V; during all surveys, a pair of night tows were completed on the Clarence River and Newcastle grounds. Catch data for the night-time tows are summarised in Table 5.

On the Brunswick Heads ground, the average night-time catch rates of school prawns (10.5 kg/tow), two-spotted crabs (9.0 kg/tow) and trash fish (62.5 kg/tow) were higher than the mean catch rates of the daytime tows; the stout whiting catch rate (25.0 kg/tow) was lower.

Night-time catches on the Clarence River ground of three-spotted crabs (all surveys) and sand flathead (Surveys VII and VIII) were substantially greater than the average daytime catches (Table 2). School prawn catches during day and night were similar; few king prawns were caught except for the two tows during Survey VII when 10.3 kg of small prawns were taken.

During Survey V, the catch rate of school prawns on the Newcastle ground was significantly higher at night compared to the daytime catch rate (4.2 kg/tow and 0.1 kg/tow respectively). Night catches of two-spotted crabs were about double those from daytime tows during Surveys VI and VII, and the catch numbers and weights of small sand flathead were several fold greater during Surveys V, VI and VIII.

Table 1: Summary of catch data for the commercial species and by-catch components caught on the Brunswick Heads inshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight per tow for each survey (* present in less than 4 tows, no catch data given).

	Survey V (May)			Survey VI (August)			Survey VII (November)			Survey VIII (February)		
	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/11	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)
Prawn-school	12	977.2	6.3	5	2.3	0.1	6	1.6	0.1	12	350.1	3.7
Prawn-banana	8	3.3	0.1	0			0			10	1.7	0.1
Prawn-king	5	1.6	0.1	2	*		7	0.8	0.1	0		
Prawn-leader	6	1.3	0.1	0			0			8	2.1	0.1
Prawn-tiger	5	0.6	0.1	0			0			1	*	
Crab-blue swimmer	3	*		2	*		10	6.8	0.2	7	1.3	0.1
Crab-coral	3	*		1	*		6	0.8	0.2	3	*	
Crab-spanner	0			0			5	0.4	0.1	4	0.4	0.1
Crab-three spotted	12	80.8	4.6	11	4.5	0.4	12	23.2	1.9	12	58.9	5.7
Crab-two spotted	0			0			5	0.75	0.1	0		
Cuttlefish	0			1	*		0			0		
Squid-bottle	12	59.0	0.7	11	32.6	0.3	12	17.1	0.3	12	120.2	1.7
Squid-broad	10	6.2	0.2	8	2.4	0.1	3	0.3	*	10	3.3	0.1
Squid-sthn calamary	1	*		1	*		6	2.2	0.1	0		
Octopus	9	7.3	0.8	1	*		0			12	100.8	11.4
Flathead-dusky	1	*		0			11	2.6	0.6	8	1.3	0.2
Flathead-sand	12	33.3	1.5	10	37.8	1.4	12	160.4	8.6	12	131.5	6.4
Flathead-nthn sand	4	0.4	0.1	1	*		12	10.4	0.5	12	3.5	0.2
Flounder-bigtooth	6	0.7	0.1	7	1.7	0.2	12	31.4	4.9	12	8.0	1.0
Flounder-smalltooth	0			4	0.6	0.1	6	0.5	0.1	0		
Flounder-smoothback	0			0			2	*		12	20.5	0.3
Goatfish-bartailed	0			1	*		0			0		
Gurnard-red	0			3	*		12	72.2	1.7	6	0.8	0.1
L'jacket-Chinaman	0			0			1	*		0		
L'jacket-mosaic	0			0			1	*		0		
Ray-shovelnose	12	12.9	3.3	11	4.8	1.5	12	91.6	27.8	12	102.7	8.5
Ray-white spotted	1	*		0			2	*		0		
Red mullet	0			2	*		2	*		1	*	
Samsonfish	0			0			0			2	*	
Shark-whaler	2	*		0			0			3	*	
Shark-wobbegong	1	*		0			0			0		
Snapper	4	0.3	0.1	0			0			4	3.7	0.2
Tailor	12	18.5	2.0	0			0			8	4.6	0.5
Tarwhine	3	*		0			0			7	2.6	0.1
Teraglin	8	1.7	0.1	0			0			7	2.8	0.3
Whiting-redspot	10	41.3	0.9	10	17.4	0.4	7	1.1	0.1	12	41.3	0.8
Whiting-stout	12	694.0	35.0	11	3054.6	44.4	12	780.8	25.6	12	327.1	22.8
Whiting-trumpeter	0			0			0			2	*	
Total crabs	12		4.8	11		0.4	12		2.3	12		5.9
Total cephalopods	12		1.8	11		0.5	12		0.3	12		13.2
Total comm. fish	12		48.1	11		48.1	12		69.9	12		42.5
Trash fish	12		33.9	11		19.6	12		89.2	12		61.8
Total by-catch	**12**		**88.6**	**11**		**68.6**	**12**		**161.7**	**12**		**123.4**
Spp-fish	12	24.0		11	20.9		12	26.0		12	38.3	
Spp-crustacea	12	7.8		11	2.9		12	9.7		12	8.4	
Spp-cephalopod	12	3.1		11	1.9		12	2.4		12	2.8	

Table 2: Summary of catch data for the commercial species and by-catch components caught on the Clarence River inshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight per tow for each survey (+ trawlers working ground; * present in less than 4 tows, no catch data given).

	Survey V (May)			Survey VI (August)			Survey VII (November)			Survey VIII+ (March–April)		
	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)
Prawn–banana	0			0			0			2	*	
Prawn–greasyback	0			0			1	*		4	0.8	0.1
Prawn–king	1	*		0			12	37.1	0.2	8	8.5	0.2
Prawn–leader	0			0			0			7	1.1	0.1
Prawn–school	1	*		1	*		5	0.9	0.1	12	1008.7	5.2
Prawn–tiger	0			0			1	*		1	*	
Crab–blue swimmer	6	0.5	0.1	7	0.8	0.1	9	1.0	0.2	10	1.9	0.4
Crab–coral	1	*		0			5	0.7	0.2	2	*	
Crab–three spotted	8	3.5	0.2	12	4.8	0.3	11	49.7	3.7	12	52.2	3.3
Crab–two spotted	1	*		1	*		12	96.6	1.0	5	0.42	0.1
Crab–spanner	0			0			3	*		0		
Cuttlefish	1	*		2	*		2	*		2	*	
Squid–bottle	12	45.2	0.4	12	39.8	0.4	12	316.3	4.2	12	386.3	5.2
Squid–broad	12	29.3	0.7	8	2.9	0.2	6	0.9	0.1	4	0.3	0.1
Squid–slender	1	*		1	*		3	*		0		
Squid–sthn calamary	8	1.4	0.6	1	*		5	0.9	0.1	0		
Octopus	2	*		0			0			0		
Cobia	0			1	*		0			2	*	
Flathead–dusky	0			0			7	0.7	0.2	5	0.7	0.1
Flathead–sand	8	1.3	0.1	11	6.4	0.4	12	95.3	11.5	12	108.0	5.5
Flathead–nthn sand	1	*		0			6	0.9	0.1	1	*	
Flounder–bigtooth	3	*		4	0.5	0.1	11	4.3	0.4	9	2.1	0.1
Flounder–smalltooth	6	0.9	0.1	1	*		12	8.0	0.2	5	0.6	0.1
Flounder–smoothback	8	1.0	0.1	6	1.5	0.1	2	*		9	9.5	0.3
Goatfish–bartailed	0			0			1	*		0		
Gurnard–red	0			0			12	155.4	5.7	1	*	
Hairtail	0			0			0			1	*	
John dory	1	*		0			2	*		0		
L'jacket–Chinaman	0			0			4	0.4	0.1	0		
L'jacket–yellowfin	0			1	*		0			0		
Mullet–red	1	*		1	*		12	6.0	0.2	0		
Mulloway	0			0			0			9	5.7	0.1
Ray–shovelnose	5	0.8	0.1	3	*		1	*		12	16.4	1.7
Shark–gummy	0			0			1	*		0		
Shark–whaler	1	*		0			0			0		
Shark–wobbegong	0			1	*		0			0		
Snapper	7	0.8	0.1	0			12	64.5	0.5	10	6.4	0.4
Tailor	1	*		1	*		0			9	4.3	0.4
Tarwhine	2	*		1	*		0			5	1.6	0.1
Teraglin	2	*		0			0			5	1.4	0.1
Whiting–redspot	7	15.9	0.3	11	168.8	3.2	11	387.1	9.2	11	28.9	0.5
Whiting–stout	12	70.8	2.5	12	589.8	12.2	12	1138.4	25.4	12	738.8	19.4
Whiting–trumpeter	0			1	*		1	*		2	*	
Total crabs	12		0.4	12		0.4	12		4.2	12		3.7
Total cephalopods	12		1.6	12		0.7	12		4.4	12		5.3
Total comm. fish	12		3.7	12		17.3	12		53.5	12		28.8
Trash fish	12		7.7	12		25.4	12		31.2	12		38.8
Total by-catch	**12**		**13.4**	**12**		**43.8**	**12**		**93.3**	**12**		**76.6**
Spp–fish	12	18.4		12	18.4		12	28.2		12	34.8	
Spp–crustacea	12	2.8		12	2.5		12	7.3		12	9.0	
Spp–cephalopods	12	3.1		12	1.9		12	2.4		12	1.8	

Table 3: Summary of catch data for the commercial species and by-catch components caught on the Tuncurry inshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight per tow for each survey (* present in less than 4 tows, no catch data given).

	Survey V (June)			Survey VI (Aug-Sept)			Survey VII (December)			Survey VIII (May)		
	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)
Prawn-king	0			0			1	*		1	*	
Prawn-school	2	*		0			0			4	44.2	0.2
Crab-blue swimmer	10	1.7	0.5	12	5.4	1.6	8	3.7	1.2	12	10.4	2.6
Crab-coral	0			1	*		1	*		6	0.7	0.1
Crab-three spotted	0			0			0			4	9.2	0.1
Crab-two spotted	6	4.8	0.2	9	26.3	2.0	1	*		0		
Cuttlefish	0			1	*		0			0		
Octopus	2	*		10	4.1	1.0	11	9.0	1.6	8	1.1	0.2
Squid-bottle	10	22.4	0.2	11	16.0	0.2	0			9	2.3	0.1
Squid-broad	12	9.5	0.6	10	3.9	0.3	0			11	30.9	1.8
Squid-Gould's	0			1	*		0			0		
Squid-sthn calamary	6	1.0	0.3	7	2.9	0.2	12	10.2	0.6	5	0.4	0.1
Squid-slender	2	*		1	*		0			4	0.6	0.1
Barred cod	1	*		0			0			1	*	
Cobia	0			0			1	*		0		
Flathead-dusky	0			0			7	0.8	0.3	3	*	
Flathead-sand	11	4.9	0.4	12	16.1	1.2	12	221.2	13.6	12	20.9	2.3
Flathead-nthn sand	0			5	0.8	0.1	6	1.1	0.1	4	0.6	0.1
Flounder-bigtooth	3	*		9	2.8	0.5	12	24.8	4.9	12	7.3	0.9
Flounder-smalltooth	1	*		3	*		9	2.3	0.4	6	0.8	0.1
Flounder-smoothback	0			1	*		8	2.5	0.1	3	*	
Goatfish-bartailed	6	2.4	0.1	5	3.4	0.1	4	2.4	0.1	9	4.3	0.2
Gurnard-red	3	*		11	5.8	0.2	11	3.5	0.2	10	4.3	0.4
John dory	6	1.0	0.2	0			1	*		0		
L'jacket-Chinaman	0			0			5	0.9	0.1	0		
L'jacket-mosaic	0			1	*		0			0		
L'jacket-yellowfin	6	0.9	0.1	9	2.3	0.1	0			4	0.4	0.1
Mulloway	0			0			0			1	*	
Ray-banjo	10	1.8	1.8	12	13.6	14.6	12	12.1	12.2	3	*	
Ray-shovelnose	10	3.2	2.5	12	10.1	9.5	12	31.8	27.1	11	4.6	3.2
Red mullet	3	*		1	*		1	*		3	*	
Samsonfish	0			0			10	2.3	0.1	0		
Shark-inshore angel	0			0			3	*		0		
Shark-wobbegong	0			1	*		0			0		
Snapper	4	1.3	0.1	1	*		7	6.7	0.4	12	46.9	2.5
Tailor	3	*		0			0			4	6.1	0.5
Tarwhine	2	*		0			5	0.7	0.1	6	5.3	0.1
Teraglin	0			0			0			4	5.9	0.1
Trevally-silver	1	*		4	0.5	0.1	0			5	6.7	1.1
Whiting-redspot	7	8.8	0.2	7	20.8	0.6	9	17.2	1.1	11	12.9	1.2
Whiting-stout	4	18.7	1.0	2	*		8	39.3	1.9	12	132.7	8.5
Whiting-trumpeter	2	*		0			1	*		8	2.4	0.3
Total crabs	12		0.7	12		3.6	12		1.2	12		2.8
Total cephalopods	12		1.1	12		1.8	12		1.6	12		2.3
Total comm. fish	12		7.6	12		27.1	12		63.3	12		21.9
Trash fish	12		126.0	12		242.2	12		182.9	12		41.2
Total by-catch	**12**		**135.4**	**12**		**274.7**	**12**		**149.0**	**12**		**68.2**
Spp-fish	12	25.2		12	27.1		12	33.8		12	31.3	
Spp-crustacea	12	1.8		12	1.9		12	0.9		12	2.3	
Spp-cephalopod	12	3.7		12	2.8		12	3.8		12	3.1	

Table 4: Summary of catch data for the commercial species and by-catch components caught on the Newcastle inshore ground. The data show the number of shots in which each was caught, and the mean number and/or weight per tow for each survey (+ trawlers working ground; * present in less than four tows, no catch data given).

	Survey V (June)			Survey VI (Aug–Sept)			Survey VII (Nov–Dec)			Survey VIII+ (April)		
	No.of Tows/11	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)
Prawn–king	0			0			8	12.1	0.1	10	40.5	0.4
Prawn–school	11	1.8	0.1	5	2.0	0.1	9	188.9	1.5	12	256.8	3.3
Prawn–banana	0			0			0			1	*	
Bug–Balmain	0			1	*		0			0		
Crab–blue swimmer	10	4.7	0.9	8	2.2	0.3	9	2.8	0.4	10	7.8	1.8
Crab–coral	0			0			1	*		5	0.5	0.1
Crab–mud	0			0			0			4	0.4	0.3
Crab–spanner	0			0			2	*		0		
Crab–three spotted	10	5.9	0.6	5	1.0	0.1	10	5.3	0.5	12	123.4	2.4
Crab–two spotted	11	34.4	3.5	12	54.1	7.3	12	63.3	4.5	12	118.8	14.7
Lobster–eastern	0			0			2	*		0		
Octopus	3	*		4	0.4	0.1	5	0.8	0.2	2	*	
Squid–bottle	11	176.3	2.0	12	89.2	1.2	12	74.5	1.1	12	274.3	3.4
Squid–broad	10	8.7	1.0	12	8.1	0.4	12	6.3	0.6	5	0.7	0.1
Squid–Gould's	0			2	*		3	*		0		
Squid–slender	4	0.4	0.1	1	*		1	*		0		
Squid–sthn calamary	2	*		6	0.6	0.1	9	2.1	0.7	0		
Bream–yellowfin	2	*		0			4	0.4	0.3	5	2.6	1.1
Flathead–dusky	0			2	*		2	*		8	1.8	0.7
Flathead–sand	11	18.2	1.2	12	7.5	0.4	12	10.8	0.9	12	9.2	0.4
Flathead–nthn sand	1	*		4	0.3	0.1	7	0.8	0.1	2	*	
Flounder–bigtooth	9	1.7	0.2	7	0.8	0.1	9	1.3	0.2	11	5.8	1.0
Flounder–smalltooth	5	0.7	0.1	5	0.8	0.1	1	*		4	0.7	0.1
Flounder–smoothback	3	*		2	*		2	*		4	0.3	0.1
Goatfish–bartailed	1	*		2	*		0			0		
Gurnard–red	8	1.7	0.1	9	2.0	0.1	12	58.6	0.4	3	*	
Hairtail	0			0			5	15.9	1.5	4	0.9	0.4
John dory	1	*		1	*		1	*		0		
L'jacket–yellowfin	4	0.6	0.1	0			1	*		0		
Mulloway	0			1	*		2	*		10	42.5	0.4
Ray–shovelnose	2	*		6	0.9	0.3	5	0.5	0.1	9	5.8	3.6
Red mullet	1	*		0			0			2	*	
Shark–gummy	0			0			1	*		0		
Shark–hammerhead	0			0			0	*		5	0.4	0.5
Shark–whaler	0			1	*		0			3	*	
Snapper	0			0			1	*		0		
Tailor	7	2.3	0.3	3	*		11	12.9	0.6	11	125.0	4.5
Tarwhine	1	*		0			1	*		4	0.3	0.1
Teraglin	0			0			1	*		8	7.1	0.3
Trevally–silver	2	*		0			3	*		2	*	
Warehou–blue	0			0			7	1.3	0.1	0		
Warehou–spotted	0			0			1	*		0		
Whiting–redspot	11	425.5	2.1	12	125.6	1.1	12	35.3	0.3	11	18.2	0.2
Whiting–stout	5	4.3	0.1	9	13.1	0.2	10	9.0	0.1	4	0.6	0.1
Total crabs	11		5.0	12		7.7	12		5.4	12		19.3
Total cephalopods	11		3.2	12		1.8	12		2.1	12		3.5
Total comm. fish	11		4.1	12		3.0	12		4.9	12		14.5
Trash fish	11		6.4	12		14.0	12		7.1	12		6.3
Total by-catch	**11**		**18.7**	**12**		**26.5**	**12**		**19.5**	**12**		**43.6**
Spp–fish	11	24.2		12	18.1		12	23.7		12	28.7	
Spp–crustacea	11	4.8		12	3.0		12	5.0		12	6.8	
Spp–cephalopod	11	2.8		12	3.3		12	3.4		12	1.7	

Table 5: Catch data for the main species caught during night-time trawling on inshore grounds.

	Tow No.	School prawn (kg)	King prawn (kg)	Three spotted crab (kg)	Stout whiting (kg)	Sand flathead (no./wt)	Total comm. fish (kg)	Trash fish (kg)	Total by-catch (kg)	Fish spp. (no.)
Brunswick V	910836	16.0	0	13.0	20.0	56/2.0	35.0	70.0	119.7	28
	910837	4.7	0	5.4	30.0	167/6.0	56.8	55.0	119.8	23
Clarence R. V	910818	0.9	0	4.3	2.1	3/0.2	5.7	15.0	28.7	32
	910819	0.5	0.1	13.0	2.0	8/0.7	4.3	9.0	21.2	30
VI	911233	0	0	0.2	17.0	37/2.8	31.5	24.0	55.9	24
	911234	1.2	0	3.6	5.2	73/2.8	10.3	37.0	52.3	28
VII	911641	0.2	6.3	14.8	0	300/40.0	66.4	35.0	127.1	22
	911642	0	4.0	4.8	7.5	33/5.5	33.7	80.0	121.5	29
VIII	920240	3.0	0.5	3.2	17.5	480/25.0	49.7	11.0	68.9	35
	920241	5.2	0.2	6.2	13.5	885/40.0	59.0	16.0	86.9	32
				Two-spot crab(kg)	Redspot whit.(kg)					
Tuncurry V	911009	0.1	0.1	0	0	19/1.5	6.5	78.0	93.1	33
	911010	0	0	0.1	0.1	7/0.9	6.8	380.0	398.7	26
Newcastle V	911105	3.8	0.1	1.8	1.5	135/4.5	7.6	10.0	45.7	25
	911106	4.5	0	2.3	2.2	119/5.3	12.1	16.0	36.2	29
VI	911421	0.3	0.1	13.6	2.2	15/1.5	6.9	10.0	36.4	24
	911422	0.8	0.1	15.0	2.3	39/2.3	6.1	27.0	52.9	27
VII	911801	2.3	0.9	10.1	0.1	16/1.0	2.9	5.0	23.1	23
	911802	1.2	0.7	8.8	0.2	18/0.9	3.3	7.0	23.2	24
VIII	920411	1.8	0.3	13.5	1.7	41/1.9	10.2	18.0	46.3	27
	920412	3.1	0.2	8.0	1.6	70/1.6	7.9	7.0	31.3	32

OFFSHORE GROUNDS (Tables 6-9)

Logistical problems prevented the completion of two surveys. A full night's sampling was lost because of persistent bad weather off the Clarence River (Survey VII). Off Tuncurry only three tows were finished before daylight on one night during Survey VII.

Prawns

Mean catch rates of king prawns on the Brunswick Heads ground were very low during Surveys V and VI (0.1 and 0.4 kg/tow); they increased to 2.8 and 5.8 kg/tow during Surveys VII and VIII. Off the Clarence River, the mean prawn catch rates were low for all surveys ranging from 1.3 to 3.6 kg/tow. Relatively few king prawns were caught on the Tuncurry ground during Surveys V, VI and VII but during Survey VIII, the mean catch rate was a high 10.5 kg/tow. Catches off Newcastle were consistently large with the means ranging from 4.3 kg/tow (Survey VIII) to 7.5 kg/tow (Survey V). Significant quantities of Racek prawns were also caught off Newcastle during Surveys VII and VIII (6.3 and 3.2 kg/tow).

Bugs and Crabs

Smooth bugs were the only commercial crustaceans other than prawns which were caught in quantity. Smooth bugs were taken on all grounds although mainly off Brunswick Heads and the Clarence River. The highest mean catch rate was off Brunswick Heads during Survey VII (21 bugs; 2.7 kg/tow).

On the Newcastle ground, a large proportion of the trash consisted of two species of non-commercial swimming crabs (*Charybdis miles* and *C. bimaculata*)

Cephalopods and Scallops
Cuttlefish were caught on all grounds but were most prolific off Tuncurry. On the Brunswick Heads ground, the highest mean catch rate was 3.6 kg/tow (Survey VIII); off the Clarence River, mean catches ranged from 1.6 kg/tow (Survey V) to 5.6 kg/tow (Survey VII). The Tuncurry catches averaged between 1.5 kg/tow (Survey VII) and 8.2 kg/tow (Surveys VI); cuttlefish catches on the Newcastle ground were consistently small with a maximum of 1.1 kg/tow (Survey VII).

Very large catches of octopus (mainly southern octopus) were taken off Brunswick Heads and the Clarence River during Survey VIII (10.0 and 21.0 kg/tow). Octopus catches were small during the other surveys and on the other grounds.

Small numbers of slender squid, southern calamary and Gould's squid were also caught on the offshore grounds but never in substantial quantities.

Small southern scallops were numerous in a number of tows off Newcastle, especially during Surveys VI and VIII. Six small (41-58 mm) saucer scallops were caught off the Clarence River during Survey VII, and a single juvenile (25 mm) was taken off Newcastle in Survey VIII.

Fish
Forty-two commercial and/or angling species were recorded from the offshore grounds, 27 from Brunswick Heads/Clarence River and 36 from Tuncurry/Newcastle. Tables 6 to 9 list the catch details for 36 of these species. Apart from some catches on the Tuncurry ground, commercial species seldom formed a large proportion of the by-catch.

Off Brunswick Heads and the Clarence River, commercial species comprised less than 10% of the total by-catch weights in all but one survey. During Survey VI off the Clarence River, redspot whiting catches averaged 5.5 kg/tow and increased the commercial fish component to 16% of the total by-catch. On the Brunswick Heads ground, the mean numbers of smooth flounder ranged from 21/tow to 58/tow; red mullet were also caught in large numbers during Survey VIII (66/tow) on this ground. Other commercial species consistently caught in small numbers on both grounds were sand flathead and red gurnard. The mean catch rates of trash fish were comparatively high on the Brunswick Heads ground ranging from 79 kg/tow (Survey V) to 318 kg/tow (Survey VIII). Off the Clarence River, large catches of trash fish were taken only during Survey VIII (162 kg/tow); mean catch rates during the other surveys were 46-48 kg/tow. The principal components of the trash fish by-catch were small butterfly gurnards and stinkfish.

On the Tuncurry ground, commercial fish species comprised between 20% and 30% of the total by-catch weights during the four surveys. Tiger flathead (7.7 kg/tow to 15.3 kg/tow during Surveys V-VII) and redspot whiting (9.0 kg/tow and 6.5 kg/tow during Surveys VI and VIII) were the main components. Catches of trash fish ranged from a minimum of 18 kg/tow during Survey VIII when the ground was being fished by commercial trawlers to a maximum of 166 kg/tow (Survey VI) and comprised mainly stingarees and butterfly gurnards.

Weights of commercial fish caught on the Newcastle ground were relatively small and ranged between 5.2 kg/tow and 11.3 kg/tow. However, significant numbers of juvenile tiger flathead (193/tow,Survey VI; 115/tow, Survey VII) and redfish (70/tow, Survey V; 87/tow, Survey VI) were caught. The by-catch of trash fish was less than 20 kg/tow for all surveys except Survey VII (70 kg/tow) when relatively large catches of yellowtail were taken.

Table 6: Summary of catch data for the commercial species and by-catch components caught on the Brunswick Heads offshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight per tow for each survey (+ trawlers working ground; * present in less than 4 tows, no catch data given).

	Survey V (May)			**Survey VI** (August)			**Survey VII** (November)			**Survey VIII+** (March-April)		
	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)
Prawn-king	6	1.1	0.1	11	9.8	0.4	12	53.6	2.8	12	95.4	5.8
Bug-Balmain	3	*		4	0.4	0.1	3	*		2	*	
Bug-smooth	11	2.7	0.3	11	4.4	0.6	12	20.7	2.7	7	2.1	0.2
Crab-blue swimmer	1	*		0			0			5	0.6	0.2
Cuttlefish	11	9.5	0.6	12	26.8	1.1	12	51.0	3.0	12	50.9	3.6
Octopus	11	5.8	0.5	11	6.3	0.5	12	4.6	0.7	12	91.4	10.0
Squid-Goulds	7	1.1	0.4	1	*		1	*		0		
Squid-slender	12	13.6	1.3	11	10.3	0.5	8	1.8	0.2	12	6.2	0.7
Squid-sthn calamary	11	1.6	0.6	4	0.5	0.3	6	0.8	0.1	8	1.3	0.2
Flathead-sand	7	1.2	0.4	12	3.2	1.3	6	1.8	0.7	9	16.8	3.6
Flathead-marbled	0			2	*		2	*		8	0.9	0.1
Flathead-spiky	6	1.2	0.2	1	*		6	0.8	0.2	2	*	
Flounder-smoothb'k	12	21.3	1.2	12	42.8	2.2	12	58.2	3.2	12	21.3	1.4
Gurnard-red	6	1.2	0.2	10	5.2	0.7	7	2.4	0.3	11	15.0	1.4
Kingfish-banded	4	0.3	0.1	1	*		0			0		
Pearl perch	2	*		0			4	1.5	0.1	1	*	
Ray-banjo	0			0			3	*		7	1.1	0.5
Ray-shovelnose	1	*		4	0.5	0.5	7	1.1	0.7	11	3.7	1.7
Red mullet	7	8.8	0.6	9	3.4	0.2	3	0.3	0.1	11	66.4	3.2
Shark-gummy	8	1.8	0.4	0			11	1.9	2.1	8	2.1	0.5
Whiting-redspot	0			8	26.3	1.7	0			4	26.6	1.3
Whiting-stout	0			5	1.4	0.1	0			3	*	
Total bugs and crabs	12		0.5	12		0.7	12		2.7	12		0.6
Total cephalopods	12		3.4	12		2.4	12		4.0	12		14.5
Total comm. fish	12		3.2	12		6.8	12		7.5	12		14.1
Trash fish	12		78.8	12		92.1	12		128.8	12		318.3
Total by-catch	**12**		**86.0**	**12**		**102.0**	**12**		**143.0**	**12**		**347.5**
Spp-fish	12	30.3		12	29.1		12	32.9		12	37.3	
Spp-crustacea	12	3.5		12	4.8		12	6.3		12	5.7	
Spp-cephalopod	12	4.8		12	3.4		12	4.4		12	4.6	

Table 7: Summary of catch data for the commercial species and by-catch components caught on the Clarence River offshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight per tow for each survey (+ trawlers working ground; * present in less than 4 tows, no catch data given).

	Survey V+ (May)			Survey VI+ (August)			Survey VII (November)			Survey VIII (March-April)		
	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/8	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)
Prawn-king	12	51.4	2.2	12	100.3	3.6	8	26.8	1.3	12	47.8	3.4
Bug-Balmain	0			3	*		3	*		0		
Bug-smooth	12	17.8	1.2	12	21.1	0.9	7	7.9	0.3	12	15.3	1.2
Cuttlefish	12	16.0	1.6	12	45.8	2.6	8	98.0	5.6	12	27.3	2.0
Octopus	12	19.3	1.4	11	2.3	0.2	8	10.6	0.7	12	202.8	21.0
Squid-Goulds	11	1.6	0.6	8	1.1	0.3	4	0.8	0.1	0		
Squid-slender	12	8.0	0.9	12	5.4	0.3	8	7.4	0.3	8	1.6	0.2
Squid-sthn calamary	8	1.4	0.6	1	*		2	*		6	0.9	0.2
Barred cod	1	*		3	*		2	*		0		
Flathead-sand	0			5	0.6	0.2	2	*		3	*	
Flathead-spiky	4	0.5	0.1	7	1.4	0.1	8	15.0	0.6	12	21.2	1.4
Flathead-marbled	2	*		3	*		2	*		8	1.4	0.2
Flathead-tiger	0			1	*		0			0		
Flounder-smoothb'k	12	6.8	0.6	12	11.6	0.9	8	9.1	1.0	12	20.2	1.5
Gurnard-red	6	3.3	0.4	11	7.3	1.1	5	1.5	0.2	10	4.1	0.5
John dory	2	*		9	1.7	0.5	0			2	*	
L'jacket-Chinaman	1	*		0			0			0		
L'jacket-yellowfin	0			1	*		0			0		
Pearl perch	4	1.1	0.1	6	0.8	0.1	4	1.1	0.1	3	*	
Ray-shovelnose	0			4	0.4	0.3	0			3	*	
Redfish	1	*		5	1.3	0.1	3	*		0		
Red mullet	1	*		0			0			11	7.1	0.4
Shark-gummy	0			3	*		4	0.6	0.1	7	2.3	1.1
Shark-wobbegong	0			1	*		0			0		
Snapper	0			0			0			1	*	
Tarwhine	1	*		0			0			0		
Whiting-redspot	0			12	104.3	5.5	0			2	*	
Total bugs	12		0.6	12		0.9	8		0.3	12		1.3
Total cephalopods	12		5.1	12		3.5	8		6.8	12		23.4
Total comm. fish	12		1.5	12		10.1	8		2.0	12		5.6
Trash fish	12		46.2	12		47.2	8		46.6	12		162.1
Total by-catch	**12**		**53.4**	**12**		**61.7**	**8**		**55.7**	**12**		**192.4**
Spp-fish	12	27.7		12	30.7		8	30.8		12	34.0	
Spp-crustacea	12	5.3		12	6.3		8	6.1		12	3.5	
Spp-cephalopod	12	5.6		12	3.7		8	4.5		12	3.8	

Table 8: Summary of catch data for the commercial species and by-catch components caught on the Tuncurry offshore ground. The data show the number of shots in which each was caught, and the mean number and/or weight per tow for each survey (+ trawlers working ground; * present in less than 4 tows, no catch data given).

	Survey V (June)			Survey VI (Aug-Sept)			Survey VII (December)			Survey VIII+ (May)		
	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/11	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)
Prawn-king	12	72.9	1.4	12	41.7	1.1	9	3.6	0.1	12	610.9	10.5
Bug-Balmain	0			0			3	*		0		
Bug-Bruce's	0			0			1	*		1	*	
Bug-smooth	10	3.7	0.3	10	1.7	0.2	7	1.7	0.1	9	3.1	0.3
Lobster-barking	1	*		0			0			1	*	
Lobster-eastern	0			0			0			1	*	
Cuttlefish	12	61.8	7.4	12	75.2	8.2	11	20.6	1.5	12	57.2	6.2
Octopus	10	1.3	0.2	10	2.3	0.7	3	0.6	0.1	11	1.8	0.2
Squid-Gould's	10	4.9	2.3	10	12.5	1.2	10	9.8	0.7	6	0.6	0.2
Squid-slender	0			0			0			9	2.7	0.2
Squid-sthn cal.	6	1.0	0.5	3	*		0			0		
Barred cod	0			3	*		4	0.7	0.1	1	*	
Boarfish-giant	0			3	*		0			0		
Flathead-marbled	8	1.2	0.3	7	1.2	0.2	6	1.6	0.3	12	4.1	0.9
Flathead-sand	1	*		1	*		0			0		
Flathead-spiky	12	26.8	1.3	11	38.6	2.4	11	47.7	4.2	12	16.4	1.6
Flathead-tiger	12	25.2	8.7	12	40.4	15.3	11	20.1	7.7	7	2.8	1.0
Flounder-smoothb'k	10	2.0	0.2	11	5.0	0.7	5	0.8	0.2	6	0.8	0.1
Gurnard-red	10	3.4	0.7	9	5.3	1.5	5	2.1	0.6	1	*	
John dory	7	0.7	0.1	9	4.8	1.2	11	7.2	0.4	7	0.8	0.2
L'jacket-Chinaman	1	*		2	*		0			0		
L'jacket-mosaic	0			0			1	*		0		
L'jacket-velvet	0			2	*		1	*		1	*	
Morwong-rubberlip	1	*		4	0.9	0.5	8	0.7	0.1	0		
Ocean perch	0			0			1	*		1	*	
Ray-banjo	0			2	*		1	*		0		
Ray-shovelnose	1	*		7	1.6	1.8	1	*		0		
Redfish	11	6.8	1.1	11	16.7	4.0	7	1.1	0.1	5	0.6	0.1
Red mullet	1	*		2	*		2	*		0		
Shark-offshore angel	0			4	0.7	4.0	5	0.6	1.6	0		
Shark-greeneye	3	*		1	*		0			0		
Shark-gummy	0			3	*		0			0		
Shark-saw	0			9	3.1	2.0	2	*		2	*	
Shark-spiky dog	1	*		1	*		0			0		
Shark-wobbegong	0			3	*		0			0		
Snapper	0			0			1	*		0		
Whiting-redspot	5	40.1	2.8	6	120.7	9.0	6	3.2	0.3	7	97.4	6.5
Total crabs and bugs	12		0.3	12		0.2	11		0.4	12		0.4
Total cephalopods	12		10.2	12		10.2	11		2.3	12		6.8
Total comm. fish	12		16.0	12		45.1	11		17.7	12		10.7
Trash fish	12		49.1	12		110.9	11		74.6	12		17.7
Total by-catch	**12**		**75.6**	**12**		**166.4**	**11**		**95.0**	**12**		**35.6**
Spp-fish	12	29.3		12	29.8		11	26.4		12	26.2	
Spp-crustacea	12	7.8		12	6.1		11	6.2		12	6.6	
Spp-cephalopod	12	2.9		12	3.3		11	2.4		12	4.0	

Table 9: Summary of catch data for the commercial species and by-catch components caught on the Newcastle offshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight per tow for each survey (+ trawlers working ground; * present in less than 4 tows, no catch data given).

	Survey V (June)			Survey VI+ (Aug-Sept)			Survey VII (Nov-Dec)			Survey VIII+ (April)		
	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)	No.of Tows/12	Mean No.	Mean Wt.(kg)
Prawn-king	12	487.3	7.5	12	311.8	5.4	12	237.3	6.5	12	295.8	4.3
Prawn-Racek	8	17.8	0.2	11	139.5	0.4	12	850.7	6.3	11	265.1	3.2
Prawn-tiger	5	0.8	0.1	2	*		0			0		
Bug-smooth	3	*		6	0.8	0.1	3	*		9	1.4	0.2
Crab-blue swimmer	1	*		0			0			6	0.6	0.2
Crab-three spotted	0			8	1.0	0.1	0			0		
Crab-two spotted	0			0			0			2	*	
Lobster-barking	0			1	*		1	*		1	*	
Lobster-eastern	0			0			4	0.3	0.3	0		
Scallop	3	*		11	23.2		3	*	–	10	19.9	–
Cuttlefish	11	3.2	0.3	12	5.3	0.3	12	19.3	1.1	12	6.0	0.3
Octopus	8	3.2	0.6	2	*		3	*		11	3.8	0.4
Squid-Gould's	1	*		3	*		12	33.5	1.8	0		
Squid-sthn calamary	4	0.6	0.1	0			5	0.5	0.1	0		
Barred cod	6	0.7	0.1	2	0.3	0.1	3	*		0		
Flathead-sand	1	*		0			0			1	*	
Flathead-spiky	9	9.8	0.3	8	6.3	0.3	11	8.9	0.6	11	4.1	0.2
Flathead-tiger	12	46.1	0.5	12	193.0	4.3	12	114.8	7.6	10	3.3	0.3
Flounder-bigtooth	1	*		0			0			0		
Flounder-smoothback		2	*		0			1	*		0	
Gurnard-red	4	0.4	0.1	8	1.0	0.1	1	*		0		
Hairtail	1	*		0			0			0		
John dory	9	2.1	0.4	6	1.0	0.1	10	4.8	0.1	10	1.8	0.3
L'jacket-Chinaman	1	*		0			0			2	*	
L'jacket-yellowfin	0			1	*		0			0		
L'jacket-velvet	0			5	0.6	0.1	2	*		1	*	
Morwong-rubberlip	0			2	*		4	0.4	0.1	0		
Ocean perch	6	7.5	0.1	7	8.6	0.1	11	9.0	0.2	12	49.8	0.2
Ray-banjo	2	*		0			1	*		1	*	
Ray-shovelnose	5	0.4	0.8	4	0.4	0.8	1	*		3	*	
Redfish	12	70.0	1.6	12	87.3	0.8	12	10.8	0.2	6	0.8	0.1
Red mullet	9	1.4	0.1	2	*		1	*		1	*	
Shark-gummy	0			0			1	*		0		
Shark-saw	0			0			4	0.4	0.1	0		
Shark-wobbegong	0			0			1	*		0		
Snapper	2	*		0			0			0		
Tailor	3	*		0			0			0		
Tilefish-pink	9	6.8	1.0	12	5.2	0.7	12	11.0	1.9	10	6.3	1.1
Warehou-blue	0			0			4	0.3	0.1	0		
Warehou-spotted	0			0			1	*				
Whiting-redspot	10	205.7	2.7	6	0.8	0.1	0			7	10.3	0.2
Total comm. crust.	12		0.1	12		0.2	12		0.4	12		0.4
Total cephalopods	12		1.0	12		0.4	12		3.1	12		0.8
Total comm. fish	12		8.1	12		7.4	12		11.3	12		5.2
Trash fish	12		14.9	12		17.3	12		70.0	12		16.4
Trash crustacea	12		12.2	12		20.3	12		6.3	12		31.0
Total by-catch	**12**		**36.3**	**12**		**45.6**	**12**		**91.1**	**12**		**53.8**
Spp-fish	12	27.8		12	23.3		12	28.0		12	26.8	
Spp-crustacea	12	11.4		12	14.5		12	14.4		12	13.8	
Spp-cephalopod	12	2.6		12	1.7		12	2.8		12	3.2	

APPENDIX I

Kapala Cruise Report No. 110. Fisheries Research Institute, NSW Fisheries, 1993, 69 pp.

Graham, K.J., G.W. Liggins, J. Wildforster and S.J. Kennelly.

KAPALA CRUISE REPORT NO. 110

by

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KAPALA CRUISE REPORT NO. 110

Report for Cruises 90-08 to 91-05 conducted between
May 1990 and April 1991.

OBJECTIVES

* To survey selected prawn grounds off northern and central New South Wales to obtain data on the relative abundances and size compositions of the prawns and associated by-catch species on those grounds.

* To collect samples of king prawns for studies of their reproductive biology.

* To conduct exploratory trawling for prawns on grounds outside the survey areas.

INTRODUCTION

In 1990, the Fisheries Research Institute began a major study of the New South Wales prawn fishery. A large part of the study was an onboard assessment of the catch and by-catch taken by estuarine and ocean prawn trawlers. In addition, a program was designed for FRV *Kapala* to independently assess the relative abundances and size compositions of prawns and by-catch species on selected prawn grounds off central and northern New South Wales.

Kapala Cruise Report No.108 (Graham et al. 1991) and Andrew et al. (1991) described in detail the prawn trawling gear to be used. Cruise Report 109 (Graham et al. 1992) and Kennelly et al. (1992) outlined two experiments which developed the sampling methodology for the *Kapala* surveys.

This report summarises the catch and size data collected during Surveys I-IV (the first year of this two year project). No statistical analyses of the results are presented as these will be included in a detailed journal publication.

GEAR AND SAMPLING METHODS

Trawling was conducted with three 22 m headline length Florida Flyer prawn nets towed in a triple-rig arrangement.

The program design was to survey four times a year prawn grounds which encompassed two of the main facets of the New South Wales prawn fishery: inshore school prawn grounds fished mainly during the day, and the more offshore king prawn grounds fished at night. Each survey comprised four 30 minute tows made during each of three days (on school prawn grounds) or three nights (on king prawn grounds) on each of the selected grounds. Trawling speed was approximately 2.75 knots. Between tows, *Kapala* travelled at 5 knots for 5 minutes in a randomly selected direction to provide independence between replicate tows.

A number of tows were also made at night on the inshore grounds and during the day on the offshore grounds to provide comparative data.

After each tow the catches from the three codends were combined for sorting. The numbers and total weights of each commercial species of fish, crustacean and cephalopod were recorded. Length measurements of all commercial species of fish, squids and crustaceans, or subsamples of large catches, were recorded; fish and most species of squids were measured to the half cm below, bottle squid and crustaceans to the mm below. Up to four of the main trash (non-commercial) species were separated and weighed, and the total trash was weighed.

Samples of prawns were collected from all grounds and forwarded to FRI to provide data on their size composition and reproductive biology. Gonad samples from female king prawns were preserved onboard and also forwarded to FRI for histological examination. The results of these studies will be separately reported.

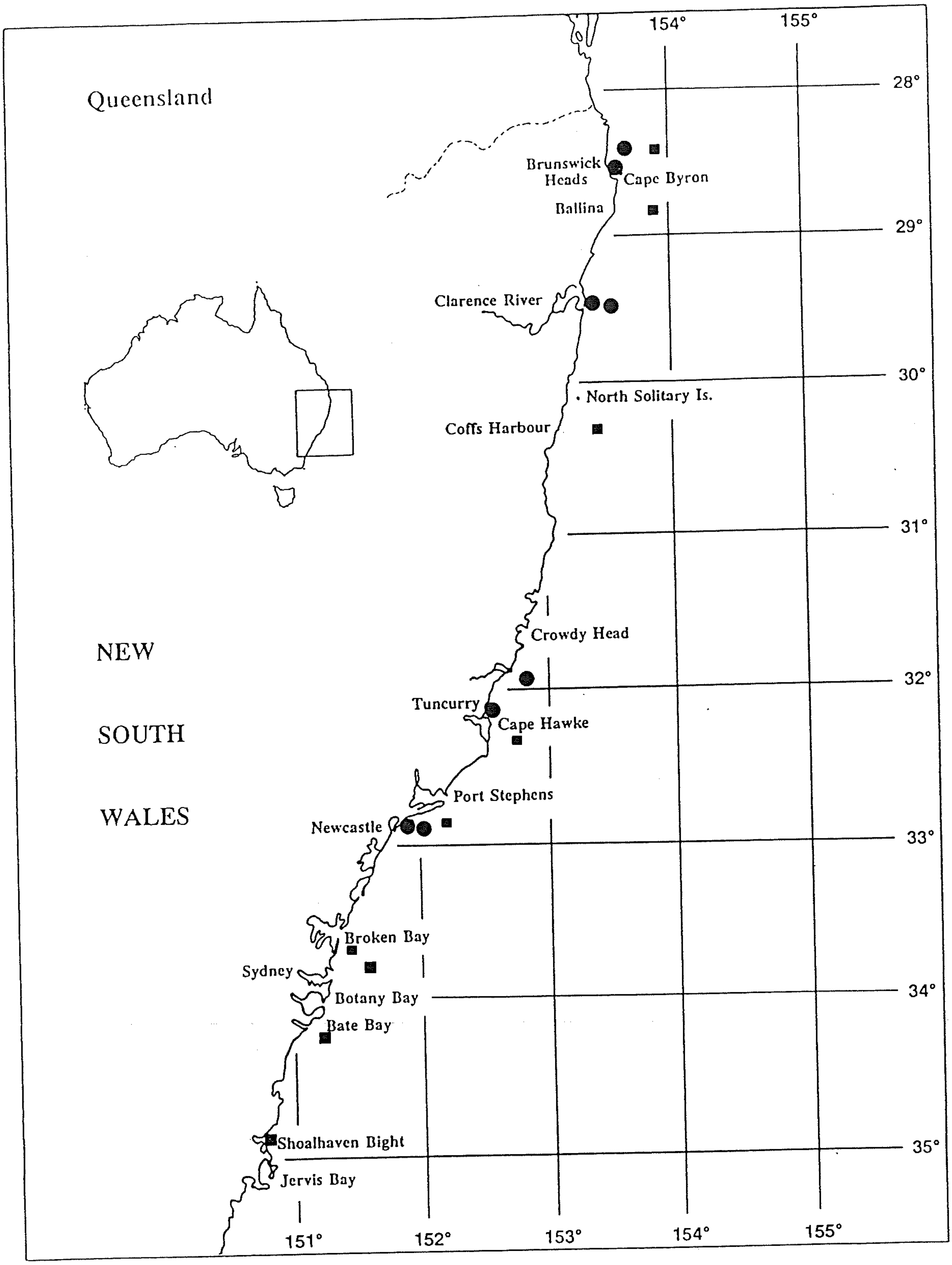

Figure 1: Map of northern and central NSW showing the survey grounds (●) off Brunswick Heads, the Clarence River, Tuncurry and Newcastle. The areas where exploratory trawling was conducted are also indicated (■).

A number of exploratory tows for prawns was made on middle to outer shelf grounds off central and northern NSW. In October, a series of 30 minute night-time tows were completed on grounds between Broken Bay and the Shoalhaven Bight.

A species list of all fishes, crustaceans, and cephalopods was compiled for all tows. Most taxa have been identified to species level; unfamiliar species were referred to taxonomists at the Australian Museum in Sydney, the CSIRO Division of Fisheries in Hobart and a number of other institutions. Voucher specimens were retained by those institutions.

The classification of the sharks and rays follows the review of this group by Last and Stevens (in press). The classification of the teleost fishes is as per Paxton et al. (1989). Common names used in the text were either those in common usage in NSW or derived from recent publications (e.g. Hutchins and Swainston 1986; Grey et al. 1983); a list of common names used in the text and their associated taxonomic names are in Appendix 1.

DATA ENTRY AND ANALYSIS

Data for each tow were entered onto a database with facilities for data verification, processing and statistical analyses. For this report, mean numbers and/or weights of commercial species, trash fish, total by-catch and number of species were generated for each area and each survey, and length-frequency histograms were produced for key species. By-catch was defined as all species except prawns.

SURVEY GROUNDS

Established school and king prawn grounds were selected for the study (Table 1; Fig. 1). These grounds were off the Clarence River and Brunswick Heads (northern New South Wales) and Newcastle and Tuncurry-Crowdy Head (central New South Wales). The eight grounds provided replication of inshore and offshore sites within each study area.

Table 1: Coordinates and depth ranges of the eight prawn grounds selected for sampling.

Ground	Coordinates	Depth Range (m)	Depth Range (fm)
Brunswick Head inshore	28°33' 153°33' , 28°33' 153°34' 28°37' 153°35' , 28°37' 153°36'	9–23	5–12
Brunswick Head offshore	28°20' 153°37' , 28°20' 153°41' 28°27' 153°38' , 28°27' 153°42'	45–60	25–32
Clarence River inshore	29°21' 153°23' , 29°21' 153°25 29°26' 153°22' , 29°26' 153°24'	10–30	6–16
Clarence River offshore	29°20' 153°34' , 29°20' 153°38' 29°30' 153°31' , 29°30' 153°35'	64–75	35–41
Tuncurry inshore	32°06' 152°31' , 32°06' 152°32' 32°10' 152°30' , 32°10' 152°32'	9–22	5–12
Tuncurry offshore	31°51' 152°53' , 31°51' 152°57' 32°05' 152°45' , 32°05' 152°49'	82–103	46–56
Newcastle inshore	32°48' 151°57' , 32°48' 151°59' 32°54' 151°48' , 32°54' 151°49'	9–26	5–14
Newcastle offshore	32°52' 152°00' , 32°52' 152°04' 32°57' 151°54' , 32°57' 151°56'	64–79	35–43

RESULTS

Operational and total catch data for each tow are presented in Appendix 2.

Tables 2 to 5 and 7 to 10 summarise the catch data for each survey. Shown are the number of tows from which each commercial species was recorded, and the mean catch numbers and/or weights for the composite by-catch components and those species caught in four or more tows per survey. The means were calculated for the total number of tows in each survey. Also shown at the bottom of each table is the prawn catch to by-catch ratio for those surveys where the mean prawn catch was at least 1.0 kg/tow (2.0 kg/h).

INSHORE GROUNDS

Operational problems were encountered on the Tuncurry and Newcastle grounds. Off Tuncurry, trawling was restricted to a depth range of 18-21 m on Day 3 of Survey I because of a dense accumulation of drifting seaweed further inshore, and throughout Survey II because of a high concentration of jelly-fish in the shallower depths. Problems with seaweed were also encountered off Newcastle during Survey IV and most tows were made near the Newcastle Harbour end of the ground.

Prawns: School prawn catches were small during most surveys. Tables 2 to 5 show that mean catch rates equalled or exceeded 1.0 kg per 30 minute tow once at Brunswick Heads (Survey III; 1.0 kg/tow), once off the Clarence River (Survey I; 6.2 kg/tow), once off Tuncurry (Survey I; 3.9 kg/tow), and during Surveys I, II and III off Newcastle (1.8, 2.7 and 1.7 kg/tow). No commercial prawn trawlers were present on the Brunswick Heads or Tuncurry grounds during any survey; prawn trawlers fished the Clarence River ground during Survey I and off Newcastle during Surveys I and II.

School prawn catch-rates within a day's sampling varied greatly (see Appendix 2). On the Clarence River ground, catches ranged from 0.2 kg to 14.0 kg/tow (Survey I), and on the Tuncurry and Newcastle grounds daily catches ranged from zero to 11.0 kg and 0.1 to 11.0 kg/tow respectively. Off the Clarence River most school prawns were caught in the half of the ground that was furthest from the river mouth whereas off Tuncurry and Newcastle the largest catches were taken close to the river mouths.

Small numbers of leader and banana prawns were caught off the Clarence River; small king prawns were frequently taken off the Clarence River, Tuncurry and Newcastle although numbers and catch weights were low.

Crabs: Five species of commercial crabs were caught although few were of marketable size. Commonest were three-spotted crabs (mainly off Brunswick Heads and the Clarence River), two-spotted and blue-swimmer crabs (Tuncurry and Newcastle). Small numbers of spanner and coral crabs were also recorded; most were caught at the two northern sites.

Squid and Octopus: Four species of squids were caught at all four sampling sites although only the small bottle squid was taken regularly in significant quantities. Large numbers of bottle squid were caught in all areas during most surveys; the largest mean catch rate per tow was 264 squid weighing 3.3 kg caught off Newcastle during Survey IV (Table 5). Of the other species, catches in excess of 1.0 kg/tow were recorded only for broad squid (Tuncurry Surveys II & IV; Table 4). Southern calamary, slender squid and octopus were frequently caught but rarely in significant numbers.

Fish: Forty-five commercial and/or angling species of fishes were caught on the inshore grounds (Appendix 3) although only 10 species were taken in significant numbers. The catch details for 37 species are shown in Tables 2 to 5; data were not collected for incidentally caught pelagic species (e.g. pilchard, common mackerel) which are marketed in small quantities.

Brunswick Heads (Table 2): Stout whiting was the dominant species in most catches during all surveys; other commercial species caught in significant numbers were sand flathead and shovelnose rays (all surveys) and red gurnard (Surveys II and III). By weight, commercial fish species made up 30-59% of the total by-catch. During Survey I, stout whiting formed 59% of the total catch. In Surveys II-IV, trash fish was the main component forming 54-61% of the total catch. The main trash fish species were stingarees and stingrays.

Clarence River (Table 3): Stout whiting was also the dominant commercial species on this ground, especially during Surveys II and IV (42% and 57% of the total by-catch weight). Large numbers of juvenile mulloway and teraglin (Survey I), snapper (Survey IV) and small tailor (Surveys I & II) were also taken. Trash fish catches were low with mean weights ranging from 9.0 kg/tow (Survey III) to 22 kg/tow (Survey I).

Tuncurry (Table 4): Commercial fish species made up less than 25% of the total by-catch in any survey. Species common in most catches were sand flathead, banjo rays and shovelnose rays; significant numbers of tailor, redspot whiting and stout whiting were caught during Surveys I and II. Trash fish catches were large, especially during Surveys II and III (means 137 kg/tow and 133 kg/tow) and comprised between 60% and 88% of the total by-catch. The main trash species were stingarees and smooth boxfish.

Newcastle (Table 5): Catches of commercial and trash fish were usually very low off Newcastle. During Survey II, large catches of adult Port Jackson sharks made up most of the fish catch; when this species was excluded from the data, the mean total fish catch for Survey II was less than 20 kg/tow, similar to the other three surveys. Significant numbers of small sand flathead were caught during all surveys; juvenile mulloway (Surveys I & II) and teraglin (Survey II) were numerous in several tows, particularly at the Newcastle Harbour end of the ground.

Total by-catch

The range of means of total by-catch per tow for the four surveys were: Brunswick Heads 43-95 kg; Clarence River 31-68 kg; Tuncurry 60-176 kg; Newcastle 19-152 kg. When the large catches of Port Jackson sharks were discounted from the Survey II data, the mean by-catch per tow for the Newcastle surveys ranged from 18 to 23 kg.

The prawn catch to by-catch ratios for those surveys when the mean prawn catch-rate exceeded 1.0 kg/tow ranged from 1:7 on the Clarence River ground (Survey I) to 1:94 on the Brunswick Heads ground (Survey III). The ratios from the Newcastle ground (excluding the catches of Port Jackson sharks from Survey II) were between 1:6 and 1:13.

Table 2: Summary of catch data for the commercial species and by-catch components caught on the Brunswick Heads inshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight for the 12 tows in each survey. (* present in less than 4 tows, no catch data given; # not recorded for Survey I.)

	Survey I (May)			**Survey II** (September)			**Survey III** (November)			**Survey IV** (February)		
	No.of Tows	Mean No.	Mean Wt(kg)	No.of Tows	Mean No.	Mean Wt(kg)	No.of Tows	Mean No.	Mean Wt(kg)	No.of Tows	Mean No.	Mean Wt(kg)
Prawn–school	9	2.4	0.1	6	2.3	0.1	12	110.0	1.0	6	6.9	0.1
Prawn–banana	1	*		0			0			0		
Prawn–king	0			0			2	*		1	*	
Prawn–tiger	2	*		0			0			0		
Balmain bug	0			0			2	*		0		
Crab–blue swimmer	2	*		0			5	*		3	*	
Crab–coral	0			7	0.9	0.1	4	0.4	0.1	1	*	
Crab–spanner	9	1.3	0.1	0			4	0.5	0.1	4	*	
Crab–three spot	12	3.4	0.3	12	8.9	0.9	12	23.3	3.8	9	2.2	0.3
Cuttlefish	0			4	0.5	0.1	0			0		
Squid–bottle	#			12	54.1	0.8	12	81.6	1.8	12	36.2	0.5
Squid–broad	9	9.0	0.4	8	1.4	0.1	10	3.1	0.3	0		
Squid–sthn calamary	0			1	*		7	1.8	0.1	0		
Octopus	3	*		3	*		0			12	3.8	0.6
Cobia	0			1	*		0			0		
Flathead–dusky	1	*		0			3	*		4	0.3	0.1
Flathead–sand	10	16.5	0.2	12	64.3	2.9	12	25.8	2.3	11	41.7	1.1
Flathead–nthn sand	0			4	0.6	0.1	1	*		8	2.3	0.2
Flounder–bigtooth	7	0.9	0.1	12	3.6	0.7	7	1.8	0.5	11	6.7	1.0
Flounder–smalltooth	4	0.4	0.1	7	0.8	0.1	3	*		3	*	
Flounder–smoothback	3	*		9	3.4	0.1	0			3	*	
Goatfish–bartailed	0			3	*		1	*		1	*	
Gurnard–red	5	6.8	0.2	9	11.9	0.3	12	19.0	0.8	8	2.0	0.1
Hairtail	0			0			1	*		0		
L'jacket–Chinaman	0			0			2	*		0		
L'jacket–mosaic	0			0			2	*		0		
Mulloway	1	*		0			0			0		
Ray–shovelnose	12	5.3	0.6	12	7.0	3.4	12	12.5	5.5	11	9.8	0.4
Red mullet	0			3	*		3	*		3	*	
Shark–hammerhead	0			0			0			1	*	
Shark–wobbegong	0			0			2	*		0		
Snapper	1	*		4	9.0	0.7	4	1.1	0.1	5	3.3	0.1
Tailor	3	*		1	*		3	*		4	3.3	0.3
Teraglin	1	*		0			0			0		
Tarwhine	0			1	*		2	*		2	*	
Whiting–stout	12	1488.2	25.0	12	369.2	9.5	12	265.7	14.5	12	535.1	21.2
Whiting–redspot	3	*		2	*		6	3.4	0.1	6	6.3	0.1
Total comm. fish	12		26.3	12		17.8	12		32.1	12		24.9
Trash fish	12		16.9	12		23.2	12		56.1	12		50.6
Total by-catch	12		44.5			43.1			94.2			83.0
No. of spp-fishes	12	24.1		12	23.4		12	24.8		12	29.3	
No. of spp-crust.	12	4.1		12	3.1		12	6.6		12	4.1	
No. of spp-ceph.	12	2.0		12	2.3		12	2.5		12	3.0	
Prawn catch : by-catch			–			–			1:94			–

Table 3: Summary of catch data for the commercial species and by-catch components caught on the Clarence River inshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight for the 12 tows (11 tows, Survey I) in each survey. (+ trawlers active on ground; * present in less than 4 tows, no catch data given; # not recorded for Survey I.)

	Survey I+ (May)			Survey II (Aug.-Sept.)			Survey III (November)			Survey IV (February)		
	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)
Prawn-banana	2	*		1	*		6	1.1	0.1	0		
Prawn-king	3	*		3	*		5	2.5	*	7	3.3	0.1
Prawn-leader	6	1.4	0.1	1	*		0			1	*	
Prawn-school	11	1293.0	6.2	5	6.0	0.1	12	65.3	0.4	10	41.2	0.3
Prawn-tiger	0			0			0			1	*	
Bug-Balmain	0			0			0			2	*	
Bug-smooth	0			0			0			2	*	
Crab-blue swimmer	3	*		2	*		8	0.8	0.2	11	5.4	0.5
Crab-coral	2	*		3	*		6	0.6	0.2	3	*	
Crab-three spot	11	58.3	4.8	12	30.3	2.2	12	50.8	4.2	11	26.1	2.4
Crab-spanner	1	*		0			0			5	0.5	0.1
Eastern rock lobster	0			0			0			1	*	
Cuttlefish	2	*		3	*		1	*		3	*	
Squid-bottle	#			12	79.8	1.0	12	136.4	2.5	12	73.2	0.9
Squid-broad	5	1.7	0.1	8	1.4	0.1	5	0.9	0.1	2	*	
Squid-slender	0			1	*		4	1.0	0.2	7	1.3	0.2
Squid-sthn calamary	0			3	*		4	1.0	0.1	1	*	
Octopus	0			1	*		1	*		8	2.8	0.6
Flathead-dusky	9	1.7	0.3	2	*		2	*		11	4.2	0.6
Flathead-sand	5	4.0	0.2	12	11.8	0.8	11	6.3	0.8	12	12.4	1.0
Flathead-nthn sand	0			0			0			11	7.9	0.4
Flounder-bigtooth	0			3	*		1	*		12	23.3	1.5
Flounder-smalltooth	0			0			11	11.2	0.2	12	8.7	0.3
Flounder-smoothback	0			1	*		2	*		12	22.8	0.5
Goatfish-bartailed	0			0			0			5	0.7	0.1
Gurnard-red	0			2	*		9	4.0	0.3	10	4.9	0.4
Hairtail	0			3	*		8	1.1	0.6	0		
L'jacket-Chinaman	0			0			3	*		0		
L'jacket-mosaic	0			0			4	0.9	0.1	0		
Mulloway	10	34.4	0.8	4	0.8	0.1	5	0.9	0.2	0		
Ray-shovelnose	8	4.0	0.3	0			12	7.5	3.5	8	1.4	0.3
Red mullet	0			2	*		5	0.9	0.1	0		
Shark-whaler	2	*		1	*		2	*		0		
Shark-wobbegong	0			2	*		1	*		0		
Snapper	2	*		1	*		9	9.9	0.2	12	98.5	3.0
Tailor	10	45.6	1.9	8	20.8	1.4	9	2.2	0.3	3	*	
Tarwhine	4	2.3	0.1	0			0			2	*	
Teraglin	11	15.3	0.9	3	*		8	3.1	0.4	2	*	
Whiting-redspot	0			11	112.0	2.5	6	2.2	0.1	9	1.5	0.1
Whiting-sand	0			0			0			1	*	
Whiting-stout	11	292.3	7.3	11	757.6	21.7	12	151.2	6.6	12	1959.3	38.2
Total comm. fish	11		12.8	12		29.0	12		14.3	12		47.3
Trash fish	11		22.1	12		21.4	12		9.0	12		14.7
Total by-catch	11		40.6	12		54.9	12		31.6	12		67.3
No.of spp-fish	11	24.8		12	17.9		12	23.5		12	30.8	
No.of spp-crust.	11	5.6		12	3.5		12	7.3		12	7.8	
No.of spp-ceph.	11	1.6		12	2.9		12	2.4		12	3.4	
Prawn catch : by-catch			1:6			-			-			-

Table 4: Summary of catch data for the commercial species and by-catch components caught on the Tuncurry inshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight for the 12 tows in each survey. (* present in less than 4 tows, no catch data given.)

	Survey I (May–June)			Survey II (September)			Survey III (December)			Survey IV (March–April)		
	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)
Prawn–king	7	25.5	0.3	2	*		0			0		
Prawn–school	9	714.5	3.9	4	11.6	0.1	1	*		4	0.6	0.1
Prawn–tiger	1	*		0			0			0		
Crab–blue swimmer	12	16.6	4.0	11	8.5	2.5	7	0.6	0.1	8	1.9	0.5
Crab–coral	1	*		1	*		0			1	*	
Crab–mud	0			0			0			1	*	
Crab–spanner	0			0			1	*		0		
Crab–two spot	7	5.5	0.3	6	1.6	0.3	5	3.8	0.1	11	279.0	6.8
Crab–three spot	6	0.8	0.1	0			0			9	3.3	0.1
Octopus	0			7	1.4	0.3	0			6	0.7	0.1
Squid–bottle	12	48.7	0.6	10	4.3	0.1	4	1.3	0.1	11	80.8	1.2
Squid–broad	12	7.3	0.6	12	17.5	1.2	8	1.6	0.1	12	39.8	1.4
Squid–sthn calamary	4	1.0	0.3	3	*		7	1.2	0.1	8	1.1	0.1
Squid–slender	1	*		1	*		1	*		6	0.8	0.1
Bonito	0			0			0			1	*	
Flathead–dusky	3	*		1	*		2	*		2	*	
Flathead–nthn sand	0			5	0.5	0.1	1	*		2	*	
Flathead–sand	12	19.8	1.4	12	79.7	6.9	12	15.3	1.1	12	10.7	0.8
Flounder–bigtooth	11	2.0	0.4	11	3.8	0.9	10	4.1	0.9	12	3.5	0.5
Flounder–smalltooth	0			7	0.9	0.3	1	*		5	1.0	0.2
Flounder–smoothback	0			4	1.2	0.1	0			2	*	
Goatfish–bartailed	0			6	0.8	0.1	0			1	*	
Gurnard–red	0			12	20.0	1.1	11	5.8	0.2	5	0.4	0.1
John dory	1	*		2	*		0			0		
L'jacket–Chinaman	0			0			7	5.2	0.1	0		
L'jacket–mosaic	0			0			10	2.2	0.1	0		
Mulloway	10	5.9	0.6	8	1.8	0.4	0			0		
Ray–banjo	10	2.6	1.5	12	9.2	8.8	12	6.7	5.6	8	1.6	1.0
Ray–shovelnose	11	5.1	3.3	12	4.5	3.1	12	9.4	9.1	11	10.5	9.5
Red mullet	0			1	*		0			0		
Samsonfish	0			0			10	4.3	0.3	0		
Shark–gummy	1	*		0			0			0		
Shark–inshore angel	0			1	*		0			1	*	
Snapper	6	7.9	0.5	1	*		5	2.3	0.1	6	7.3	0.4
Tailor	12	30.3	2.3	8	8.3	0.9	1	*		7	1.9	0.2
Tarwhine	5	1.3	0.1	0			5	3.0	0.1	7	1.1	0.1
Teraglin	6	6.2	0.1	6	1.2	0.2	0			1	*	
Trevally–silver	4	1.2	0.1	7	2.3	0.5	0			0		
Whiting–redspot	12	34.0	3.0	11	116.3	7.1	4	1.2	0.1	12	6.9	0.1
Whiting–sand	0			0			1	*		0		
Whiting–stout	9	57.3	3.6	10	64.8	3.5	7	8.8	0.5	4	4.3	0.2
Whiting–trumpeter	0			5	0.4	0.1	3	*		1	*	
Total comm. fish	12		17.5	12		34.1	12		17.2	12		13.8
Trash fish	12		55.1	12		136.8	12		132.5	12		36.3
Total by–catch	12		77.8	12		175.5	12		151.5	12		60.3
No. of spp–fishes	12	31.3		12	26.7		12	20.8		12	23.0	
No. of spp–crust.	12	3.8		12	2.4		12	1.1		12	3.6	
No. of spp–ceph.	12	2.3		12	2.7		12	1.8		12	3.7	
Prawn catch : by–catch			1:20			–			–			–

Table 5: Summary of catch data for the commercial species and by-catch components on the Newcastle inshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight for the 12 tows in each survey. (+ trawlers active on ground; * present in less than 4 tows, no catch data given.)

	Survey I+ (May–June)			Survey II+ (September)			Survey III (December)			Survey IV (March)		
	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)
Prawn–king	2	*		12	59.7	0.8	5	21.0	0.1	4	0.5	0.1
Prawn–school	7	166.0	1.8	12	331.6	2.7	8	189.1	1.7	9	2.9	0.1
Balmain bug	0			1	*		0			0		
Crab–blue swimmer	6	4.8	1.2	9	2.8	0.7	6	1.2	0.2	9	1.6	0.2
Crab–coral	1	*		1	*		1	*		3	*	
Crab–two spot	9	53.3	2.8	12	81.0	4.4	11	181.7	6.0	11	63.8	2.6
Crab–three spot	10	11.8	0.3	12	36.7	2.0	7	3.4	0.2	8	2.5	0.1
Eastern rock lobster	0			0			0			2	*	
Octopus	2	*		4	0.6	0.1	0			1	*	
Squid–bottle	12	69.8	1.0	12	79.3	1.2	12	85.0	0.8	12	264.2	3.3
Squid–broad	11	10.3	0.8	6	1.7	0.1	7	2.8	0.1	12	8.6	0.4
Squid–Gould's	0			1	*		1	*		0		
Squid–slender	3	*		1	*		1	*		9	3.7	0.2
Squid–sthn calamary	3	*		0			0			2	*	
Barred cod	0			0			0			2	*	
Boarfish–giant	1	*		0			0			0		
Bonito	0			0			0			2	*	
Bream–yellowfin	3	*		10	0.9	0.6	9	1.6	0.9	0		
Flathead–dusky	0			1	*		3	*		3	*	
Flathead–nthn sand	0			7	0.8	0.1	1	*		0		
Flathead–sand	12	4.9	0.7	12	33.7	2.6	11	12.8	1.2	11	3.8	0.2
Flounder–bigtooth	10	1.8	0.3	9	1.6	0.4	8	3.0	0.7	6	1.0	0.1
Flounder–smalltooth	0			3	*		3	*		2	*	
Gurnard–red	0			12	20.8	0.2	11	5.0	0.1	2	*	
Hairtail	4	14.2	4.9	9	5.2	0.7	0			1	*	
L'jacket–Chinaman	0			0			4	0.3	0.1	0		
L'jacket–mosaic	0			0			2	*		0		
Mulloway	7	24.8	2.0	10	8.9	2.2	4	0.9	1.0	0		
Ray–banjo	0			1	*		0			0		
Ray–shovelnose	4	0.7	0.2	4	0.7	0.8	7	0.8	0.4	3	*	
Redfish	0			1	*		0			1	*	
Samsonfish	0			0			7	1.1	0.1	0		
Shark–hammerhead	0			0			1	*		6	1.0	0.8
Shark–whaler	0			0			0			5	2.2	4.8
Snapper	4	2.8	0.2	0			2	*		3	*	
Tailor	6	2.2	0.1	4	3.8	0.2	5	0.6	0.1	2	*	
Tarwhine	2	*		0			3	*		1	*	
Teraglin	3	*		11	39.0	0.4	2	*		3	*	
Trevally–silver	9	1.8	0.2	3	*		4	0.3	0.3	1	*	
Whiting–redspot	3	*		10	5.6	0.1	11	19.8	0.2	12	110.6	1.0
Whiting–sand	0			1	*		2	*		0		
Whiting–stout	5	14.3	0.6	12	78.4	0.7	11	93.6	0.9	11	121.1	3.2
Total comm. fish	12		10.3	12		9.7	12		6.4	12		10.9
Trash fish	12		6.6	12		132.3	12		6.5	12		1.1
Total by-catch	12		22.5	12		151.4	12		20.5	12		19.1
No. of spp-fishes	12	19.4		12	23.8		12	19.6		12	19.3	
No. of spp-crust.	12	4.1		12	8.0		12	4.3		12	4.3	
No. of spp-ceph.	12	2.6		12	2.2		12	1.9		12	2.9	
Prawn catch : by-catch			1:13			1:56			1:12			–

Night-time Trawling on Inshore Grounds

On the inshore grounds, night-time tows were made off Brunswick Heads (3), the Clarence River (6), and Newcastle (4); catch data for the night-time tows are summarised in Table 6.

On the Clarence River ground, night-time catches of school prawns were significantly larger than those during the day tows (see Table 3) and this was reflected by the night-time presence of many commercial trawlers on the ground during the Survey IV sampling period. Night catches on the Brunswick Heads and Clarence River grounds also contained much greater quantities of some by-catch species, most notably three-spotted crabs and stout whiting (see Tables 2 and 3). The catch composition of night shots on the Newcastle ground were similar to the day shots except for the capture of small quantities of king prawns, a species not usually caught during the day.

Table 6: Catch data for the main species caught during night-time trawling on inshore grounds.

		Tow No.	School prawn (kg)	King prawn (kg)	Three spotted crab (kg)	Stout whit. (kg)	Sand f'hd (no.)	Total comm. fish (kg)	Trash fish (kg)	Total by-catch (kg)	Fish spp. (no.)
Brunswick	I	900818	0.3	0	3.5	40.0	15	42.4	25.0	71.5	28
	II	901236	0.6	0	14.0	85.0	45	103.8	22.0	142.9	23
		901237	0.1	0	14.4	87.0	90	94.0	31.5	151.1	36
Clarence R.	I	900845	40.0	0.1	18.0	20.0	11	30.6	23.0	75.6	30
		900846	1.3	0.1	13.0	12.0	23	14.6	10.0	39.7	26
	II	901209	0	0	12.0	12.3	48	27.2	32.0	74.0	19
		901210	0	0	15.0	6.5	61	24.3	33.5	77.0	20
	IV	910106	6.7	1.0	21.8	16.0	19	31.1	40.0	99.0	19
		910107	12.4	1.0	15.5	8.0	11	17.5	45.0	85.0	36
Newcastle	II	901425	0.2	2.5	2.5	4.5	18	18.7	130.0	157.5	22
		901426	2.1	0.1	1.5	0.3	7	6.2	50.0	62.4	22
	III	901905	0.8	1.0	0.3	7.5	8	11.6	10.0	28.0	21
		901906	0.2	0.4	0.2	2.4	50	12.8	18.0	36.4	21

OFFSHORE GROUNDS (Tables 7-10)

Prawns: Mean catch rates of king prawns on all grounds were generally small. The average catch only exceeded 5.0 kg/tow off Brunswick Heads during Survey III, off the Clarence River during Survey II, and off Crowdy Head and Newcastle during Surveys I and IV. The maximum of 10.4 kg/tow was obtained on the Newcastle ground during Survey IV. Racek prawns were caught only off Newcastle, but were consistently taken only during Survey II; the largest catch for any tow was 1.6 kg.

Bugs and crabs: Balmain bugs, smooth bugs and blue-swimmer crabs were the only commercial crustaceans other than prawns which were caught in significant quantities. Balmain bugs were caught only on the shallowest offshore ground (Brunswick Heads) and mainly during Survey IV. The very similar smooth bug was more common and was taken on all grounds although mainly off Brunswick Heads and the Clarence River; the mean catch rates on those grounds were between 1.0 and 2.9 kg/tow. Blue-swimmer crabs were caught in small numbers off Brunswick Heads and Newcastle.

On the Newcastle ground, two species of non-commercial swimming crabs (*Charybdis miles* and *C. bimaculata*) made up most of the trash (10-17 kg/tow).

Cephalopods: Cuttlefish were caught on all grounds in nearly all tows. The largest mean catch rates were recorded off Crowdy Head during Surveys I (10.6 kg/tow) and IV (4.7 kg/tow).

Octopus were taken mainly on the two northern grounds; mean catch rates exceeded 3.0 kg/tow off Brunswick Heads (3.6 kg/tow; Survey IV) and off the Clarence River (4.2 kg/tow; Survey I).

Three species of squids were caught on the offshore grounds, mainly in small quantities; these were slender squid, southern calamary and Gould's squid. A large number of juvenile slender squid was caught off Brunswick Heads during Survey II (115/tow) and, to a lesser extent, off Tuncurry during Survey I (12/tow). The Clarence River ground produced significant numbers of small southern calamary during Surveys III (34/tow) and IV (29/tow). Gould's squid was the main species caught off Tuncurry with mean catch weights for the four surveys between 0.7 and 2.4 kg/tow. Few squid were caught off Newcastle.

Fish: Forty-six commercial and/or angling species were recorded from the offshore grounds, 27 from Brunswick Heads/Clarence River and 37 from Tuncurry/Newcastle (Appendix 3). Tables 7 to 10 list the catch details for 37 of these species. However, apart from the Tuncurry ground, commercial species seldom formed a large proportion of the by-catch.

Off Brunswick Heads and the Clarence River, commercial species comprised less than 10% of the total by-catch weights in all but one survey. During Survey II off the Clarence River, 19% of the total by-catch was redspot whiting. Other commercial species consistently caught in small numbers were sand flathead and smooth-backed flounder. The principal components of the trash fish by-catch were small butterfly gurnards and stinkfish.

The Tuncurry ground produced relatively large catches of commercial fish, with the mean total catches ranging from 12.7 kg to 60.1 kg/tow. The main species were tiger flathead (max. 24.3 kg/tow in Survey II) and redspot whiting (max. 22.6 kg/tow in Survey I). The trash fish component ranged from a mean of 15 kg (Survey IV) to 136 kg/tow (Survey II) and comprised mainly stingarees and butterfly gurnards.

Redspot whiting was the most common commercial fish taken off Newcastle (max. mean 38.3 kg/tow in Survey I); juvenile tiger flathead, john dory and redfish were also common in some catches. The mean trash fish by-catch was low (less than 20 kg/tow) for all surveys.

Table 7: Summary of catch data for the commercial species and by-catch components caught on the Brunswick Heads offshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight for the 12 tows in each survey. (+ trawlers active on ground; * present in less than 4 tows, no catch data given.)

	Survey I (May)			Survey II (August)			Survey III+ (November)			Survey IV+ (February)		
	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)
Prawn-king	12	25.4	1.1	12	6.9	0.3	12	76.8	6.1	12	147.3	4.0
Prawn-tiger	0			0			2	*				
Bug-Balmain	5	0.6	0.1	2	*		5	0.8	0.1	12	12.3	0.3
Bug-smooth	9	19.5	1.8	12	9.3	1.1	12	19.1	2.9	12	38.3	1.7
Crab-blue swimmer	5	0.4	0.1	2	*		3	*		4	0.4	0.1
Crab-coral	0			0			1	*		3	*	
Crab-three spot	0			0			2	*		2	*	
Cuttlefish	12	4.3	0.5	12	11.0	0.8	12	32.9	2.5	12	28.9	1.1
Octopus	10	1.5	0.2	6	0.8	0.1	12	4.7	1.0	12	43.8	3.6
Squid-Gould's	2	*		0			0			0		
Squid-slender	7	1.2	0.1	12	115.4	3.5	7	1.3	0.3	9	2.3	0.1
Squid-sthn calamary	9	1.8	0.3	0			12	18.3	0.6	11	14.0	1.0
Cobia	0			0			1	*		0		
Flathead-sand	10	2.8	0.7	10	1.8	0.7	12	7.3	3.6	5	3.8	0.9
Flathead-marble	3	*		7	1.2	0.2	3	*		4	0.5	0.1
Flathead-spiky	8	2.7	0.4	6	3.2	0.6	3	*		10	2.3	0.5
Flounder-smoothb'k	12	7.3	1.2	11	9.1	0.7	12	47.0	3.6	12	71.0	3.8
Gurnard-red	4	1.0	0.1	11	4.8	0.7	8	4.6	0.8	5	0.5	0.1
L'jacket-mosaic	0			0			1	*		0		
Pearl perch	0			1	*		6	3.7	0.1	5	1.8	0.1
Ray-banjo	0			1	*		5	0.4	0.1	0		
Ray-shovelnose	3	*		5	1.1	0.6	4	0.3	0.3	2	*	
Redfish	0			1	*		1	*		0		
Red mullet	10	3.8	0.2	0			6	0.5	0.1	3	*	
Shark-gummy	5	1.6	0.2	9	2.0	1.1	10	3.2	2.5	8	2.8	0.8
Tailor	0			1	*		0			0		
Whiting-redspot	0			0			8	13.4	1.2	0		
Whiting-stout	0			0			5	102.5	3.2	0		
Total comm. fish	12		3.0	12		4.8	12		16.0	12		6.2
Trash fish	12		104.2	12		74.8	12		166.3	12		103.3
Total by-catch	12		111.4	12		85.3	12		190.8	12		118.2
No. of spp-fishes	12	25.2		12	23.1		12	32.2		12	31.0	
No. of spp-crust.	12	4.3		12	4.4		12	8.0		12	7.6	
No. of spp-ceph.	12	3.3		12	4.0		12	4.8		12	4.7	
Prawn catch : by-catch			1:101			–			1:31			1:29

Table 8: Summary of catch data for the commercial species and by-catch components on the Clarence River offshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight for the 12 tows in each survey. (+ trawlers active on ground; * present in less than 4 tows, no catch data given.)

	Survey I+ (May)			Survey II+ (August)			Survey III (November)			Survey IV (February)		
	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)
Prawn-king	12	63.3	3.2	12	172.3	6.1	12	59.7	3.9	12	68.0	4.3
Bug-Balmain	5	0.8	0.1	1	*		1	*		4	0.8	0.1
Bug-smooth	12	27.7	1.2	12	12.8	1.0	12	19.4	1.0	12	61.9	1.9
Crab-blue swimmer	0			0			1	*		0		
Crab-spanner	0			0			0			1	*	
Crab-three spot	0			0			1	*		0		
Eastern rock lobster	0			0			1	*		0		
Cuttlefish	12	3.5	0.3	12	31.3	2.7	12	54.3	3.7	12	24.9	1.5
Octopus	12	50.7	4.2	12	6.8	0.6	12	4.0	0.5	12	37.3	2.6
Squid-Gould's	0			2	*		7	0.8	0.2	9	1.7	0.7
Squid-slender	5	0.7	0.1	9	19.4	0.4	9	1.8	0.2	1	*	
Squid-sthn calamary	2	*		0			12	33.8	0.9	12	28.8	3.3
Barred cod	0			0			1	*		2	*	
Flathead-marble	2	*		5	0.8	0.2	0			0		
Flathead-sand	0			2	*		4	0.6	0.3	0		
Flathead-spiky	6	1.9	0.2	4	0.5	0.1	3	*		11	5.4	1.0
Flounder-smoothback	3	*		12	3.6	0.5	11	3.8	0.6	12	17.3	1.9
Goatfish-bartailed	4	2.0	0.1	0			0			0		
Gurnard-red	0			9	1.2	0.2	4	0.7	0.1	4	0.5	0.1
Hairtail	0			2	*		0			0		
John dory	1	*		3	*		1	*		0		
L'jacket-Chinaman	0			1	*		0			2	*	
L'jacket-mosaic	0			1	*		0			1	*	
Mulloway	1	*		0			0			0		
Pearl perch	1	*		0			2	*		1	*	
Ray-shovelnose	0			3	*		0			0		
Redfish	0			4	0.4	0.1	0			0		
Red mullet	12	4.3	0.3	0			7	4.2	0.2	3	*	
Shark-gummy	0			0			5	0.8	0.7	5	0.6	0.2
Snapper	0			1	*		0			1	*	
Tailor	2	*		0			0			0		
Tarwhine	1	*		1	*		0			0		
Whiting-redspot	7	1.7	0.1	12	152.8	6.0	5	4.5	0.3	5	4.3	0.3
Total comm. fish	12		1.8	12		7.8	12		2.3	12		3.7
Trash fish	12		43.6	12		19.5	12		18.8	12		48.8
Total by-catch	12		51.9	12		32.4	12		28.5	12		54.4
No. of spp-fishes	12	28.1		12	25.8		12	25.8		12	30.0	
No. of spp-crust.	12	5.3		12	7.9		12	6.9		12	7.2	
No. of spp-ceph.	12	2.6		12	3.3		12	5.3		12	4.3	
Prawn catch : by-catch		1:16			1:5			1:7			1:13	

Table 9: Summary of catch data for the commercial species and by-catch components caught on the Tuncurry offshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight for the 12 tows in each survey. (+ trawlers active on ground; * present in less than 4 tows, no catch data given.)

	Survey I (May-June)			Survey II (September)			Survey III+ (December)			Survey IV+ (April)		
	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)
Prawn-king	12	217.0	5.1	12	14.5	0.5	12	144.1	2.6	12	399.7	6.0
Bug-Balmain	0			0			3	*		3	*	
Bug-Bruce's	0			1	*		2	*		1	*	
Bug-smooth	11	5.3	0.4	9	2.1	0.2	11	5.6	0.6	11	3.8	0.3
Crab-coral	0			1	*		0			0		
Cuttlefish	12	65.2	5.3	12	21.3	1.7	12	35.8	3.2	12	46.4	4.7
Octopus	3	*		9	2.0	0.5	10	1.6	0.6	7	1.0	0.1
Squid-Gould's	10	3.4	0.7	12	18.9	1.5	12	24.3	1.6	10	11.7	2.4
Squid-slender	11	12.1	0.3	0			0			3	*	
Squid-sthn calamary	10	1.5	0.4	1	*		0			7	1.6	0.4
Barred cod	1	*		0			1	*		0		
Boarfish-giant	0			1	*		0			0		
Flathead-marble	8	4.0	0.6	6	1.4	0.3	5	1.4	0.3	9	1.4	0.3
Flathead-sand	4	0.8	0.3	0			0			0		
Flathead-spiky	5	2.2	0.3	11	6.8	1.1	11	4.5	0.7	12	15.2	0.9
Flathead-tiger	12	38.6	14.4	12	70.3	24.3	12	26.5	8.3	11	9.1	2.9
Flounder-smoothback	3	*		5	0.7	0.1	8	1.8	0.3	5	1.2	0.2
Gurnard-red	2	*		6	1.4	0.6	3	*		5	1.4	0.2
Hairtail	0			1	*		0			0		
John dory	5	0.7	0.2	5	0.7	0.4	9	1.9	0.2	12	3.2	0.6
L'jacket-Chinaman	0			1	*		0			5	1.2	0.1
L'jacket-mosaic	0			1	*		2	*		1	*	
Mulloway	1	*		0			0			0		
Ocean perch	0			0			1	*		2	*	
Ray-banjo	0			3	*		0			0		
Ray-shovelnose	1	*		6	1.3	1.9	1	*		0		
Redfish	12	23.8	3.7	7	8.5	1.5	8	18.8	1.0	5	1.8	0.3
Red mullet	0			0			2	*		1	*	
Rubberlip morwong	1	*		4	0.7	0.6	0			0		
Shark-offshore angel	0			8	0.9	7.8	3	*		2	*	
Shark-greeneye dog	0			7	0.8	1.2	0			1	*	
Shark-gummy	1	*		12	2.3	3.6	0			0		
Shark-saw	0			10	6.7	5.2	3	*		4	0.8	0.5
Shark-spiky dog	0			12	10.2	6.5	0			0		
Shark-wobbegong	0			3	*		1	*		0		
Whiting-redspot	12	373.0	22.6	6	36.8	3.7	9	29.6	2.1	10	86.3	4.8
Total comm. fish	12		44.5	12		60.1	12		16.8	12		12.7
Trash fish	12		42.6	12		136.0	12		41.7	12		15.3
Total by-catch	12		94.4	12		200.3	12		64.9	12		36.2
No. of spp-fishes	12	21.6		12	27.2		12	25.6		12	29.8	
No. of spp-crust.	12	5.6		12	4.3		12	5.8		12	9.4	
No. of spp-ceph.	12	3.8		12	2.8		12	3.2		12	3.8	
Prawn catch : bycatch			1:18			-			1:25			1:6

Table 10: Summary of catch data for the commercial species and by-catch components caught on the Newcastle offshore ground. The data show the number of tows in which each was caught, and the mean number and/or weight for the 12 tows in each survey. (+ trawlers active on ground; * present in less than 4 tows, no catch data given.)

	Survey I (May–June)			Survey II (September)			Survey III+ (December)			Survey IV+ (March)		
	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)	No.of Tows	Mean No.	Mean Wt.(kg)
Prawn–king	12	420.3	6.4	12	198.4	3.1	12	381.0	4.3	12	1210.2	10.4
Prawn–Racek	2	*		12	86.8	0.4	8	20.3	0.1	9	21.7	0.1
Prawn–tiger	6	0.8	0.1	3	*		0			2	*	
Bug–smooth	7	1.3	0.1	5	0.6	0.1	4	0.4	0.1	4	0.3	0.1
Crab–blue swimmer	3	*		7	1.0	0.3	2	*		3	*	
Crab–three spot	0			0			0			3	*	
Lobster–barking	0			0			1	*		0		
Lobster–east. rock	0			0			4	0.3	0.4	0		
Cuttlefish	9	1.8	0.3	10	1.8	0.2	9	3.1	0.2	10	2.7	0.1
Octopus	7	2.0	0.5	4	0.4	0.2	1	*		7	1.4	0.3
Squid–Gould's	3	*		8	1.3	0.1	8	0.8	0.1	0		
Squid–slender	4	1.1	0.1	4	1.1	0.1	0			0		
Squid–sthn calamary	9	2.3	0.5	3	*		0			2	*	
Scallop	4	0.9	–	0			0			0		
Barred cod	1	*		9	1.4	0.1	5	1.3	0.1	2	*	
Flathead–dusky	5	0.6	0.4	1	*		0			1	*	
Flathead–marble	1	*		0			0			0		
Flathead–sand	9	4.5	1.6	3	*		1	*		0		
Flathead–spiky	0			8	2.2	0.1	10	9.3	0.2	12	14.3	0.3
Flathead–tiger	8	1.4	0.3	12	44.4	8.1	11	16.3	3.0	12	16.4	0.3
Flounder–bigtooth	10	2.2	0.9	0			3	*		0		
Flounder–smoothback	2	*		1	*		1	*		0		
Gurnard–red	0			2	*		1	*		0		
Hairtail	1	*		2	*		3	*		8	1.5	0.1
John dory	10	2.7	1.0	8	1.7	0.2	12	11.3	0.3	9	1.3	0.2
L'jacket–mosaic	0			0			1	*		0		
Ocean perch	0			1	*		0			7	4.4	0.1
Ray–banjo	5	0.6	0.6	0			0			0		
Ray–shovelnose	12	13.1	15.0	6	0.9	1.6	1	*		1	*	
Redfish	4	18.9	1.9	10	7.8	0.5	8	12.7	0.5	10	3.3	0.1
Red mullet	0			0			0			4	0.6	0.1
Shark–gummy	0			0			0			1	*	
Shark–offshore angel	0			0			1	*		1	*	
Shark–saw	0			2	*		1	*		0		
Shark–wobbegong	0			2	*		3	*		0		
Tilefish–pink	10	16.2	2.6	9	2.4	0.3	10	4.0	0.5	10	11.0	1.3
Trevally–silver	3	*		0			0			0		
Whiting–redspot	12	839.1	38.3	10	129.3	4.6	10	311.4	8.1	12	230.0	3.8
Total comm. fish	12		64.5	12		18.1	12		14.4	12		6.7
Trash fish	12		14.4	12		18.4	12		8.4	12		6.1
Trash crustaceans	12		13.7	12		10.8	12		17.0	12		10.0
Total by–catch	12		93.3	12		48.1	12		40.3	12		24.7
No. of spp–fishes	12	26.3		12	21.8		12	20.8		12	22.9	
No. of spp–crust.	12	9.9		12	11.5		12	14.0		12	12.0	
No. of spp–ceph.	12	2.7		12	2.8		12	1.5		12	2.3	
Prawn catch : by–catch		1:15			1:16			1:9			1:2	

Total by-catch

The range of means of total by-catch per tow for the four surveys were: Brunswick Heads 85-191 kg; Clarence River 28-55 kg; Tuncurry 36-201 kg; and Newcastle 24-94 kg. The prawn catch to by-catch ratios for all surveys off the Clarence River and Newcastle were less than 1:20. Larger values were obtained for the Brunswick Heads ground (1:30 to 1:101) and off Tuncurry (1:6 to 1:25).

Daytime Trawling on Offshore Grounds

Daytime tows on offshore grounds were completed off Brunswick Heads (1), the Clarence River (2) and Tuncurry (1); catch data are summarised in Table 11. Very few or no prawns were caught in the four tows and the catches of fish and other by-catch species were substantially lower than for the night-time tows.

Table 11: Catch data for the main species caught during daytime tows on offshore grounds (* smooth bug; + Bruce's bug).

	Operation No.	King prawn (no.)	Bug (no.)	Bug (kg)	Slender squid (no.)	Slender squid (kg)	Comm. fish (kg)	Trash fish (kg)	Total by-catch (kg)	Fish spp. (no.)
Brunswick Hds I	900827	1	13*	1.0	3	0.4	0.8	45.0	48.1	21
Clarence R. I	900855	5	0	-	5	0.3	0.2	12.0	13.3	18
	900855	4	1*	0.1	0	-	0.1	20.0	23.5	25
Tuncurry I	900905	2	5+	0.3	119	7.0	5.3	5.7	22.5	21

SIZE COMPOSITION OF CATCHES

Prawns: Table 12 shows the counts for prawns (no./kg) for each area and survey when significant quantities were caught. These indices are inversely proportional to the average size of prawns in the sample.

School prawns caught off Brunswick Heads (110/kg) and Newcastle (92-123/kg) were relatively large compared to those from the Clarence River (150-209/kg) and Tuncurry (186/kg) grounds.

Table 12: Mean counts (no./kg) of school and king prawns caught during Surveys I - IV.

Survey:		I (May-June) King	I School	II (Aug.-Sept.) King	II School	III (Nov.-Dec.) King	III School	IV (Feb.-April) King	IV School
Brunswick Heads	inshore	-	-	-	-	-	110	-	-
	offshore	23	-	21	-	13	-	37	-
Clarence River	inshore	-	209	-	-	-	175	91	150
	offshore	20	-	24	-	15	-	16	-
Tuncurry	inshore	-	186	-	-	-	-	-	-
	offshore	43	-	30	-	55	-	67	-
Newcastle	inshore	-	92	75	123	-	111	-	-
	offshore	66	-	64	-	89	-	116	-

King prawns of similar size were caught on both the northern offshore grounds during Surveys I and II (20–24/kg) and Survey III (13–15/kg). During Survey IV the Clarence River king prawns were still large (16/kg), but off Brunswick Heads an influx of small prawns increased the count to 37/kg. Off Crowdy Head, king prawns were mainly medium sized and ranged from 30/kg (Survey II) to 67/kg (Survey IV). King prawns off Newcastle were smaller again; counts of 64/kg and 66/kg were recorded for Surveys I and II, increasing to 89/kg and 116/kg for Surveys III and IV.

King prawns were also caught in significant numbers during night shots on inshore grounds during two surveys. Off the Clarence River, the count for the inshore king prawns of 91/kg (Survey IV) contrasted markedly with those from the offshore ground (16/kg). During Survey II off Newcastle, inshore king prawns (75/kg) were only a little smaller than those from offshore (64/kg).

Fish: Length-frequency histograms for commercial species which were caught in significant numbers during Surveys I to IV are presented in Figures 2 to 12. Where catches were subsampled, the data have been scaled to represent total catch numbers. Minimum legal lengths are indicated on the histograms.

Catches from the inshore grounds were dominated by small and/or juvenile fish. The length data for a number of species show dominant modal peaks of juveniles with increasing modal lengths from survey to survey showing growth increments. This was particularly evident for sand flathead, red gurnard, snapper, tailor and shovelnose rays from the inshore catches, and for tiger flathead and redfish from the Newcastle offshore ground.

Almost all sand flathead, snapper, mulloway and teraglin were smaller than their minimum legal lengths. Most red gurnard, tailor and the two whitings, which are species without legal lengths, were also very small and much less than acceptable commercial size. The data for shovelnose rays show that the catches from the Brunswick Heads and Clarence River inshore grounds were dominated by small size classes compared to the mainly large rays on the Tuncurry ground.

On the offshore grounds, the small numbers of sand flathead were mainly larger than the minimum legal length (33 cm TL), and similarly red gurnard from offshore grounds were larger than those from inshore. Redspot whiting from the Clarence River and Tuncurry were mostly medium sized (15–20 cm FL) compared to those off Newcastle which were almost all less than 15 cm in length. Tiger flathead from Tuncurry were mainly larger than the legal minimum length (33 cm TL) in contrast to the predominantly small and juvenile tiger flathead from the Newcastle ground. Redfish showed a similar pattern in that the Tuncurry fish were on average much larger than the mainly juvenile redfish from Newcastle. Smooth-backed flounder ranged from 10 to 30 cm TL and the data shown were representative of the species from all areas. Pink tilefish were caught only off Newcastle and were mostly smaller than a marketable size of about 25 cm.

Crabs and Bugs: Length-frequency histograms for blue swimmer, two-spotted and three-spotted crabs, and smooth bugs are shown in Figures 13 to 15.

Almost all blue swimmer crabs caught off Tuncurry were larger than the minimum legal size of 60 mm carapace length; off the Clarence River most were undersize. Three-spotted and two-spotted crabs do not have minimum legal sizes but the data show that very few taken during these surveys were larger than a commercially acceptable size of approximately 60 mm carapace length.

The smooth bug data, especially for the Clarence River catches, show the presence of distinct size classes of juvenile bugs. Off Brunswick Heads, almost all bugs caught in the first three surveys ranged from 50 to 70 mm carapace length; a modal group of juvenile bugs 16–20 mm was present in Survey III, and two modes of 20–25 and 26–33 mm carapace length. The Clarence River data showed distinct modes of 25-32 mm in Survey I and 33-39 mm in Survey II; in the latter two surveys, a pulse of smaller bugs 16-20 mm (Survey III) and 20–25 mm (Survey IV) made up the most of the numbers caught. No female smooth bugs with eggs were caught in any survey.

Squids: Length-frequency histograms for slender squid (totalled for all offshore grounds per survey), broad squid (combined for Tuncurry and Newcastle surveys) and bottle squid for the Newcastle surveys are presented in Figures 15 and 16.

Slender squid ranged from 4 cm to 27 cm mantle length; the large numbers of juveniles (5-15 cm) caught off Tuncurry during Survey I and off Brunswick Heads and the Clarence River during Survey II comprise about 90% of the total catch. The smaller numbers of slender squid caught during Surveys III and IV showed no obvious size modes.

The size range of broad squid was 3 cm to 20 cm mantle length. The data for Survey IV showed evidence of an influx of small squid onto the grounds with a modal peak at 8 cm. The sex ratios of the catches did not vary greatly from 1:1.

The small bottle squid from Newcastle ranged between 26 and 60 mm mantle length for males and 28 and 82 mm for females; the data from other grounds were similar. The bi-modal size distributions evident in the data for Surveys II and IV reflects the differences in the sizes of males and females, and possibly differences in growth rates between the sexes. The proportion of males in the catches progressively increased from 35 per cent in Survey I to 70 per cent in Survey IV.

Faunal Assemblages

Fishes: Lists of all species caught during Surveys I-IV are presented in Appendix 3. The lists show the frequency of occurrence of each species (no. of tows in which each species was recorded) for each ground and survey. In all, 298 species of fishes were identified from the eight survey grounds, 176 from the inshore sites and 204 from the offshore sites. With reference to Paxton et al. (1989) and Gunn (1990), 22 of these species (from families Heterodontidae to Carangidae) had not been recorded previously from NSW and are noted in Appendix 3.

Table 13 shows the total number of species recorded from each site, the number of species caught during each survey and the mean number per tow. The data shows that the mean number of fish species per tow ranged from 17 to 32 for the inshore grounds and 20 to 32 for the offshore grounds. The number of species per survey was 44 to 69 (inshore) and 48 to 65 (offshore).

Table 13: Total number of fish species recorded for each area and survey. The mean number per tow is shown in brackets.

		Inshore Surveys					Offshore Surveys			
	Total Spp.	I	II	III	IV	Total Spp.	I	II	III	IV
Brunswick Hds	109	64 (24)	51 (23)	56 (25)	64 (29)	106	58 (25)	48 (23)	60 (32)	58 (31)
Clarence R.	100	63 (25)	45 (18)	56 (24)	64 (31)	99	61 (28)	65 (26)	61 (26)	54 (30)
Tuncurry	103	69 (31)	46 (27)	40 (21)	62 (23)	97	52 (22)	62 (27)	55 (26)	62 (30)
Newcastle	97	56 (19)	44 (24)	49 (20)	54 (19)	98	65 (26)	56 (22)	50 (21)	59 (23)

Fourteen species of fishes were recorded from all eight grounds. Eight were commercially exploited species: shovelnose ray, red gurnard, sand flathead, barred cod, redspot whiting, common mackerel, chinaman leatherjacket and mosaic leatherjacket. Six were non-commercial species: yellowtail, common seapike, smooth boxfish, numbfish, red bullseye and blue toadfish. As previously discussed, redspot whiting were at times common on all grounds, and shovelnose rays, red gurnard and sand flathead were more numerous on inshore than offshore grounds. Juvenile barred cod and the two species of leatherjackets were caught in very small numbers. Common mackerel, yellowtail and seapike are primarily pelagic species and were occasionally caught in large numbers, especially inshore. Smooth boxfish were more common inshore especially off Tuncurry; numbfish, red bullseye and the blue toadfish were only caught in small numbers on any ground.

Table 15 lists the 46 species which were recorded in at least 50% of tows on any ground. The data for the inshore grounds show that the most common species (present in at least half of the tows on every ground) were stout whiting, sand flathead and big-toothed flounder (commercial species), and common stingaree, longspined flathead, yellowtail, common seapike and Halstead's toadfish (trash species). The most commonly caught species from the offshore grounds were all trash species: the little conger, longfinned gurnard and crested flounder which was recorded from every offshore tow. Weights of individual trash fish species were recorded when they formed a significant proportion of the by-catch, but no counts were made. However, all of the above trash species were caught in large numbers in many tows.

Table 14 shows the degree of overlap in the geographical and depth distributions of the fish species. The data show that for adjacent sampling sites, the percentage of species recorded from both grounds was 70-74 for the inshore sites, and 59-68 for the offshore grounds. For both inshore and offshore grounds the lowest degree of overlap was between the two most distant sites (Brunswick Heads and Newcastle): 55% for the inshore grounds and 42% for the offshore grounds. A comparison of the species assemblages between adjacent inshore and offshore sites showed the overlap for the Brunswick Heads, Clarence River and Newcastle grounds was 37-38%, and 26-28% for the Tuncurry grounds.

Similar analyses of the distribution data after deleting the records of species which were caught only once, increased the percentages by up to 5 points but resulted in no changes to the overall patterns.

Table 14: Percentage similarity matrix showing the percentage overlap of species among the four inshore sites and four offshore sites, and between adjacent inshore and offshore sites. The table shows the number of species recorded at each site and the percentages of the total species at each site which were also recorded from the other sites. (BH=Brunswick Heads; CR=Clarence River; T=Tuncurry; N=Newcastle)

	No.of Spp.	INSHORE BH	INSHORE CR	INSHORE T	INSHORE N	OFFSHORE BH	OFFSHORE CR	OFFSHORE T	OFFSHORE N
INSHORE									
Brunswick Hds	109	100	68	62	55	37			
Clarence R.	100	74	100	65	59		37		
Tuncurry	103	65	63	100	70			26	
Newcastle	97	62	61	74	100				37
OFFSHORE									
Brunswick Hds	106	38				100	63	42	42
Clarence R.	99		37			68	100	54	54
Tuncurry	97			28		45	55	100	60
Newcastle	98				37	45	54	59	100

Table 15: List of fishes which were caught in 50 per cent or more of tows on any ground. The data show the percentage of tows on each ground that the species was recorded. (BH=Brunswick Heads; CR=Clarence River; T=Tuncurry; N=Newcastle)

		INSHORE				OFFSHORE			
		BH	CR	T	N	BH	CR	T	N
Heterodontus portusjacksoni	Port Jackson shark	–	–	77	50	–	–	–	31
Aptychotrema rostrata	Shovelnose ray	96	60	96	40	25	4	2	40
Hypnos monopterygium	Numbfish	56	55	19	6	27	46	2	79
Trygonoptera testaceus	Common stingaree	100	96	100	60	–	–	–	13
Gnathophis sp.	Little conger	–	–	–	–	100	94	96	71
Saurida filamentosa	Long-finned grinner	–	–	–	–	4	90	71	63
S. undosquamis	Large-scaled grinner	85	28	29	2	69	–	–	–
Trachinocephalus myops	Painted grinner	–	2	–	15	100	48	–	–
Gonorynchus greyi	Sandfish	–	–	–	–	96	90	79	19
Antennarius striatus	Striped anglerfish	25	25	–	6	65	71	19	21
Pseudophycis breviuscula	Little cod	–	–	2	13	–	6	58	96
Optivus sp.	Slender roughy	2	–	–	10	88	33	6	33
Centroberyx affinis	Redfish	–	–	4	2	–	6	58	96
Zeus faber	John dory	–	2	4	2	–	2	65	79
Macroramphosus scolopax	Common bellowsfish	–	–	–	–	–	90	4	100
Maxillicosta whitleyi	Little scorpionfish	–	–	–	–	–	90	4	100
Chelidonichthys kumu	Red gurnard	88	20	60	56	71	35	35	2
Lepidotrigla argus	Long-finned gurnard	8	2	–	–	100	100	73	100
L. umbrosa	Butterfly gurnard	100	40	–	–	–	–	–	–
Platycephalus caeruleopunctatus	Sand flathead	100	83	100	96	79	8	8	27
P. longipinnis	Long-spined flathead	100	75	81	81	100	100	–	10
P. richardsoni	Tiger flathead	–	–	–	–	–	–	100	96
Ratabulus diversidens	Spiky-headed flathead	–	–	–	–	40	65	96	65
Priacanthus macracanthus	Red bullseye	65	63	27	25	17	4	10	13
Sillago bassensis	Redspot whiting	44	60	79	94	17	52	77	96
S. robusta	Stout whiting	100	98	65	83	10	–	–	–
Trachurus novaezelandiae	Yellowtail	90	87	100	96	33	81	37	98
Gerres subfasciatus	Silver biddy	37	63	33	37	–	–	–	–
Sphyraena africana	Common seapike	67	75	92	75	25	2	19	2
Repomucenus calcaratus	Mottled stinkfish	63	28	2	4	98	17	–	2
Synchiropus calauropomus	Common stinkfish	–	–	–	–	75	100	–	19
Engyprosopon grandisquamma	Wide-eyed flounder	–	–	–	–	69	90	–	–
Lophonectes gallus	Crested flounder	–	–	–	–	100	100	100	100
Pseudorhombus arsius	Big-toothed flounder	60	55	96	60	–	–	–	25
P. jenynsii	Small-toothed flounder	48	54	44	23	–	–	–	–
P. tenuirastrum	Smooth-backed flounder	21	40	8	–	98	100	31	4
Synaptura nigra	Black sole	2	72	79	25	–	–	–	–
Aseraggodes macleayanus	Narrow-banded sole	79	79	63	83	–	–	–	37
Zebrias fasciatus	Banded sole	–	2	–	–	85	27	–	–
Paraplagusia unicolor	Tongue sole	92	43	54	52	–	–	–	–
Anoplocapros inermis	Smooth boxfish	2	53	100	42	48	69	41	23
Trioris reipublicae	Turret fish	–	–	–	–	96	96	–	2
Lagocephalus cheesemani	Blue toadfish	23	25	2	10	83	65	27	6
Reicheltia halsteadi	Halstead's toadfish	100	83	100	60	–	–	–	–
Torquigener altipinnis	Mottled toadfish	10	–	–	–	100	71	–	6
Dicotylichthys punctulatus	Three-barred porcupinefish	–	–	92	35	–	–	–	–

Invertebrates

Appendix 4 lists all the crustaceans and cephalopods recorded from Surveys I–IV and indicates the frequency of occurrence (percentage of total tows in which each was recorded) for each species. Table 16 gives the most common 18 species of invertebrates (caught in at least 75% of the total tows on any ground).

Table 16: List of invertebrates which were caught in 75% or more of tows in any of the survey grounds. The data show the percentage of tows in each area that the species was recorded. (BH=Brunswick Heads; CR=Clarence River; T=Tuncurry; N=Newcastle)

		INSHORE				OFFSHORE			
		BH	CR	T.	N.	BH	CR	T.	N.
Metapenaeus macleayi	School prawn	69	81	40	73	–	–	–	–
Penaeus plebejus	King prawn	6	44	17	48	100	100	100	100
Trachypenaeus curvirostris	Hardbacked prawn	23	63	13	44	75	100	4	8
Solenocera choprai	Ridgebacked prawn	–	–	–	–	–	–	81	94
Ibacus sp.nov.	Smooth bug	–	4	–	–	96	100	90	40
Charybdis bimaculata	Swimmer crab	–	–	4	19	–	13	56	100
C. miles	Spiny swimmer crab	–	–	–	–	–	27	2	100
Ovalipes australiensis	Two-spotted crab	10	8	60	92	–	–	–	–
Portunus pelagicus	Blue swimmer crab	21	46	83	65	29	2	–	27
P. rubromarginatus	Swimmer crab	75	27	–	–	100	31	–	–
P. sanguinolentus	Three-spotted swimmer	94	98	33	77	8	2	–	4
Alima laevis	Common mantis shrimp	17	100	4	35	13	2	–	–
Anchisquilla mcneilli	Yellow-spined mantis	–	–	–	–	–	–	65	98
Loligo chinensis	Broad squid	50	83	75	72	–	–	–	–
Loliolus noctiluca	Bottle squid	100	100	69	100	–	–	–	–
Nototodarus gouldi	Gould's squid	–	–	–	8	4	67	95	40
Sepia sp.	Cuttlefish	11	–	–	–	96	100	100	79
Octopus sp.	Plain octopus	35	22	44	14	90	100	10	6

A total of 72 species of crustacea were recorded; 33 from inshore grounds and 59 from offshore. The main groups represented were prawns (17 spp.), portunid (swimmer) crabs (18 spp.) and mantis shrimps (11 spp.). Twelve species of cephalopods were caught; these were mainly commercially exploited species of squids (5 spp.), cuttlefish (1 sp.) and octopus (3 spp.).

Exploratory Trawling

Five exploratory tows were made off Brunswick Heads and Ballina, three off Coffs Harbour, two off Cape Hawke and one off Newcastle. South of the survey areas, 18 tows were completed; these were six off Broken Bay, three off Sydney, three off Bate Bay and six in the Shoalhaven Bight. Operational and catch data are presented in Appendix 5.

Off northern NSW, significant quantities of king prawns were caught on the outer shelf off Coffs Harbour in May (operation 900857; 28 kg/h) and off Brunswick Heads in September (901227; 23 kg/h). Very few king prawns were taken in any of the other shots.

Two 90 minute tows off Cape Hawke in June (901001) and April (910501) caught small quantities of king prawns (8 kg and 1 kg); off Newcastle, a 75 minute tow in 110 m in June (901105) caught 23 kg of king prawns and 4 kg of Racek prawns.

Few king prawns were caught on the grounds between Broken Bay and the Shoalhaven Bight. In the tows off Broken Bay, redspot whiting was the main commercial species caught; off Sydney and Bate Bay, redfish and tiger flathead were prominent; and in the Shoalhaven Bight, flatheads, redfish and redspot whiting formed the major part of most catches. Of note also was the large number of juvenile blue and spotted warehou (10-16 cm fork length) caught in the Shoalhaven Bight; a few individuals were also taken off Broken Bay and Bate Bay.

Appendix 6 lists the fish and invertebrate species taken during exploratory trawling; two species of fish are noted as new distributional records for NSW.

DISCUSSION

The areas selected for sampling were on established prawn trawling grounds. Because of the program design and the seasonal nature of prawn abundance, many of the survey periods did not coincide with times of commercial trawling activity on these grounds. It is also recognised that within certain surveys, some sampling of king prawn grounds took place on full or near full moon nights, when prawn catch-rates are generally less than those during the dark phase of the moon. Nevertheless the overall results of this two year program will establish relative abundance indices for prawns and associated by-catch species for the eight grounds in a manner that can be repeated in the future.

Two factors influenced sampling on the inshore grounds. The first was the restricted size of the grounds, especially in width, which usually precluded the five minute steam in a random direction between tows; in practice, considerably more time was often spent moving to a start position which provided enough room for the completion of the next tow. The second was the perceived influence of the adjacent estuary system on the availability of school prawns and associated by-catch species, which was overcome by sampling all parts of the ground. The typical trawling pattern on the inshore grounds for the four tows each day was two pairs of parallel tows either starting or finishing at each end of the ground.

Catches of school prawns and the composition of the associated by-catch on inshore grounds were influenced by the outflow from the adjacent river or lake system. Throughout the sampling period, climatic conditions generally were dry and school prawn catches were small during most surveys. No commercial catch-rates of school prawns were achieved on the Brunswick Heads and Tuncurry grounds. Above average rainfall in the Clarence River and Hunter River catchments (ref. Australian Bureau of Meteorology Monthly Rainful Reviews) preceded the relatively large prawn catches off the Clarence River (Survey I) and Newcastle (Surveys I and II) and it was during these surveys that significant numbers of juvenile mulloway and teraglin were caught. As expected, commercial trawlers were only active on these grounds during these periods.

The patchy distributions of school prawns within grounds resulted in large variability between individual catches and, because of the random distribution of tows, resulted in relatively small mean catch-rates. In contrast, commercial trawlers target patches of high prawn density to maximise catches.

On the offshore grounds, the mean catch-rates of prawns and total by-catch per survey varied widely between grounds and probably reflected the amount of current commercial trawling on the grounds. Off Brunswick Heads, the mean total by-catches (85-190 kg/tow) were much larger than for the Clarence River ground (28-55 kg/tow) where many more trawlers work. Similarly off Tuncurry and Newcastle, the smallest by-catch was taken during Survey IV when most trawlers were seen on the grounds.

Andrew and Pepperell (in press) quote Slavin's (1982) prawn to by-catch ratios of 1:5 for temperate and sub-tropical fisheries and 1:10 in tropical fisheries, but warn that whilst these ratios are often cited they have seldom been tested. The wide range of ratios evident in our data highlight a number of factors which may affect the amount of by-catch. In general, the ratios reflected the magnitude of the prawn catches and the associated level of commercial fishing activity. That is, when the prawn catch-rate on a ground was sufficiently high to attract commercial fishing, there was usually a low level of by-catch possibly because of the fishing-down effect of intense trawling. During our study, prawn trawlers were active on inshore grounds off the Clarence River during Survey I and off Newcastle during Surveys I and II and the ratios of 1:7 and 1:13 (excluding the large Port Jackson shark catches during Survey II) were lower than those during the other surveys when there was less commercial trawling. Similarly, the smallest prawn catch to by-catch ratios on the Clarence River, Tuncurry and Newcastle offshore grounds were in the surveys which produced the highest prawn catch-rates and when there were periods of commercial trawling on the grounds.

It is recognised that the calculation of a prawn catch to by-catch ratio for a fishery is more relevant when the fishery is assessed as a whole rather than for a single survey period. For the NSW offshore prawn fishery, a more appropriate calculation would be made from data collected onboard commercial trawlers.

Faunal assemblages

Pairs of inshore and offshore grounds in the two study areas were selected for sampling to provide replication of sites within each study area. Despite some variation in the depth ranges of the grounds, especially the offshore sites, and a geographical range of about 260 n.miles, the faunal diversities of the respective inshore and offshore sites were similar: each ground was subjected to the same fishing effort (48 x 30 minute tows) and resulted in the capture of almost the same number of fish species per ground (range 97-109).

The large total number of species recorded reflected the amount of sampling effort. Although the cumulative total number of species recorded from any study site continually increased over the course of the four surveys, the rate of increase diminished with time. On average, about 25% of the total fish fauna recorded for each ground were caught each tow and between 45% and 65% of the total were caught during the course of each survey. A pilot study on the same grounds off Newcastle using the same gear and methods preceded this program (Graham et al, 1992). The mean number of fish species per tow of 21.4 was almost identical to the 21.7 recorded during this study. During the pilot study, a total of 73 species of fishes was recorded from the inshore ground after 24 tows, and 68 species from 21 tows on the offshore ground. Comparable data from this study (collected during same months of March and April) showed that for Survey IV the number of species recorded from the 12 inshore tows was 54 and 59 from the 12 offshore tows. At the end of the four surveys of this study, the total fish fauna recorded from the Newcastle grounds was only about 30% greater than that recorded during the pilot study although the fishing effort was almost double.

Some seasonal influences on the species diversity of inshore grounds were apparent. Table 12 shows that on all grounds the number of species per survey was a little greater during Surveys I (May-June) and IV (February-April). The family Carangidae was one group of fishes which was better represented during those surveys, especially off Brunswick Heads and Tuncurry during Survey I and on all grounds during Survey IV. The adults of most of the recorded carangids (trevallies and scads) are normally found in more tropical waters (Gunn 1990), and the species were represented in our catches by juveniles.

The geographical distributions of the inshore fish species showed a greater affinity between sites than did the offshore species. Of the 109 species recorded from the Brunswick Heads inshore ground, 55% were caught off Newcastle and 62% of the 97 Newcastle species were taken off Brunswick Heads. In contrast, the respective values for the Brunswick Heads and Newcastle offshore grounds were 42% and 45%. The data for the Clarence River and Newcastle grounds, sites with very similar depth ranges, showed that about 60% of inshore species and 54% of offshore species were common to both grounds.

Overall, the fish fauna taken during this program was mainly composed of temperate and sub-tropical species. Jones and Derbyshire (1988) found that the demersal trawl fauna of central Queensland shared over 50% of species with the tropical west Pacific region; in our study, less than 20% of the fish species we recorded were also caught during the Queensland study.

Our study showed that the distribution of fish species varied among depths more than among geographical locations. The depth distributions of fishes caught off Newcastle during the pilot study were discussed by Graham et al. (1992) and the fauna found to divide into distinct inshore (10-30 m) and offshore (130-140 m) assemblages with only 6% of the total species present in both depths; 38% of the fauna from the intermediate depth zone (55-75 m) were also caught on the inshore ground. The results from our present study were very similar with 37% of species being caught on both the inshore (10-21 m) and offshore (64-77 m) Newcastle grounds.

The degree of similarity of depth distributions of species on the northern NSW grounds was almost identical (37–38% overlap) even though the difference between the depths of the Brunswick Heads grounds (10–19 m and 45–60 m) was appreciably less than for the other grounds. In contrast, the faunas of the Tuncurry grounds were more distinct (26–28% overlap) probably reflecting the greater difference in depth between the inshore (10–21 m) and offshore (84–103 m) grounds.

The total of 71 species of crustaceans recorded during this study was substantially less than the 91 crustaceans reported by Jones and Derbyshire (1988) for their survey of central Queensland prawn grounds. Although the Queensland sampling was conducted only at night in depths mainly between 40 and 100 m, the larger number of crustaceans most likely indicates a greater faunal diversity in more tropical waters. As for the fish fauna, the crustacean fauna recorded during our survey showed little affinity with that of central Queensland as only 20 (28%) of the NSW species were also reported from central Queensland.

Distributional records

Lists of fish species caught during recent *Kapala* studies were published in Kapala Cruise Report Nos 102, 108 and 109 (Graham et al., 1987; 1991; 1992). Three of the 24 species noted in this report as new distributional records for NSW (*Uroconger lepturus*, *Erosa erosa*, and *Dactyloptena papilio*) were previously listed (Graham et al. 1992). It is probable that a number of species recorded from the families Coryphaenidae to Diodontidae are also new records for NSW; these families will be reviewed in *Zoological Catalogue of Australia*, Fishes (Part 2) which is in preparation (J. Paxton, pers comm.)

Specimens of the six-gilled shark *Hexanchus nakamurai* were first caught by *Kapala* on the outer shelf off northern NSW in 1978 and deposited in the Australian Museum (K.J. Graham pers. obs.). Our capture of a specimen in 152 m off Ballina is the first published record for Australian waters; other recent records from northern and north-western Australian will be reported by Last and Stevens (in press).

During their recent study of Australia's sharks and rays, Last and Stevens (in press) found that the specific names previously applied to the NSW offshore angelshark (*Squatina* sp.), common sawshark (*Pristiophorus* sp.) and banjo ray (*Trygonorrina* sp.) were incorrect, and in fact these common commercial species required new names and descriptions.

Records of upper continental slope crabs and prawns caught by *Kapala* are contained in Griffin and Brown (1975) and Kensley et al (1987). Appendix 4 records for the first time a comprehensive account of the crustaceans from NSW continental shelf trawling grounds. Stomatopods (mantis shrimps) were identified by S. Ahyong at the Australian Museum; *Lysiosquilla* sp. is an undescribed species, *Lenisquilla lata* and *Oratosquilla imperialis* are new records for Australian waters, and two other species have not previously been reported from off NSW (see Appendix 4).

SUMMARY

1. Between May 1990 and April 1991, four surveys of inshore and offshore prawn grounds off Brunswick Heads, the Clarence River, Tuncurry and Newcastle completed the first half of a two year sampling program.

2. Initial abundance indices (mean catch rates) on a seasonal basis were calculated for school and king prawns and the associated by-catch (commercial species and trash).

3. Size-frequency data was collected for the prawn and commercial by-catch species taken during the surveys.

4. A total of 376 species of fishes, crustaceans and cephalopods was recorded on the survey grounds; geographical and depth distributional data were collected for these species.

5. Exploratory trawling was conducted in outer shelf waters off Brunswick Heads and Coffs Harbour, and on grounds between Cape Hawke and Jervis Bay. Substantial catches of king prawns were caught off Coffs Harbour (May), Brunswick Heads (September), and off Newcastle (June).

ACKNOWLEDGEMENTS

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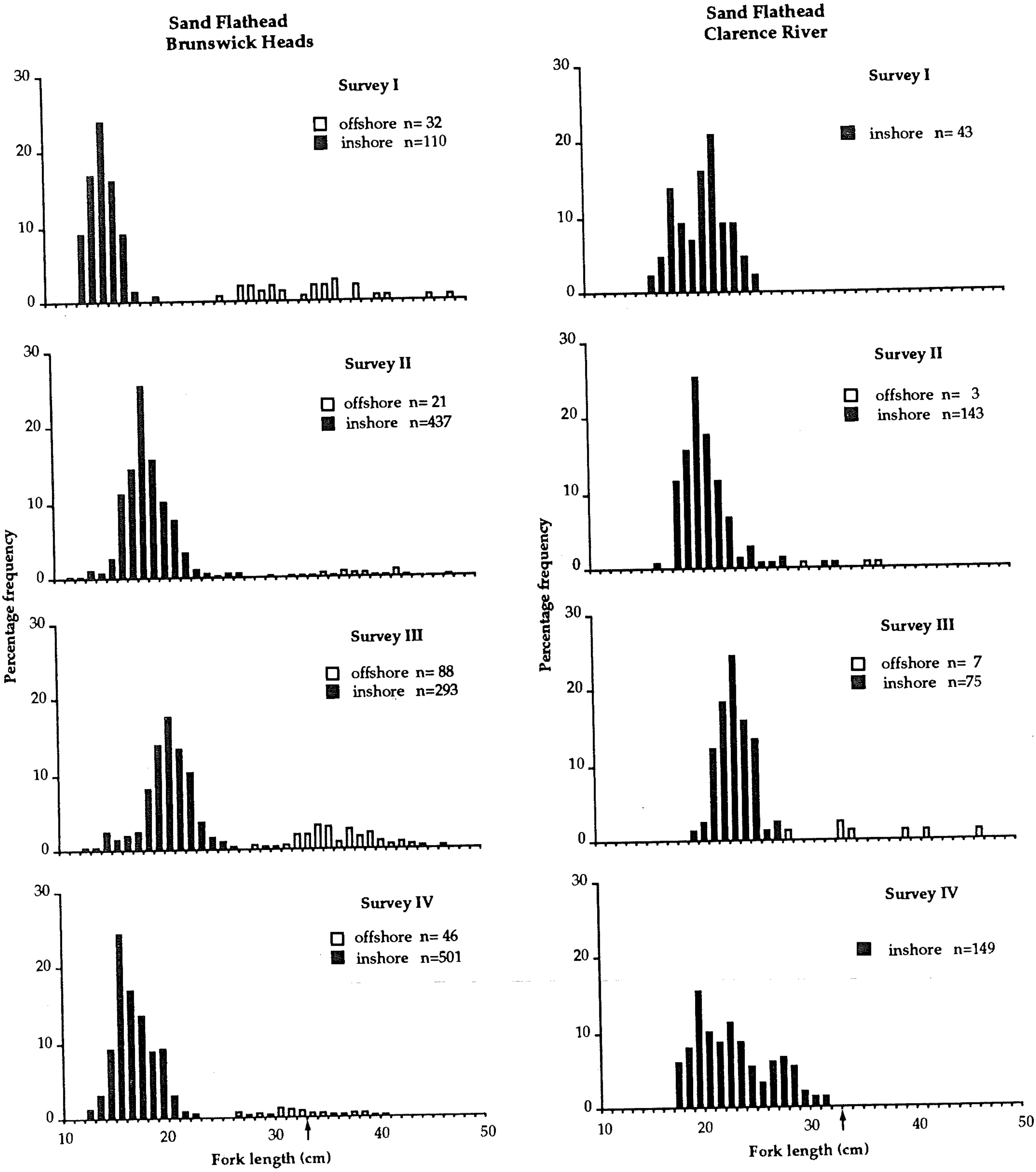


Figure 2: Length frequency of sand flathead for Surveys I-IV off Brunswick Heads and the Clarence River (the arrows indicate the minimum legal length).

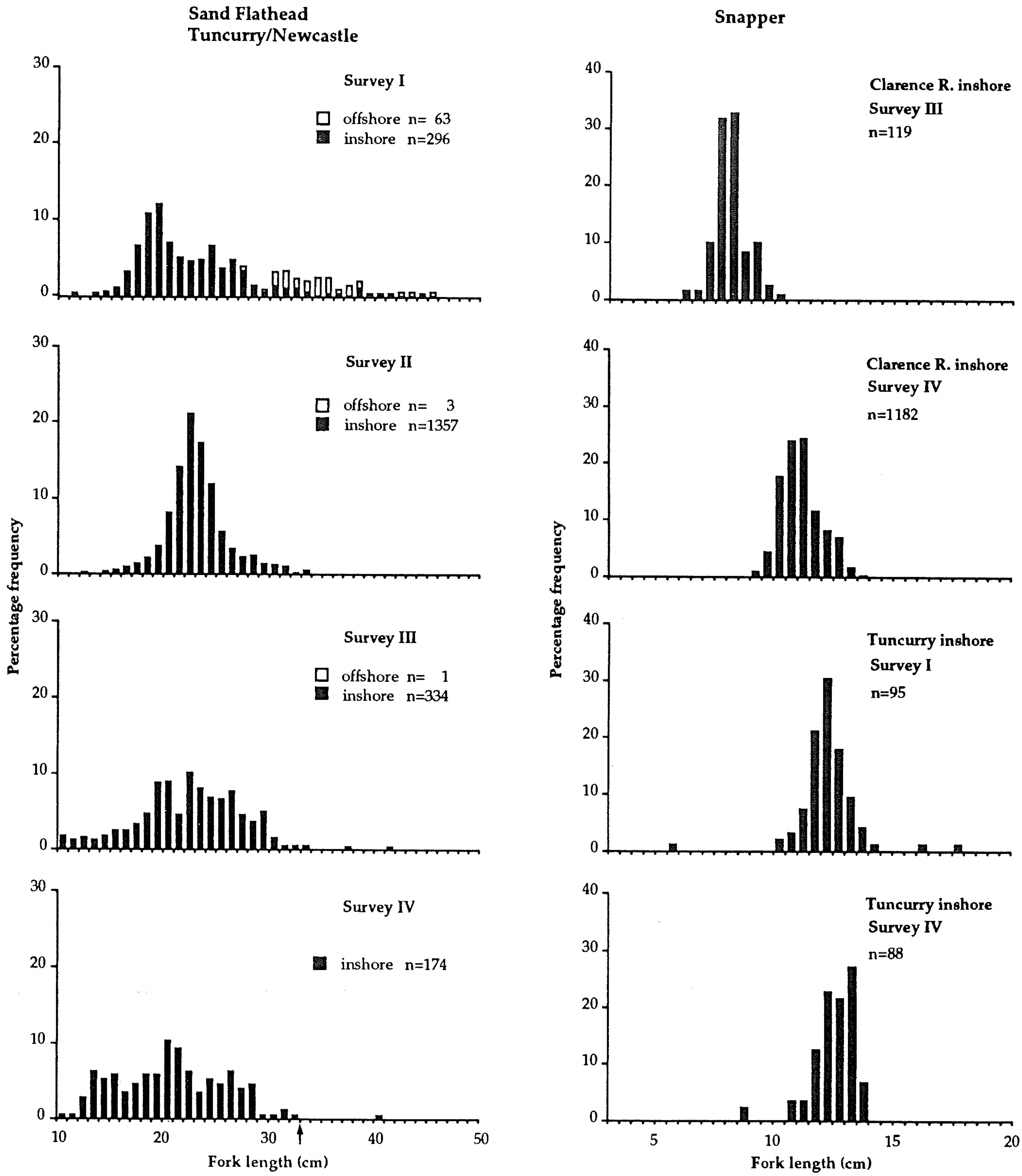


Figure 3: Length frequency of sand flathead for Surveys I-IV off Tuncurry and Newcastle (combined); and length frequency of snapper for Surveys III & IV off the Clarence River and Surveys I & IV off Tuncurry (the arrows indicate minimum legal lengths).

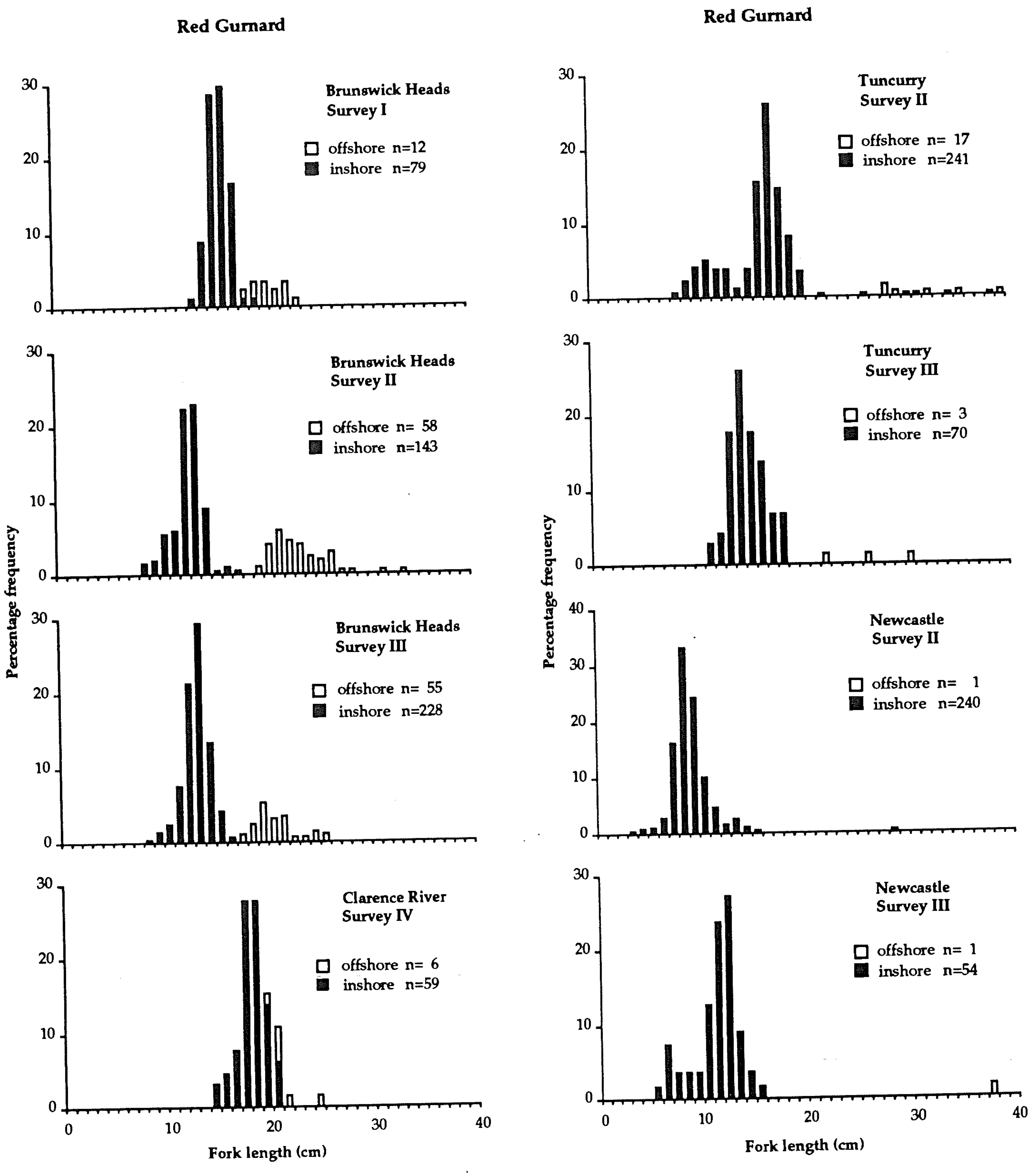


Figure 4: Length frequency of red gurnard for Surveys I-III off Brunswick Heads, Survey IV off the Clarence River, Surveys II & III off Tuncurry and for Surveys II & III off Newcastle.

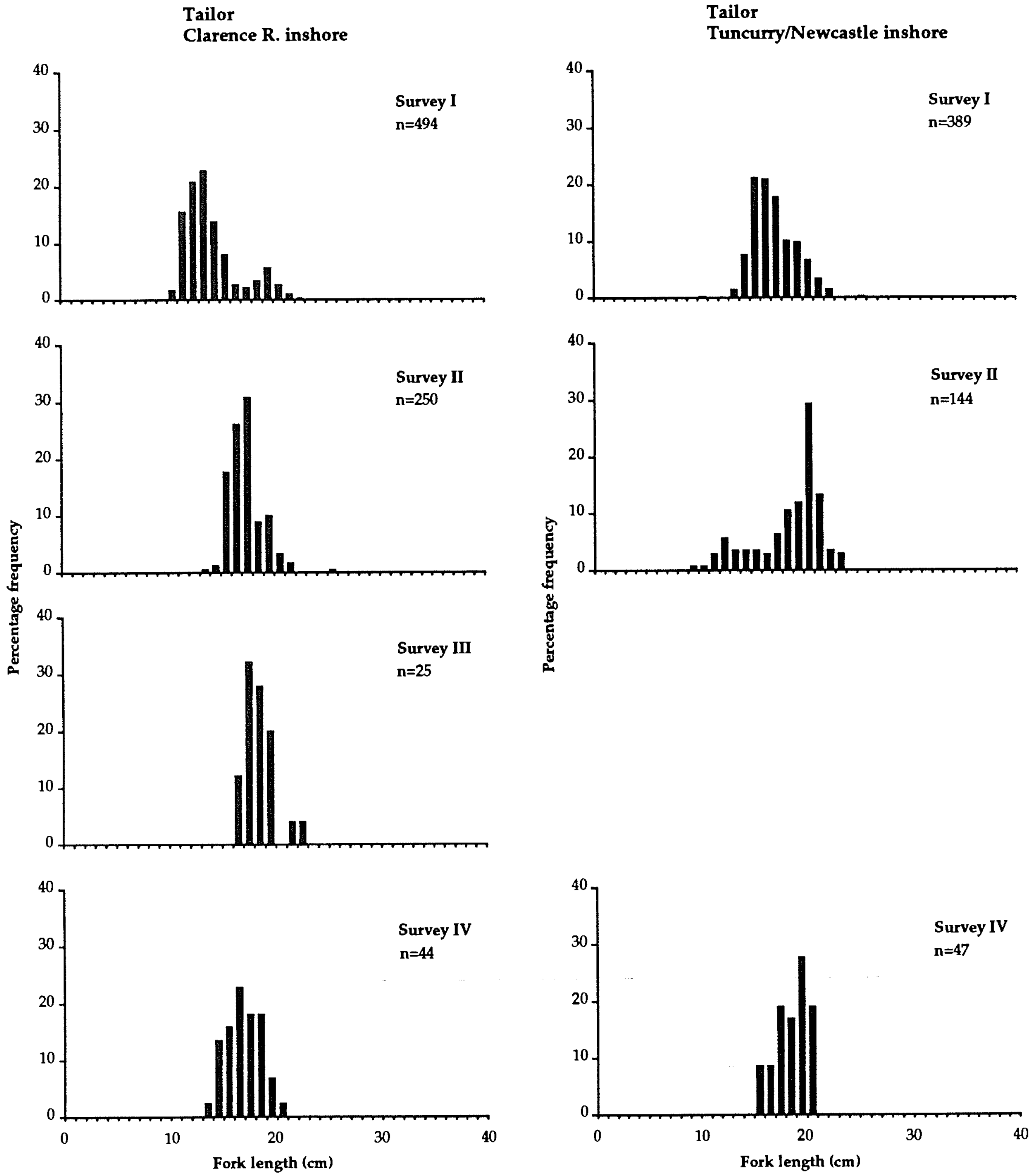


Figure 5: Length frequency of tailor for Surveys I-IV off the Clarence River and Surveys I,II & IV off Tuncurry and Newcastle (combined).

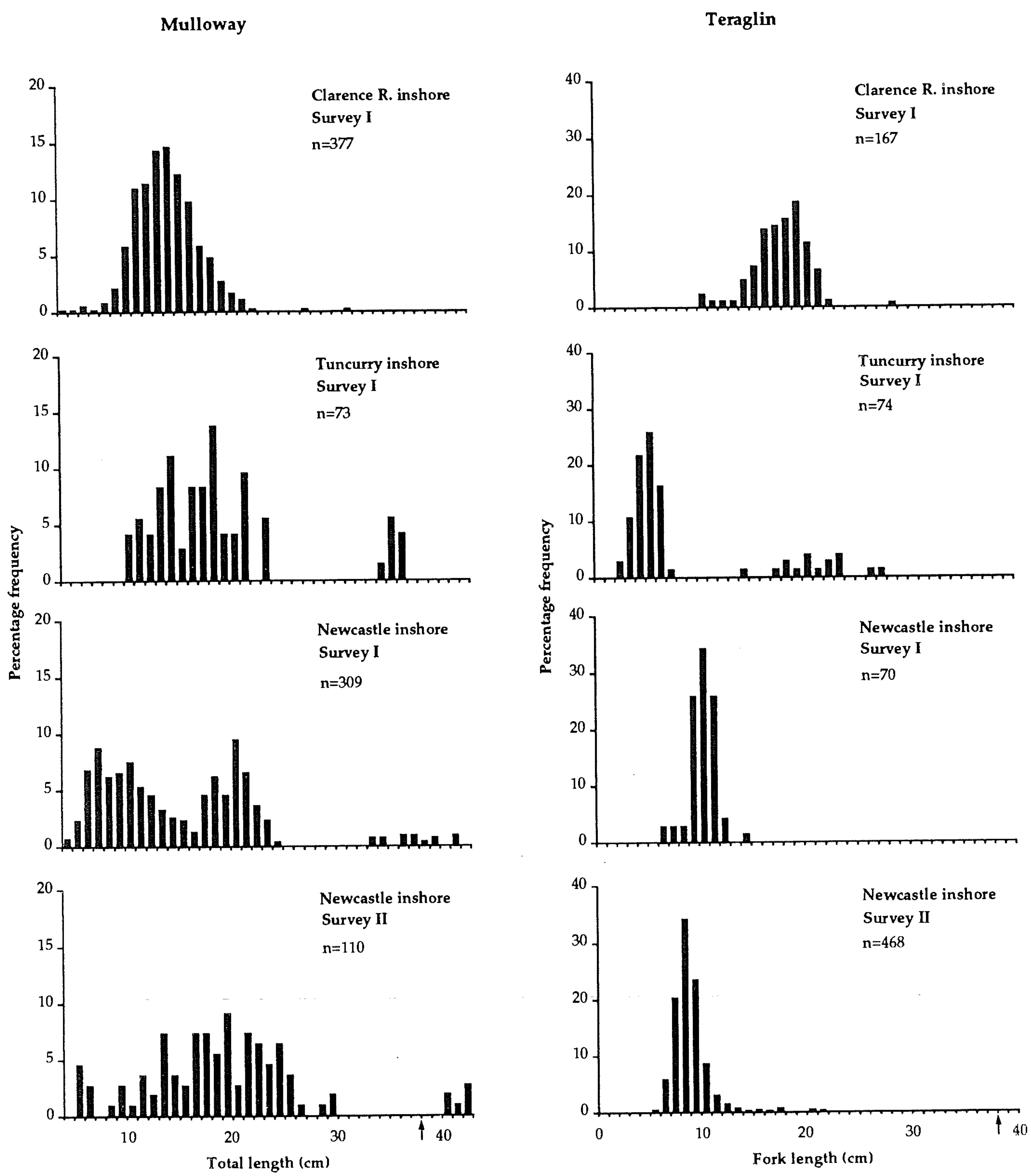


Figure 6: Length frequency of mulloway for Survey I off the Clarence River, Survey I off Tuncurry and Surveys I & II off Newcastle; and length frequency of teraglin for Survey I off the Clarence River, Survey I off Tuncurry and Surveys I & II off Newcastle (the arrows indicate minimum legal lengths).

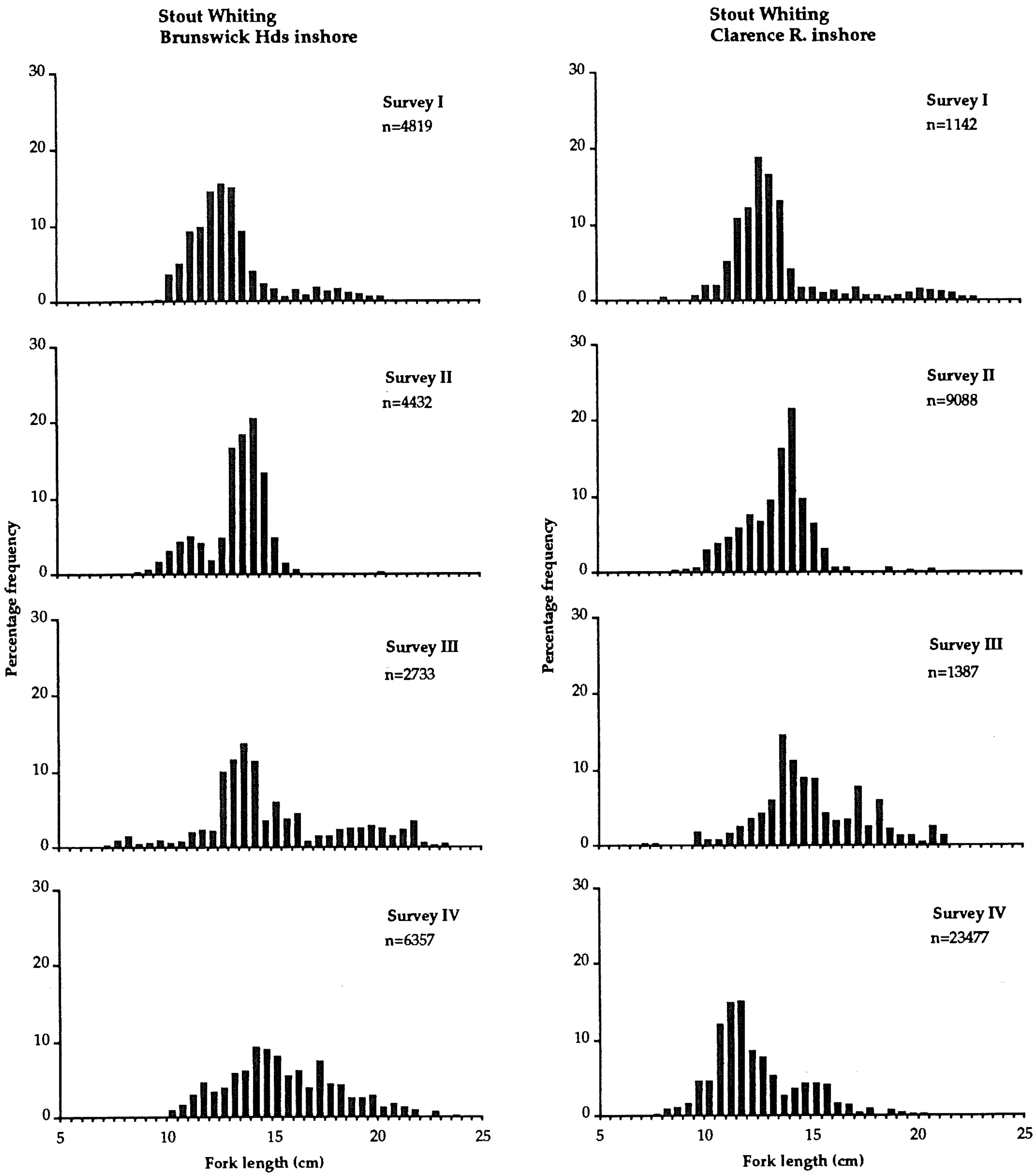


Figure 7: Length frequency of stout whiting for Surveys I-IV off Brunswick Heads and the Clarence River.

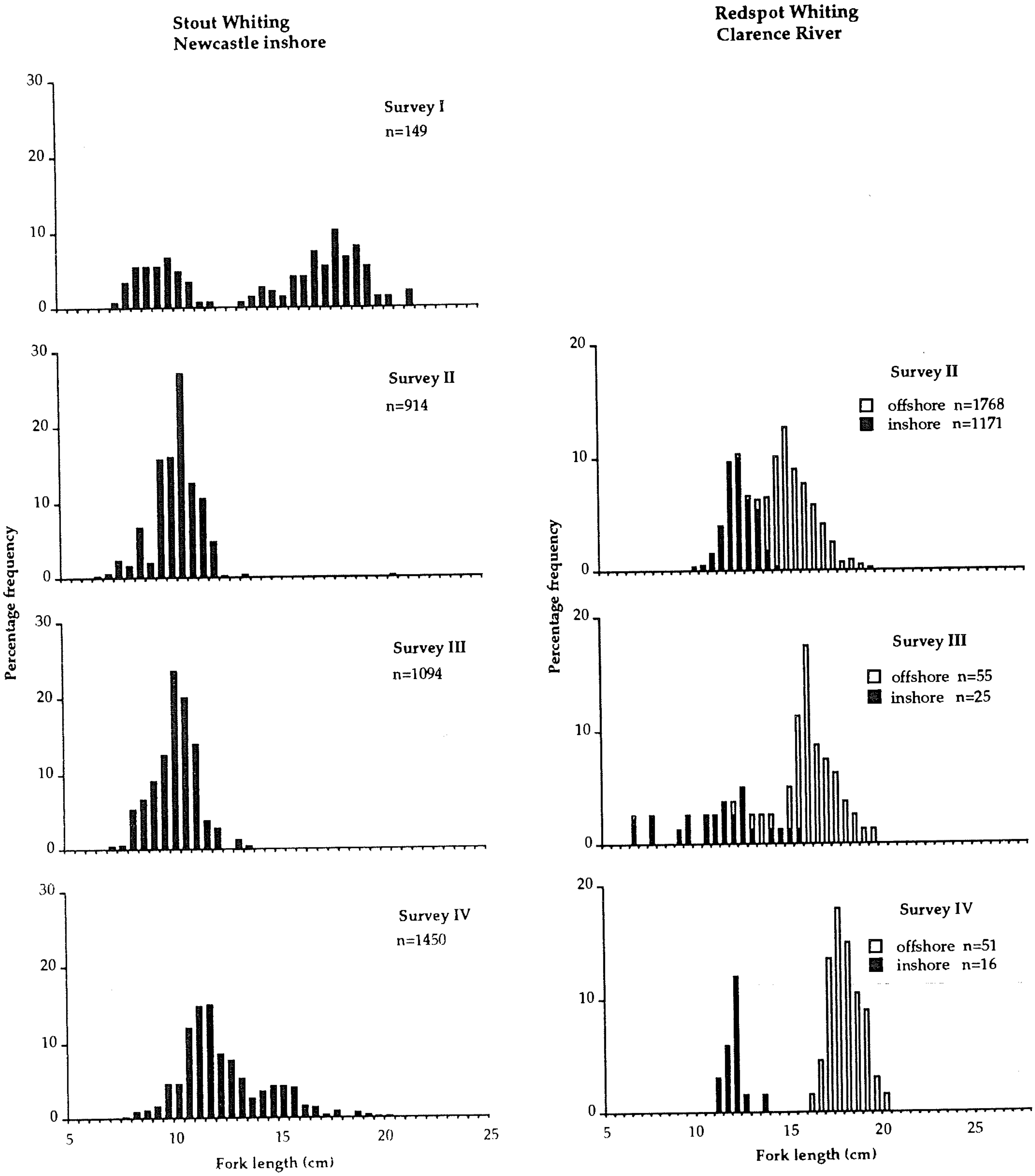


Figure 8: Length frequency of stout whiting for Surveys I-IV off Newcastle; and length frequency of redspot whiting for Surveys II-IV off the Clarence River.

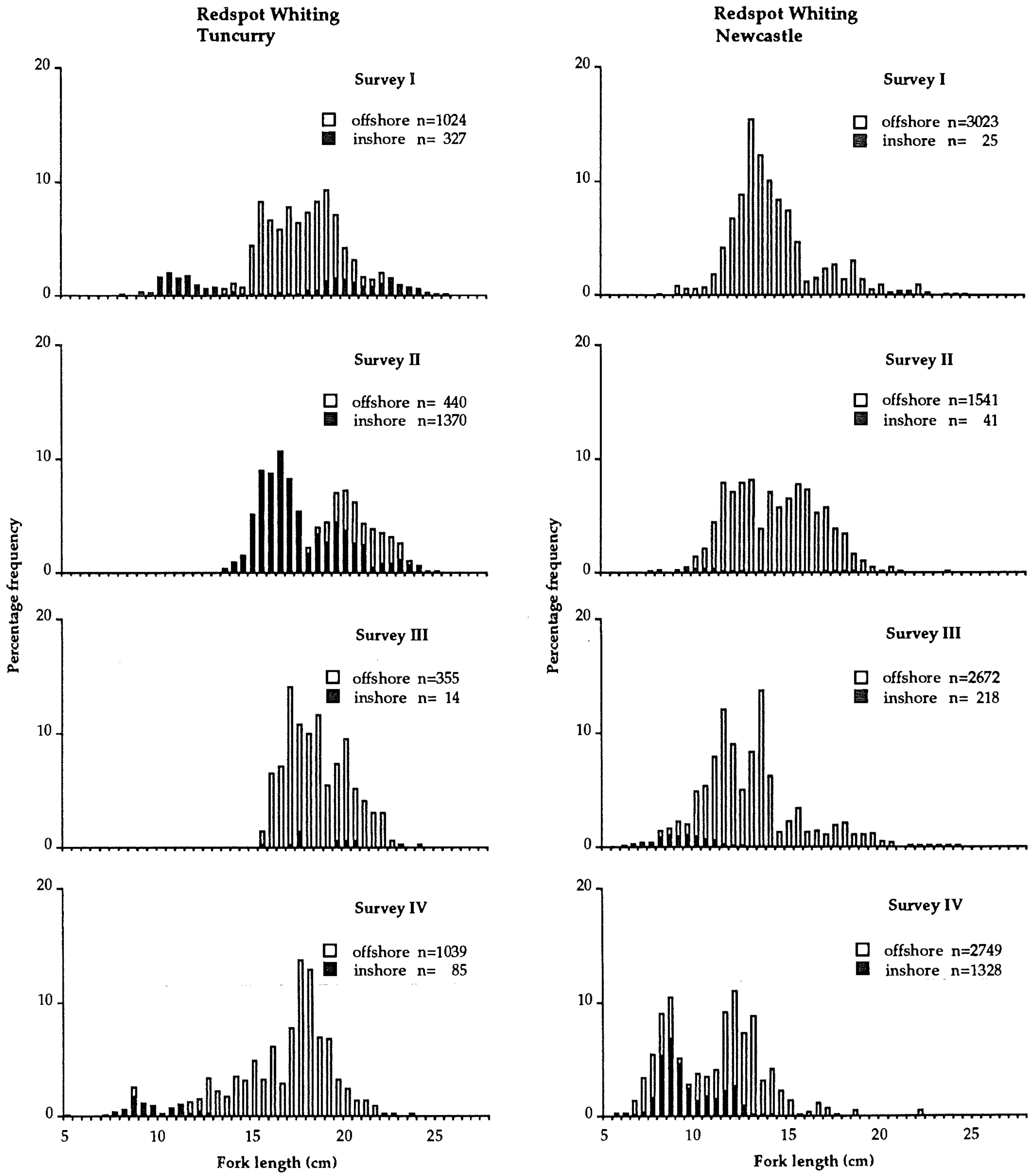


Figure 9: Length frequency of redspot whiting for Surveys I-IV off Tuncurry and Newcastle.

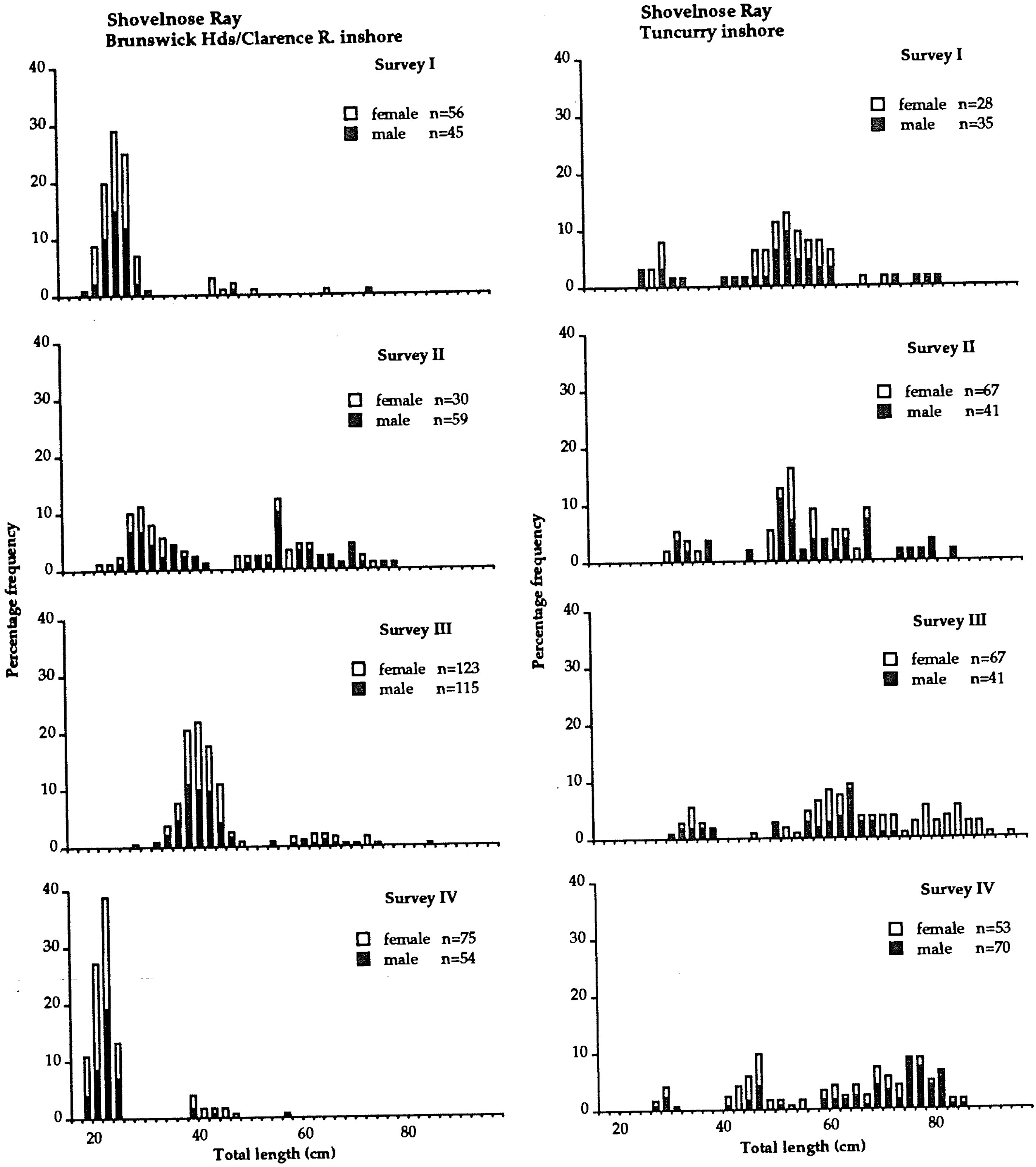


Figure 10: Length frequency of shovelnose rays for Surveys I-IV off Brunswick Heads and Tuncurry.

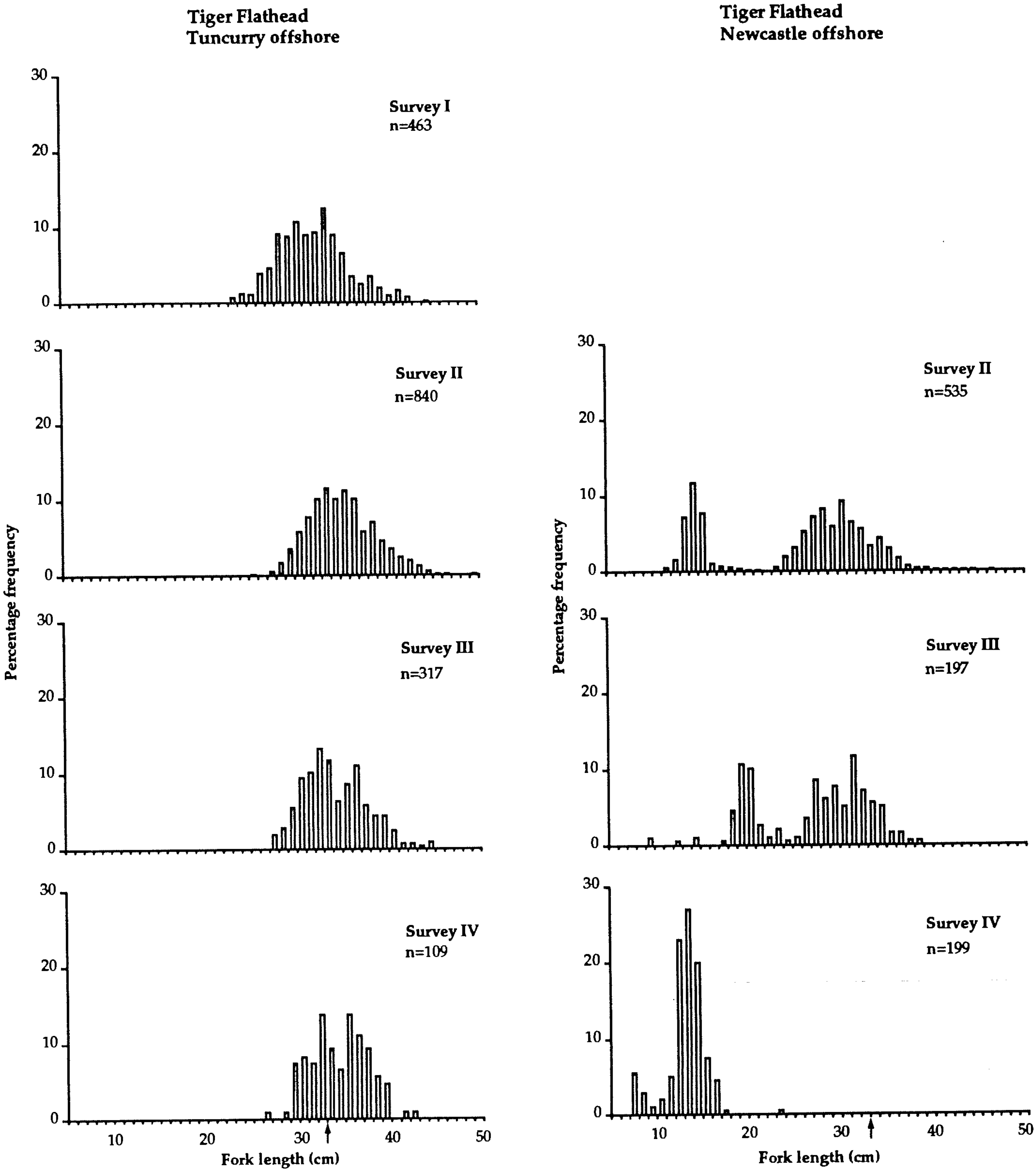


Figure 11: Length frequency of tiger flathead for Surveys I–IV off Tuncurry and Surveys II–IV off Newcastle (the arrows indicate the minimum legal length).

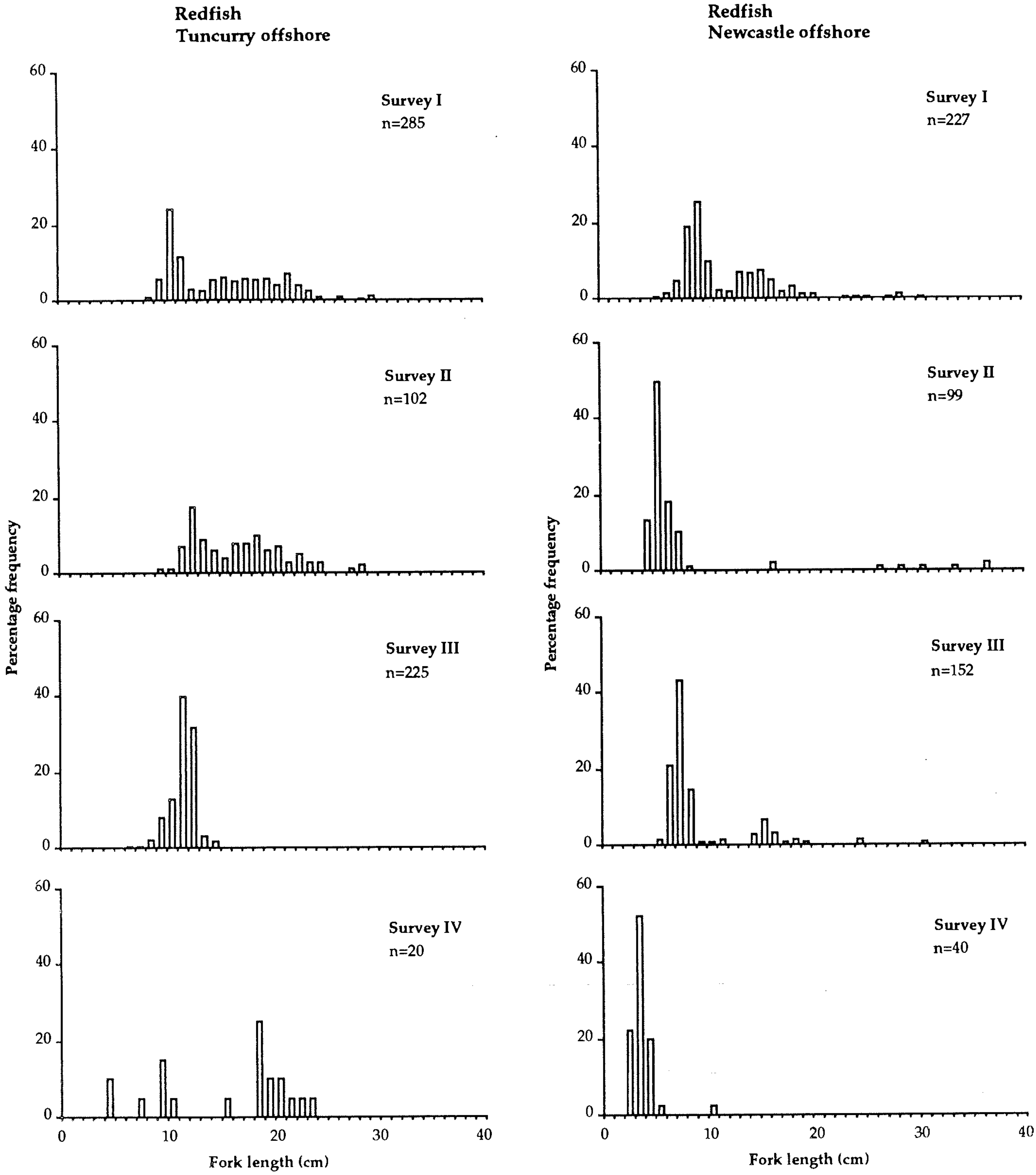


Figure 12: Length frequency of redfish for Surveys I-IV off Tuncurry and Newcastle.

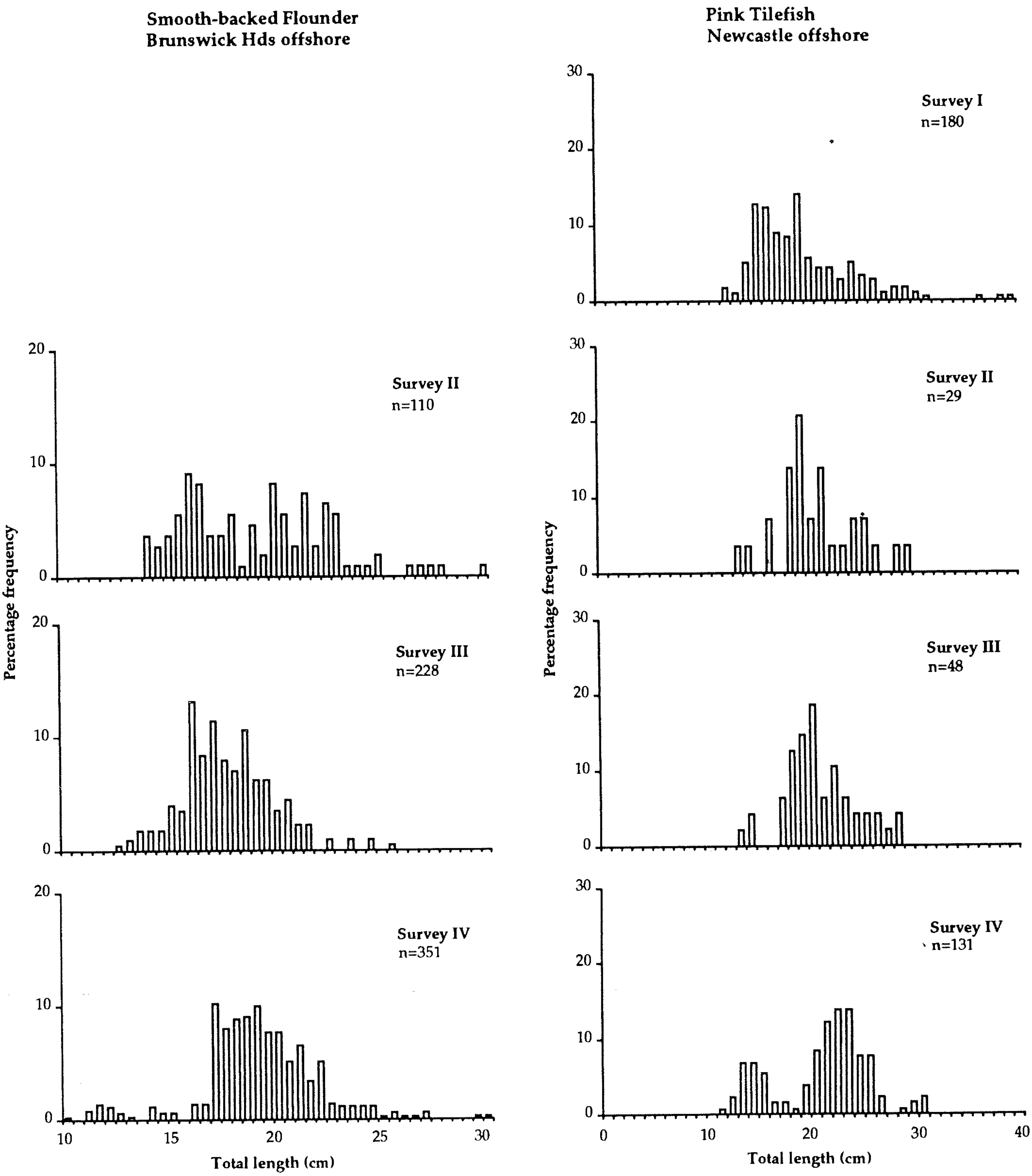


Figure 13: Length frequency of smooth-backed flounder for Surveys II-IV off Brunswick Heads; and length frequency of pink tilefish for Surveys I-IV off Newcastle.

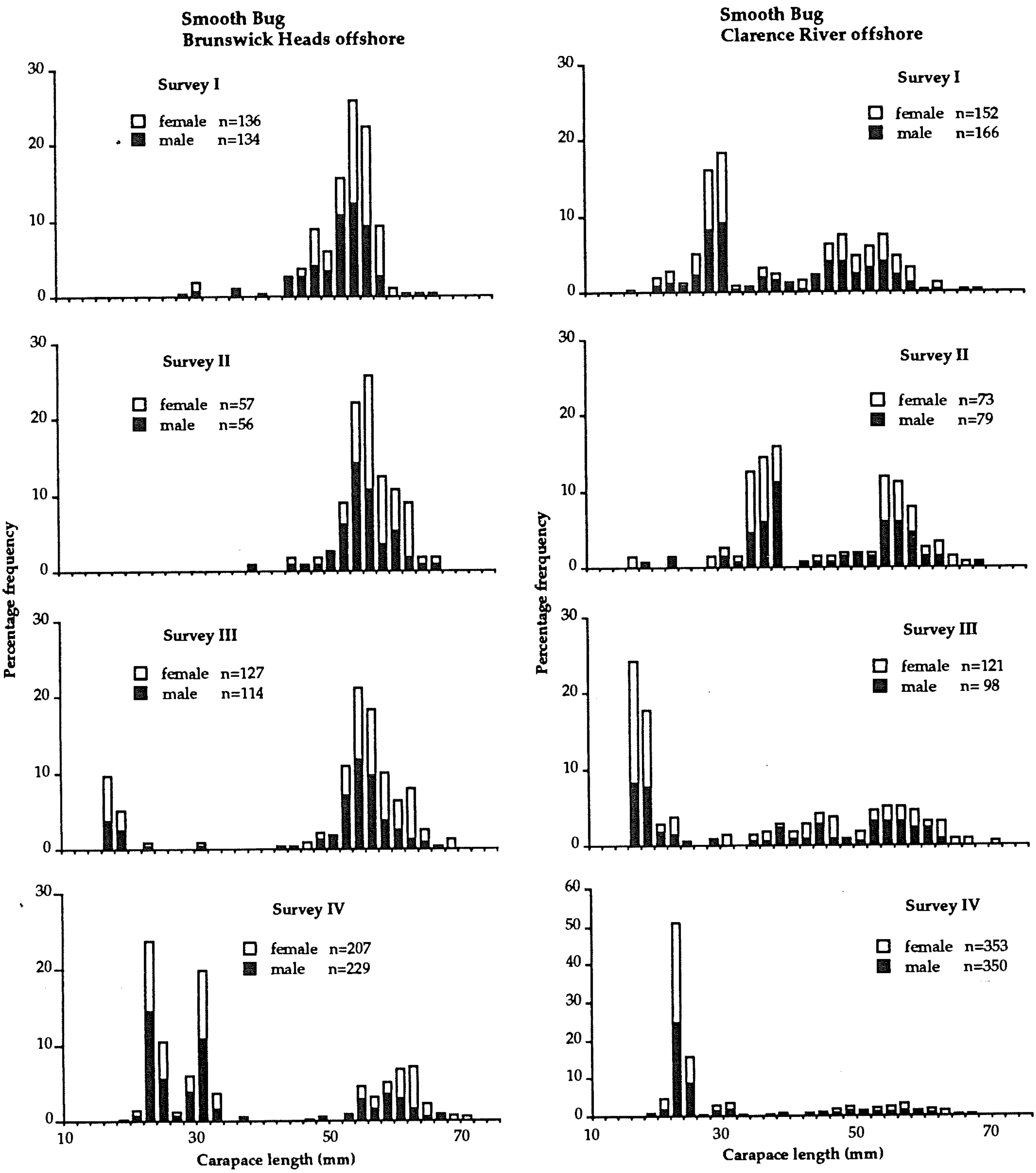


Figure 14: Length frequency of smooth bugs for Surveys I-IV off Brunswick Heads and the Clarence River.

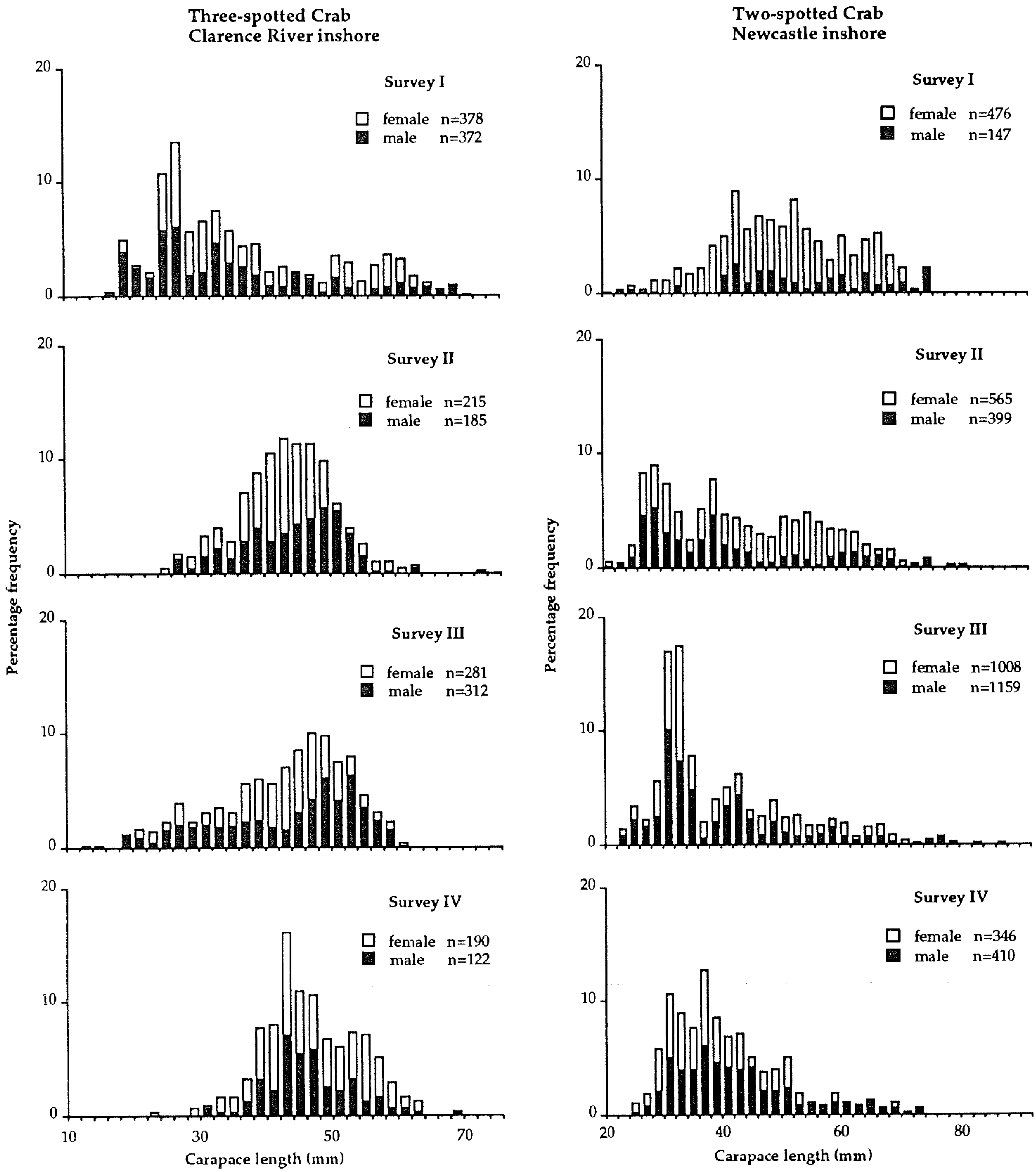


Figure 15: Length frequency of three-spotted crabs for Surveys I-IV off the Clarence River; and length frequency of two-spotted crabs for Surveys I-IV off Newcastle.

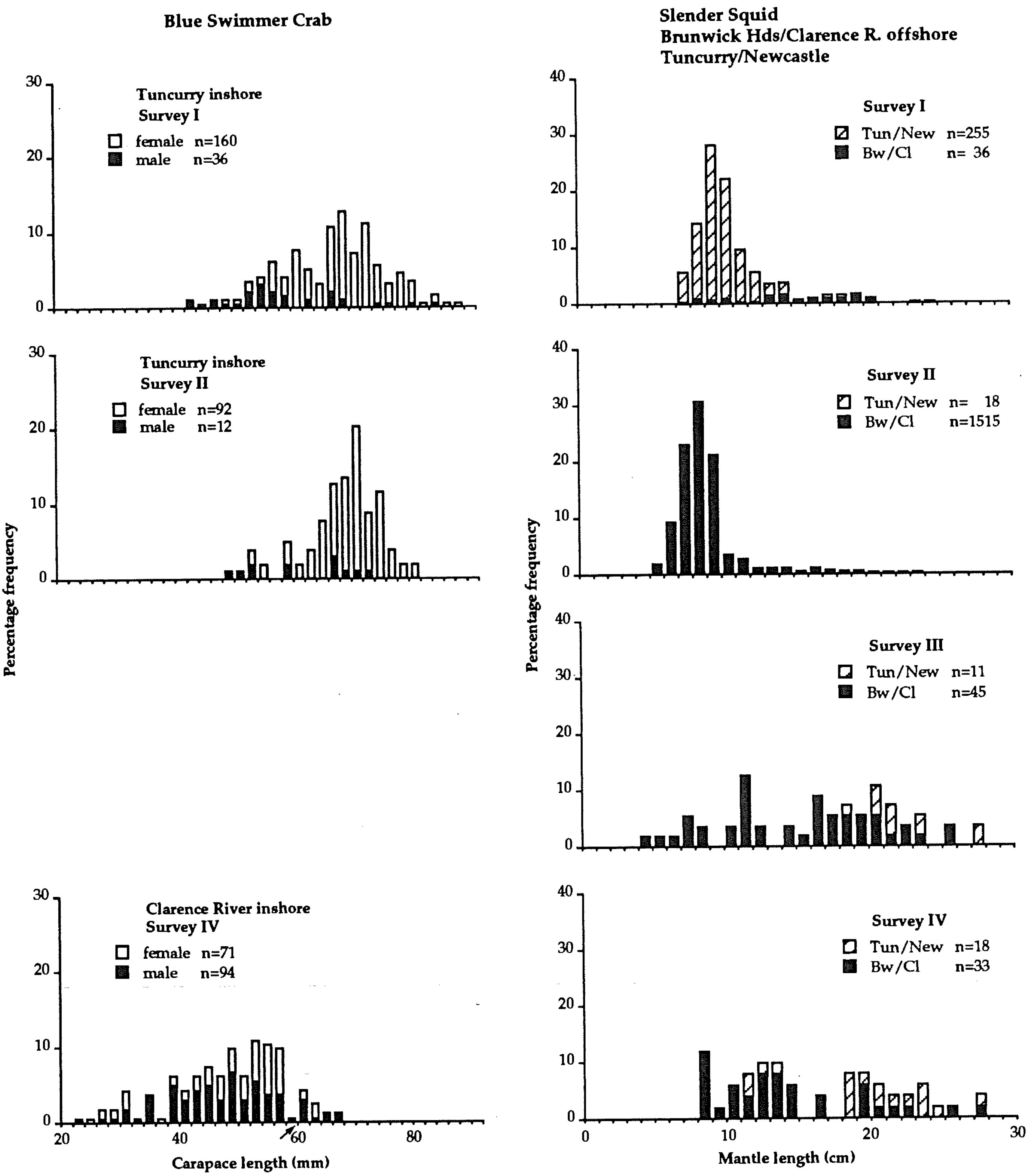


Figure 16: Length frequency of blue swimmer crabs for Surveys I & II off Tuncurry and Survey IV off the Clarence River (the arrow indicates the minimum legal length); and length frequency of slender squid for Surveys I–IV for all offshore gounds.

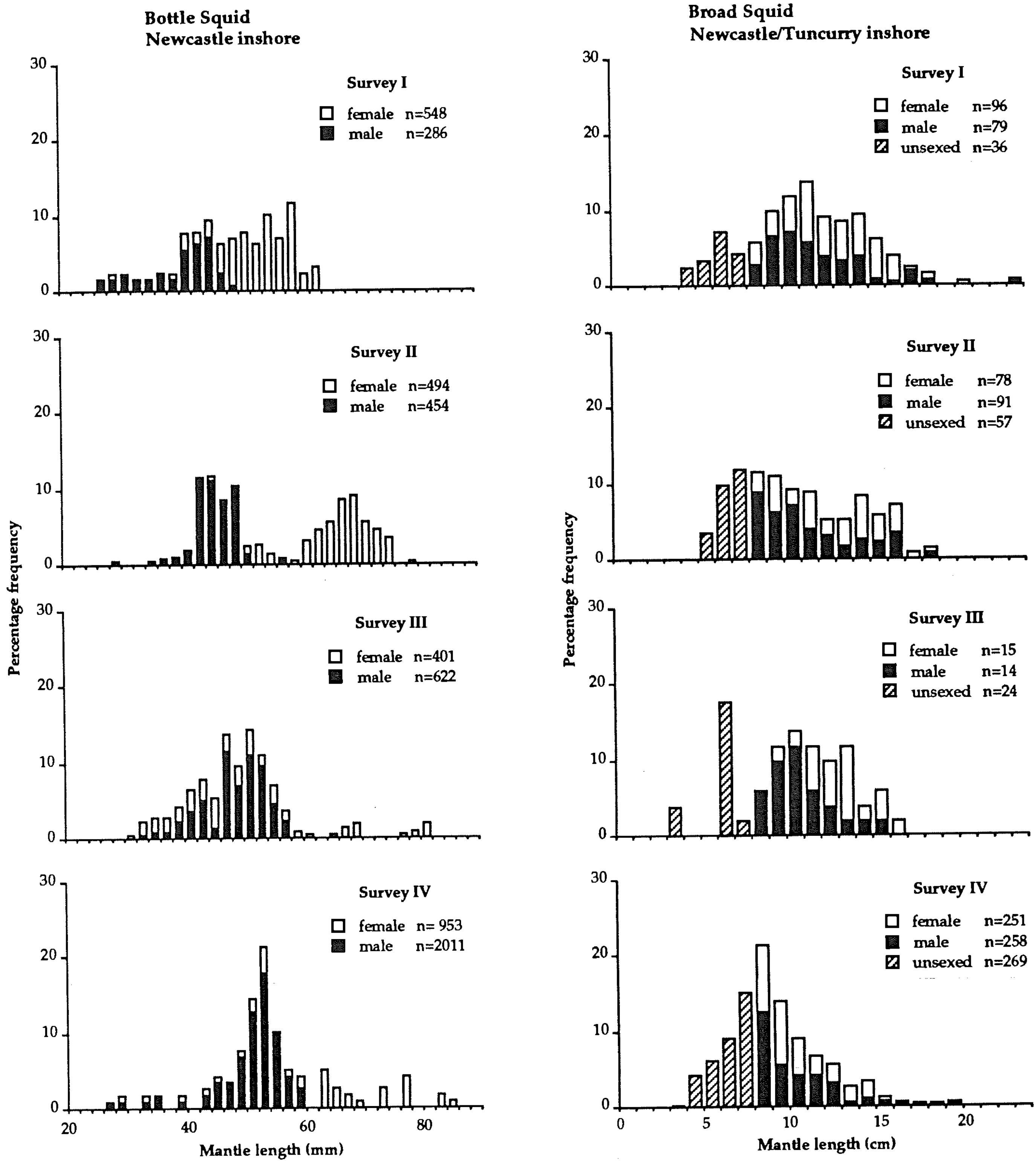


Figure 17: Length frequency of bottle squid for Surveys I-IV off Newcastle; and length frequency of broad squid for Surveys I-IV off Tuncurry and Newcastle (combined).

Appendix 1: List of common names and taxonomic names of species referred to in the tables and text.

Barred cod		*Epinephalus ergastularius*
Boarfish	- giant	*Paristiopterus labiosus*
Bonito		*Sarda australis*
Boxfish	- smooth	*Anoplocapros inermis*
Bream	- yellowfin (silver)	*Acanthopagrus australis*
Cobia		*Rachycentron canadus*
Flathead	- dusky	*Platycephalus fuscus*
	- marble	*P. marmoratus*
	- northern sand	*P. arenarius*
	- sand (blue-spotted)	*P. caeruleopunctatus*
	- tiger	*P. richardsoni*
	- spiky	*Ratabulus diversidens*
Flounder	- big-toothed	*Pseudorhombus arsius*
	- small-toothed	*P. jenynsii*
	- smooth-backed	*P. tenuirastrum*
Goatfish	- bartailed	*Upeneus tragula*
Gurnard	- butterfly	*Lepidotrigla* spp.
	- long-finned	*Lepidotrigla argus*
	- red	*Chelidonichthys kumu*
John dory		*Zeus faber*
Hairtail		*Trichiurus lepturus*
Leatherjacket	- Chinaman	*Nelusetta ayraudi*
	- mosaic	*Eubalichthys mosaicus*
Mackerel	- common	*Scomber australasicus*
Morwong	- rubberlip	*Nemadactylus douglasii*
Mulloway (jewfish)		*Argyrosomus hololepidotus*
Ocean perch		*Helicolenus percoides*
Pearl perch		*Glaucosoma scapulare*
Pilchard		*Sardinops sagax neopilchardus*
Ray	- banjo	*Trygonorrina* sp.
	- shovelnose	*Aptychotrema rostrata*
Redfish		*Centroberyx affinis*
Red mullet		*Upeneichthys lineatus*
Samson fish		*Seriola hippos*
Shark	- angel	*Squatina* sp.
	- greeneye dog	*Squalus mitsukurii*
	- gummy	*Mustelus antarcticus*
	- hammerhead	*Sphyrna zygaena*
	- inshore angel	*Squatina australis*
	- offshore angel	*Squatina* sp.
	- Port Jackson	*Heterodontus portusjacksoni*
	- saw	*Pristiophorus* sp.
	- spiky dog	*Squalus megalops*
	- whaler	*Carcharhinus* spp.
	- wobbegong	*Orectolobus maculatus*
Snapper		*Pagrus auratus*
Stingaree		fam. Urolophidae
Stingray		fam. Dasyatididae
Stinkfish		fam. Callionymidae
Tailor		*Pomatomus saltatrix*
Tarwhine		*Rhabdosargus sarba*
Teraglin		*Atractoscion aequidens*
Tilefish	- pink (moonfish)	*Branchiostegus wardi*
Trevally	- silver	*Pseudocaranx dentex*
Whiting	- redspot	*Sillago bassensis*
	- sand	*S. ciliata*
	- stout	*S. robusta*
	- trumpeter	*S. maculata*

Appendix 1: (continued)

Prawn	- banana	*Penaeus merguiensis*
	- king	*P. plebejus*
	- leader	*P. monodon*
	- Racek	*Parapenaeus australiensis*
	- school	*Metapenaeus macleayi*
	- tiger	*P. esculentus*
Bug	- Balmain	*Ibacus peronii*
	- Bruce's	*Ibacus brucei*
	- smooth	*Ibacus* sp.nov.
Crab	- blue swimmer	*Portunus pelagicus*
	- coral	*Charybdis cruciata*
	- mud	*Scylla serrata*
	- spanner	*Ranina ranina*
	- three-spotted	*P. sanguinolentus*
	- two-spotted	*Ovalipes australiensis*
Lobster	- barking	*Linuparus trigonus*
	- eastern rock	*Jasus verrauxii*
Cuttlefish		fam. Sepiidae
Octopus		*Octopus* spp.
Squid	- bottle	*Loliolus noctiluca*
	- broad	*Loligo chinensis*
	- slender	*Loligo* sp.
	- Gould's	*Nototodarus gouldi*
	- southern calamary	*Sepioteuthis australis*
Scallop		*Pectin fumatus*

Appendix 2(a): Operational data, prawn catches and by-catch totals for trawling conducted on the northern NSW grounds during Survey I. (* night-time tow on inshore ground; + daytime tow on offshore ground; # trawl fouled, no catch.)

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Total Bycatch (kg)
Brunswick Heads Inshore									
900814	03-05-90	1400	28°33';153°34'	28°34';153°33'	06–08	11–15	–	0.1	70
900815	03-05-90	1455	28°34';153°34'	28°35';153°35'	06–08	11–15	–	0.1	77
900816	03-05-90	1545	28°35';153°34'	28°34';153°34'	06–08	11–15	–	–	65
900817	03-05-90	1635	28°34';153°34'	28°35';153°34'	06–07	11–13	–	0.1	54
900818*	03-05-90	1805	28°35';153°34'	28°34';153°34'	07–09	12–17	–	0.3	72
900823	04-05-90	1045	28°33';153°34'	28°35';153°34'	06–08	11–15	–	0.1	42
900824	04-05-90	1130	28°35';153°34'	28°33';153°34'	06–08	11–15	–	0.1	38
900825	04-05-90	1220	28°33';153°34'	28°35';153°34'	06–08	11–15	–	0.1	32
900826	04-05-90	1325	28°35';153°34'	28°34';153°34'	06–08	11–15	–	–	40
900832	05-05-90	0955	28°34';153°34'	28°33';153°34'	06–08	11–15	–	0.1	18
900833	05-05-90	1040	28°33';153°34'	28°34';153°34'	06–08	11–15	–	0.1	26
900834	05-05-90	1135	28°35';153°34'	28°35';153°34'	06–08	11–15	–	–	31
900835	05-05-90	1225	28°33';153°34'	28°35';153°34'	07–09	12–17	–	0.1	36
Brunswick Heads Offshore									
900809	02-05-90	1945	28°25';153°41'	28°24';153°41'	30–32	54–59	1.0	–	132
900810	02-05-90	2050	28°25';153°41'	28°23';153°41'	30–32	54–59	1.8	–	115
900811	02-05-90	2150	28°23';153°41'	28°22';153°41'	31–32	56–59	1.8	–	145
900812	02-05-90	2255	28°21';153°40'	28°20';153°40'	30–32	54–59	1.8	–	108
900819	03-05-90	2015	28°25';153°40'	28°23';153°40'	28–29	51–53	0.9	–	104
900820	03-05-90	2120	28°20';153°38'	28°22';153°39'	26–27	47–50	0.7	–	98
900821	03-05-90	2220	28°22';153°37'	28°20';153°39'	27–29	49–53	0.4	–	77
900822	03-05-90	2330	28°20';153°40'	28°21';153°40'	30–31	54–57	1.8	–	105
900827+	04-05-90	1540	28°26';153°41'	28°24';153°41'	30–32	54–59	0.1	–	48
900828	04-05-90	1920	28°23';153°41'	28°24';153°41'	31–32	56–59	0.4	–	105
900829	04-05-90	2015	28°25';153°40'	28°27';153°41'	29–31	53–57	1.0	–	174
900830	04-05-90	2110	28°27';153°41'	28°26';153°41'	29–31	53–57	0.4	–	84
900831	04-05-90	2235	28°26';153°40'	28°24';153°40'	31–32	56–59	0.8	–	79
Clarence River Inshore									
900805	02-05-90	0845	29°25';153°23'	29°23';153°24'	10–15	18–28	0.1	7.6	23
900806	02-05-90	0935	29°22';153°23'	29°21';153°24'	14–16	25–30	–	10.8	54
900807	02-05-90	1020	29°21';153°24'	29°22';153°24'	15–16	27–30	–	17.0	35
900808	02-05-90	1125	29°23';153°23'	29°25';153°23'	11–12	20–22	–	3.5	29
900841	07-05-90	1315	29°22';153°23'	29°23';153°23'	11–14	20–26	–	0.8	36
900842	07-05-90	1405	29°23';153°23'	29°25';153°23'	10–12	18–22	–	8.8	40
900843	07-05-90	1500	29°25';153°23'	29°22';153°23'	08–09	14–17	–	3.5	68
900844#	07-05-90	1600	29°23';153°23'	29°22';153°23'	07–09	12–17	–	–	–
900845*	07-05-90	1940	29°23';153°23'	29°24';153°23'	13–15	23–28	0.1	40.0	76
900846*	07-05-90	2030	29°25';153°23'	29°24';153°23'	09–10	16–19	–	1.3	40
900851	08-05-90	1010	29°22';153°23'	29°23';153°23'	13–15	23–28	0.1	14.0	58
900852	08-05-90	1100	29°23';153°23'	29°25';153°23'	11–12	20–22	–	0.4	47
900853	08-05-90	1155	29°25';153°23'	29°24';153°23'	14–15	25–28	–	1.6	40
900854	08-05-90	1250	29°24';153°23'	29°25';153°23'	09–12	16–22	–	0.2	21
Clarence River Offshore									
900801	01-05-90	2240	29°25';153°36'	29°24';153°36'	39–40	71–73	3.4	–	58
900802	01-05-90	2340	29°21';153°36'	29°20';153°37'	39–40	71–73	4.3	–	59
900803	02-05-90	0030	29°21';153°36'	29°23';153°37'	37–40	67–73	8.4	–	76
900804	02-05-90	0130	29°24';153°35'	29°25';153°34'	39–40	71–73	5.1	–	78
900837	06-05-90	2315	29°20';153°36'	29°22';153°35'	38–42	69–77	2.0	–	65
900838	07-05-90	0040	29°23';153°35'	29°24';153°35'	37–39	67–72	2.0	–	56
900839	07-05-90	0115	29°24';153°35'	29°26';153°35'	39–40	71–74	3.2	–	35
900840	07-05-90	0245	29°27';153°34'	29°28';153°34'	38–40	69–74	7.0	–	54
900847	07-05-90	2245	29°25';153°34'	29°23';153°34'	35–36	64–66	0.7	–	38
900848	07-05-90	2345	29°24';153°35'	29°22';153°35'	35–37	64–68	0.5	–	32
900849	08-05-90	0045	29°21';153°35'	29°23';153°35'	37–39	67–72	1.0	–	49
900850	08-05-90	0145	29°25';153°35'	29°25';153°34'	38–40	69–74	0.8	–	19
900855+	08-05-90	1500	29°25';153°33'	29°26';153°33'	36–37	65–68	0.1	–	13
900856+	08-05-90	1555	29°27';153°33'	29°28';153°33'	36–37	65–68	0.1	–	24

Appendix 2(b): Operational data, prawn catches and by-catch totals for trawling conducted on the central NSW grounds during Survey I. (+ daytime tow on offshore ground.)

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Racek Prawn (kg)	Total Bycatch (kg)
Tuncurry Inshore										
900901	22-05-90	0840	32°07';152°31'	32°08';152°30'	07-11	13-20	-	1.4	-	166
900902	22-05-90	0935	32°08';152°32'	32°07';152°32'	07-11	13-20	0.1	5.6	-	46
900903	22-05-90	1025	32°09';152°31'	32°07';152°31'	06-09	11-17	0.1	10.0	-	71
900904	22-05-90	1120	32°07';152°31'	32°09';152°30'	05-10	09-19	-	1.0	-	45
901002	05-06-90	0920	32°09';152°31'	32°08';152°31'	08-09	14-17	1.0	11.0	-	69
901003	05-06-90	1020	32°07';152°31'	32°06';152°31'	11-12	20-22	-	-	-	71
901004	05-06-90	1120	32°06';152°31'	32°07';152°31'	10-12	18-22	-	-	-	87
901005	05-06-90	1210	32°08';152°31'	32°09';152°31'	08-09	14-17	1.0	11.0	-	55
901010	06-06-90	1025	32°09';152°31'	32°08';152°31'	08-10	15-19	0.1	1.0	-	31
901011	06-06-90	1130	32°07';152°31'	32°06';152°31'	09-11	16-20	-	0.1	-	114
901012	06-06-90	1335	32°06';152°31'	32°07';152°31'	11-12	20-22	0.1	-	-	125
901013	06-06-90	1430	32°08';152°31'	32°09';152°31'	09-10	16-19	0.7	5.8	-	54
Tuncurry Offshore										
900905+	22-05-90	1530	31°54';152°53'	31°53';152°53'	52-53	95-97	0.1	-	-	23
900906	22-05-90	2005	31°54';152°54'	31°56';152°54'	53-55	97-101	3.8	-	-	23
900907	22-05-90	2105	31°55';152°52'	31°56';152°52'	51-52	93-95	4.8	-	-	43
900908	22-05-90	2215	31°57';152°51'	31°58';152°50'	50-52	91-95	5.0	-	-	159
900909	22-05-90	2325	31°58';152°49'	31°59';152°48'	50-51	91-94	3.4	-	-	84
901006	05-06-90	1910	32°02';152°46'	32°01';152°47'	49-50	89-92	1.0	-	-	93
901007	05-06-90	2015	32°00';152°48'	31°59';152°49'	50-51	91-94	3.0	-	-	68
901008	05-06-90	2115	31°58';152°49'	31°57';152°50'	50-51	91-94	12.0	-	-	95
901009	05-06-90	2225	31°57';152°49'	31°58';152°48'	49-50	89-92	5.2	-	-	95
901014	06-06-90	1830	32°05';152°47'	32°04';152°48'	53-54	96-99	1.4	-	-	94
901015	06-06-90	1935	32°02';152°48'	32°01';152°49'	53-54	96-99	1.4	-	-	144
901016	06-06-90	2035	32°00';152°49'	31°59';152°50'	52-53	95-97	2.6	-	-	100
901017	06-06-90	2140	31°58';152°51'	31°57';152°52'	52-53	95-97	18.0	-	-	134
Newcastle Inshore										
900910	23-05-90	1030	32°49';151°57'	32°48';151°59'	08-09	15-17	0.1	0.1	-	22
900911	23-05-90	1120	32°48';151°59'	32°49';151°58'	13-14	24-26	-	-	-	11
900912	23-05-90	1210	32°49';151°56'	32°50';151°55'	13-14	24-26	-	-	-	26
900913	23-05-90	1305	32°50';151°55'	32°51';151°53'	10-12	18-22	0.5	4.5	-	118
901018	07-06-90	1050	32°52';151°51'	32°53';151°51'	06-09	11-17	-	-	-	8
901019	07-06-90	1145	32°53';151°51'	32°52';151°51'	07-09	12-17	-	-	-	7
901020	07-06-90	1335	32°52';151°51'	32°52';151°53'	07-10	12-19	-	0.1	-	8
901021	07-06-90	1425	32°51';151°53'	32°52';151°52'	10-12	18-22	-	-	-	3
901106	13-06-90	0805	32°52';151°50'	32°53';151°48'	08-09	15-17	-	5.0	-	21
901107	13-06-90	0900	32°53';151°48'	32°52';151°49'	07-09	12-17	-	11.0	-	18
901108	13-06-90	0950	32°51';151°51'	32°51';151°53'	09-11	16-20	-	0.1	-	12
901109	13-06-90	1105	32°52';151°50'	32°53';151°48'	09-10	16-19	-	0.2	-	15
Newcastle Offshore										
900914	23-05-90	1815	32°55';151°57'	32°54';151°58'	39-43	71-79	1.5	-	-	61
900915	23-05-90	1920	32°53';151°59'	32°52';152°00'	40-41	73-75	2.3	-	-	26
900916	23-05-90	2020	32°52';152°00'	32°53';151°59'	36-39	66-72	4.0	-	-	78
900917	23-05-90	2135	32°54';151°57'	32°56';151°55'	35-38	64-70	2.4	-	-	122
901022	07-06-90	1800	32°54';151°59'	32°53';152°00'	37-41	67-75	12.1	-	-	69
901023	07-06-90	1905	32°52';152°01'	32°51';152°02'	35-37	64-68	1.0	-	-	196
901024	07-06-90	2030	32°51';152°03'	32°52';152°02'	40-42	73-77	4.0	-	-	111
901025	07-06-90	2130	32°53';152°01'	32°54';151°59'	40-43	73-79	4.8	-	-	76
901101	12-06-90	2310	32°55';151°56'	32°54';151°57'	35-36	64-66	5.0	-	-	169
901102	13-06-90	0005	32°54';151°58'	32°53';151°59'	39-40	71-74	13.0	-	-	66
901103	13-06-90	0115	32°53';151°59'	32°54';151°58'	39-42	71-77	17.0	-	-	57
901104	13-06-90	0215	32°54';151°57'	32°55';151°55'	38-39	69-72	9.6	-	-	89

Appendix 2(c): Operational data, prawn catches and by-catch totals for trawling conducted on the northern NSW grounds during Survey II. (* night-time tow on inshore ground.)

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Total Bycatch (kg)
Brunswick Heads Inshore									
901223	01-09-90	1235	28°34';153°34'	28°35';153°35'	08-11	15-20	-	-	45
901224	01-09-90	1330	28°36';153°35'	28°34';153°35'	11-12	20-22	-	-	42
901225	01-09-90	1430	28°33';153°36'	28°34';153°35'	12-13	22-23	-	-	42
901226	01-09-90	1520	28°35';153°34'	28°34';153°34'	07-08	13-15	-	0.1	29
901232	02-09-90	1145	28°36';153°36'	28°35';153°35'	06-11	10-20	-	0.1	28
901233	02-09-90	1300	28°36';153°35'	28°37';153°34'	06-09	10-16	-	0.1	18
901234	02-09-90	1400	28°35';153°34'	28°36';153°35'	09-10	17-18	-	-	57
901235	02-09-90	1450	28°36';153°34'	28°35';153°34'	08-10	15-18	-	-	82
901236*	02-09-90	1835	28°35';153°34'	28°34';153°34'	08-10	15-18	-	0.6	143
901237*	02-09-90	1930	28°34';153°34'	28°35';153°34'	09-10	17-18	-	0.1	151
901247	04-09-90	1320	28°36';153°35'	28°35';153°35'	08-10	15-18	-	0.1	60
901248	04-09-90	1410	28°35';153°35'	28°36';153°35'	07-08	13-15	-	0.1	45
901249	04-09-90	1505	28°36';153°34'	28°35';153°34'	06-07	11-12	-	0.1	30
901250	04-09-90	1625	28°34';153°34'	28°35';153°34'	09-10	17-18	-	-	36
Brunswick Heads Offshore									
901228	01-09-90	2125	28°23';153°39'	28°22';153°39'	30-31	55-56	0.1	-	78
901229	01-09-90	2220	28°21';153°40'	28°20';153°39'	29-30	53-55	0.1	-	76
901230	01-09-90	2320	28°21';153°40'	28°22';153°40'	30-31	55-57	0.1	-	89
901231	02-09-90	0020	28°23';153°40'	28°25';153°41'	29-30	53-54	1.2	-	99
901238	02-09-90	2200	28°26';153°40'	28°24';153°39'	28-29	51-53	1.0	-	99
901239	02-09-90	2300	28°23';153°39'	28°22';153°39'	28-29	51-53	0.1	-	95
901240	02-09-90	2400	28°21';153°39'	28°20';153°39'	28-29	51-53	0.1	-	75
901241	03-09-90	0100	28°20';153°40'	28°22';153°40'	30-31	55-57	0.3	-	83
901242	03-09-90	1850	28°25';153°40'	28°24';153°40'	29-30	53-55	0.5	-	88
901243	03-09-90	1955	28°22';153°40'	28°21';153°40'	30-31	55-57	0.4	-	78
901244	03-09-90	2055	28°22';153°40'	28°20';153°41'	31-32	57-58	0.1	-	60
901245	03-09-90	2200	28°22';153°41'	28°23';153°40'	31-32	57-58	0.1	-	104
Clarence River Inshore									
901205	30-08-90	1220	29°25';153°23'	29°23';153°23'	13-14	24-25	-	-	21
901206	30-08-90	1330	29°23';153°23'	29°24';153°23'	10-12	18-22	-	0.1	43
901207	30-08-90	1420	29°24';153°23'	29°23';153°23'	12-14	22-25	-	-	40
901208	30-08-90	1515	29°23';153°23'	29°25';153°24'	12-14	22-25	-	0.1	36
901209*	30-08-90	1910	29°25';153°23'	29°24';153°23'	14-15	26-27	-	-	74
901210*	30-08-90	2000	29°23';153°23'	29°25';153°23'	12-13	22-23	-	-	77
901215	31-08-90	1335	29°24';153°23'	29°23';153°23'	12-13	22-23	-	-	35
901216	31-08-90	1425	29°23';153°23'	29°22';153°23'	09-14	17-25	-	-	109
901217	31-08-90	1520	29°21';153°24'	29°22';153°23'	13-15	23-27	-	-	117
901218	31-08-90	1610	29°23';153°23'	29°24';153°23'	11-13	20-23	-	-	71
901251	05-09-90	0730	29°22';153°24'	29°23';153°23'	13-16	23-29	0.1	0.2	46
901252	05-09-90	0820	29°23';153°22'	29°23';153°23'	10-11	18-20	-	-	72
901253	05-09-90	0915	29°24';153°22'	29°23';153°24'	10-15	18-28	-	0.1	18
901254	05-09-90	1005	29°23';153°23'	29°21';153°23'	15-16	27-29	0.1	0.1	50
Clarence River Offshore									
901201	29-08-90	1920	29°29';153°33'	29°28';153°34'	37-38	67-70	6.8	-	24
901202	29-08-90	2020	29°27';153°33'	29°26';153°34'	36-38	66-69	3.7	-	37
901203	29-08-90	2120	29°26';153°34'	29°25';153°35'	37-38	67-69	8.0	-	41
901204	29-08-90	2220	29°25';153°35'	29°24';153°36'	39-40	71-73	1.9	-	37
901211	30-08-90	2240	29°22';153°35'	29°21';153°36'	36-37	66-67	10.0	-	48
901212	30-08-90	2340	29°21';153°36'	29°23';153°36'	38-40	70-73	7.5	-	49
901213	30-08-90	0040	29°23';153°36'	29°24';153°36'	40-41	73-75	3.0	-	45
901214	30-08-90	0140	29°24';153°36'	29°27';153°35'	40-41	73-75	7.0	-	21
901219	31-08-90	1900	29°24';153°34'	29°26';153°34'	36-38	66-69	6.8	-	23
901220	31-08-90	2005	29°27';153°34'	29°28';153°33'	38-39	70-71	7.8	-	18
901221	31-08-90	2100	29°28';153°34'	29°27';153°34'	39-40	71-73	4.7	-	17
901222	31-08-90	2300	29°27';153°34'	29°25';153°35'	38-39	70-71	7.0	-	29

Appendix 2(d): Operational data, prawn catches and by-catch totals for trawling conducted on the central NSW grounds during Survey II. (* night-time tow on inshore ground.)

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Racek Prawn (kg)	Total Bycatch (kg)
Tuncurry Inshore										
901305	19-09-90	1135	32°09';152°31'	32°08';152°31'	09-11	16-20	-	0.5	-	156
901306	19-09-90	1250	32°07';152°31'	32°08';152°31'	10-12	18-22	0.1	0.2	-	198
901307	19-09-90	1440	32°09';152°31'	32°08';152°31'	11-12	20-22	0.1	0.2	-	186
901308	19-09-90	1535	32°07';152°31'	32°09';152°31'	10-11	18-20	-	0.1	-	133
901405	25-09-90	1015	32°08';152°31'	32°07';152°31'	06-08	11-15	-	-	-	226
901406	25-09-90	1105	32°07';152°31'	32°08';152°31'	05-07	09-13	-	-	-	167
901407	25-09-90	1210	32°07';152°31'	32°06';152°31'	10-12	18-22	-	-	-	134
901408	25-09-90	1300	32°06';152°31'	32°07';152°31'	08-10	14-19	-	-	-	226
901413	26-09-90	1205	32°07';152°31'	32°08';152°31'	09-11	16-20	-	-	-	226
901414	26-09-90	1300	32°09';152°31'	32°07';152°31'	10-11	18-20	-	-	-	154
901415	26-09-90	1410	32°08';152°30'	32°09';152°30'	05-07	09-13	-	-	-	139
901416	26-09-90	1510	32°09';152°31'	32°08';152°31'	10-11	18-20	-	-	-	162
Tuncurry Offshore										
901309	19-09-90	2000	32°06';152°46'	32°05';152°47'	53-54	96-99	0.6	-	-	157
901310	19-09-90	2105	32°05';152°47'	32°04';152°48'	53-54	96-99	0.6	-	-	180
901311	19-09-90	2205	32°03';152°48'	32°02';152°49'	52-54	95-99	0.5	-	-	211
901312	19-09-90	2310	32°02';152°49'	32°01';152°49'	53-54	96-99	0.4	-	-	305
901409	25-09-90	1940	31°58';152°50'	31°57';152°51'	50-52	91-95	0.8	-	-	171
901410	25-09-90	2045	31°58';152°51'	31°57';152°52'	53-56	96-103	0.5	-	-	176
901411	25-09-90	2150	31°56';152°53'	31°55';152°53'	55-56	100-103	0.4	-	-	127
901412	25-09-90	2300	31°56';152°53'	31°55';152°52'	53-54	96-99	0.2	-	-	182
901417	26-09-90	1850	31°58';152°50'	31°57';152°51'	49-51	89-94	0.3	-	-	263
901418	26-09-90	2000	31°56';152°52'	31°55';152°53'	50-54	91-99	0.5	-	-	232
901419	26-09-90	2100	31°55';152°53'	31°56';152°52'	51-53	93-97	1.0	-	-	192
901420	26-09-90	2200	31°57';152°51'	31°58';152°50'	49-51	89-94	0.2	-	-	207
Newcastle Inshore										
901313	20-09-90	1020	32°51';151°52'	32°51';151°54'	09-11	16-20	2.4	0.7	-	161
901314	20-09-90	1115	32°50';151°54'	32°50';151°52'	09-12	16-22	1.6	0.9	-	193
901315	20-09-90	1215	32°51';151°50'	32°52';151°49'	07-08	12-14	0.1	2.2	-	95
901316	20-09-90	1315	32°53';151°49'	32°51';151°50'	06-08	11-15	0.1	4.3	-	89
901421	27-09-90	1400	32°53';151°48'	32°52';151°49'	07-09	12-17	0.1	7.0	-	24
901422	27-09-90	1505	32°51';151°51'	32°50';151°52'	09-11	16-20	1.0	2.5	-	238
901423	27-09-90	1555	32°51';151°53'	32°51';151°51'	10-11	18-20	1.7	2.4	-	182
901424	27-09-90	1655	32°52';151°50'	32°53';151°49'	07-09	12-17	0.3	2.9	-	47
901425*	27-09-90	1920	32°52';151°53'	32°52';151°51'	10-12	18-22	2.5	0.2	-	158
901426*	27-09-90	2015	32°52';151°50'	32°53';151°49'	08-09	14-17	0.1	2.1	-	62
901427	28-09-90	0620	32°53';151°49'	32°52';151°50'	06-09	11-17	0.1	3.4	-	31
901428	28-09-90	0715	32°52';151°51'	32°51';151°52'	09-10	16-19	0.8	3.3	-	65
901429	28-09-90	0810	32°51';151°52'	32°52';151°50'	10-11	18-20	1.2	1.4	-	633
901430	28-09-90	0910	32°52';151°50'	32°53';151°49'	08-09	14-17	0.1	1.5	-	59
Newcastle Offshore										
901301	18-09-90	2300	32°55';151°57'	32°54';151°58'	37-42	67-77	1.1	-	0.1	49
901302	19-09-90	0000	32°54';151°58'	32°53';152°00'	38-41	69-75	3.2	-	0.2	37
901303	19-09-90	0100	32°52';152°00'	32°52';152°02'	35-40	64-74	1.8	-	0.1	76
901304	19-09-90	0200	32°52';152°01'	32°53';151°59'	39-42	71-77	5.4	-	0.1	55
901317	20-09-90	1925	32°53';151°59'	32°52';152°00'	37-38	67-70	4.7	-	0.2	53
901318	20-09-90	2025	32°52';152°00'	32°53';151°58'	36-37	65-68	4.5	-	0.3	41
901319	20-09-90	2130	32°53';151°59'	32°53';152°00'	37-38	67-70	3.7	-	0.4	34
901320	20-09-90	2240	32°53';151°59'	32°54';151°59'	34-38	62-70	4.4	-	0.2	48
901401	24-09-90	2230	32°56';151°56'	32°56';151°55'	36-40	65-74	1.5	-	1.2	42
901402	24-09-90	2330	32°54';151°57'	32°54';151°57'	40-42	73-77	0.4	-	1.6	40
901403	25-09-90	0030	32°53';151°59'	32°53';151°59'	34-38	62-70	3.9	-	0.1	47
901404	25-09-90	0130	32°52';152°01'	32°52';152°02'	36-38	65-70	2.5	-	0.1	55

Appendix 2(e): Operational data, prawn catches and by-catch totals for trawling conducted on the northern NSW grounds during Survey III. (# tow not included in analysis.)

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Total Bycatch (kg)
Brunswick Heads Inshore									
901709	13-11-90	1400	28°36';153°35'	28°35';153°35'	09–11	17–20	–	0.1	56
901710	13-11-90	1500	28°34';153°34'	28°33';153°33'	07–09	13–16	–	0.1	13
901711	13-11-90	1550	28°33';153°33'	28°34';153°34'	08–09	15–16	–	0.1	17
901712	13-11-90	1655	28°35';153°34'	28°34';153°34'	08–09	15–16	–	0.2	29
901717	14-11-90	1010	28°36';153°35'	28°35';153°34'	09–10	17–18	–	0.3	137
901718	14-11-90	1100	28°35';153°34'	28°33';153°34'	08–09	15–16	–	0.6	95
901719	14-11-90	1210	28°34';153°34'	28°34';153°36'	08–09	15–16	–	0.3	113
901720	14-11-90	1300	28°36';153°35'	28°34';153°35'	08–09	15–16	–	0.1	103
901725	15-11-90	0840	28°33';153°34'	28°35';153°34'	09–10	16–18	0.1	0.4	222
901726	15-11-90	0935	28°35';153°35'	28°34';153°34'	09–10	16–18	0.1	0.2	111
901727	15-11-90	1020	28°34';153°34'	28°35';153°34'	07–08	13–15	–	6.5	101
901728	15-11-90	1140	28°35';153°34'	28°36';153°34'	07–08	13–15	–	2.8	135
Brunswick Heads Offshore									
901705	12-11-90	2235	28°21';153°40'	28°22';153°40'	29–30	53–55	5.0	–	129
901706	12-11-90	2345	28°24';153°40'	28°25';153°39'	27–29	49–53	8.2	–	203
901707	13-11-90	0045	28°25';153°39'	28°24';153°39'	27–28	49–51	11.3	–	202
901708	13-11-90	0150	28°23';153°39'	28°22';153°39'	27–28	49–51	3.8	–	161
901713	13-11-90	2000	28°26';153°40'	28°25';153°40'	28–29	51–53	1.4	–	104
901714	13-11-90	2100	28°24';153°40'	28°23';153°40'	29–30	53–55	6.8	–	174
901715	13-11-90	2205	28°22';153°39'	28°21';153°39'	28–29	51–53	7.8	–	389
901716	13-11-90	2300	28°21';153°39'	28°23';153°38'	27–28	49–51	9.0	–	222
901721	14-11-90	2030	28°25';153°39'	28°23';153°38'	27–28	49–51	9.0	–	172
901722	14-11-90	2125	28°23';153°39'	28°22';153°39'	28–29	51–53	3.5	–	204
901723	14-11-90	2220	28°22';153°39'	28°20';153°40'	29–30	53–55	3.3	–	157
901724	14-11-90	2315	28°21';153°39'	28°22';153°39'	28–29	51–53	3.7	–	175
Clarence River Inshore									
901733	21-11-90	1350	29°25';153°23'	29°25';153°23'	10–11	18–20	0.1	1.0	27
901734	21-11-90	1435	29°23';153°22'	29°24';153°23'	09–16	17–29	–	0.1	19
901735	21-11-90	1530	29°22';153°23'	29°23';153°23'	13–16	24–29	0.1	0.3	18
901736	21-11-90	1640	29°23';153°23'	29°23';153°22'	12–15	22–27	0.1	0.1	27
901739	23-11-90	0825	29°22';153°23'	29°23';153°23'	12–16	22–29	0.2	0.1	99
901740	23-11-90	0925	29°24';153°22'	29°25';153°23'	10–12	18–22	–	1.5	39
901741	23-11-90	1010	29°25';153°22'	29°23';153°22'	07–12	13–22	–	0.3	31
901742	23-11-90	1110	29°23';153°23'	29°24';153°22'	09–13	17–23	–	0.3	28
901747	24-11-90	0610	29°24';153°23'	29°22';153°23'	12–13	22–24	–	0.2	21
901748	24-11-90	0700	29°23';153°23'	29°24';153°23'	11–12	20–22	–	0.3	27
901749	24-11-90	0745	29°24';153°22'	29°23';153°23'	09–10	17–20	–	0.2	20
901750	24-11-90	0830	29°23';153°23'	29°25';153°23'	10–11	18–20	–	0.2	21
Clarence River Offshore									
901701	07-11-90	0100	29°30';153°32'	29°29';153°33'	36–39	66–71	3.2	–	18
901702	07-11-90	0205	29°28';153°33'	29°26';153°34'	36–39	66–71	2.8	–	13
901703	07-11-90	0310	29°26';153°34'	29°25';153°35'	38–40	70–73	3.4	–	38
901704	07-11-90	0410	29°24';153°35'	29°23';153°35'	39–40	71–73	6.0	–	28
901729	20-11-90	2030	29°22';153°33'	29°28';153°33'	35–36	64–66	3.2	–	26
901730	20-11-90	2125	29°28';153°33'	29°26';153°33'	37–38	68–70	3.2	–	20
901731	20-11-90	2220	29°25';153°33'	29°24';153°33'	36–37	66–68	1.5	–	23
901732	20-11-90	2315	29°23';153°33'	29°22';153°33'	34–35	62–65	7.0	–	40
901737#	21-11-90	2050	29°20';153°34'	29°22';153°34'	32–34	59–62	7.0	–	70
901743	23-11-90	2030	29°20';153°34'	29°21';153°35'	33–37	60–68	4.8	–	29
901744	23-11-90	2125	29°22';153°36'	29°24';153°35'	38–39	70–71	7.0	–	45
901745	23-11-90	2220	29°24';153°35'	29°26';153°34'	39–40	71–73	3.0	–	41
901746	23-11-90	2320	29°26';153°33'	29°24';153°33'	35–38	64–70	2.2	–	22

Appendix 2(f): Operational data, prawn catches and by-catch totals for trawling conducted on the central NSW grounds during Survey III. (* night-time tow.)

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Racek Prawn (kg)	Total Bycatch (kg)
Tuncurry Inshore										
901805	04-12-90	1400	32°09';152°31'	32°07';152°30'	09-12	16-22	-	-	-	146
901806	04-12-90	1505	32°07';152°30'	32°09';152°30'	06-07	11-13	-	-	-	142
901807	04-12-90	1600	32°09';152°30'	32°08';152°30'	05-06	09-11	-	-	-	133
901808	04-12-90	1720	32°08';152°30'	32°07';152°31'	06-08	11-15	-	-	-	71
901813	05-12-90	1150	32°10';152°30'	32°08';152°30'	06-07	11-13	-	-	-	199
901814	05-12-90	1240	32°08';152°31'	32°07';152°31'	08-10	14-19	-	-	-	176
901815	05-12-90	1335	32°07';152°31'	32°08';152°31'	07-09	12-17	-	0.1	-	181
901816	05-12-90	1430	32°09';152°30'	32°07';152°30'	08-10	14-19	-	-	-	145
901821	06-12-90	1250	32°08';152°31'	32°09';152°30'	08-11	14-20	-	-	-	229
901822	06-12-90	1345	32°09';152°30'	32°09';152°30'	08-09	14-17	-	-	-	110
901823	06-12-90	1435	32°08';152°30'	32°09';152°30'	07-10	12-19	-	-	-	109
901824	06-12-90	1525	32°09';152°30'	32°08';152°30'	05-07	09-13	-	-	-	126
Tuncurry Offshore										
901809	04-12-90	2100	31°59';152°47'	31°58';152°48'	45-48	82-88	5.1	-	-	74
901810	04-12-90	2200	31°57';152°49'	31°56';152°50'	48-50	87-92	4.1	-	-	61
901811	04-12-90	2255	31°55';152°51'	31°54';152°52'	51-53	93-97	3.3	-	-	54
901812	05-12-90	0000	31°55';152°52'	31°56';152°51'	51-53	93-97	3.8	-	-	45
901817	05-12-90	2047	32°03';152°46'	32°02';152°46'	47-49	86-90	0.3	-	-	151
901818	05-12-90	2145	32°01';152°47'	32°00';152°48'	50-51	91-94	0.3	-	-	102
901819	05-12-90	2245	32°00';152°49'	31°58';152°50'	51-53	93-97	0.4	-	-	86
901820	06-12-90	0000	31°57';152°48'	31°56';152°49'	46-48	84-88	4.4	-	-	31
901825	06-12-90	2035	31°54';152°50'	31°53';152°51'	47-48	86-88	3.8	-	-	41
901826	06-12-90	2135	31°52';152°51'	31°51';152°52'	47-49	86-90	1.1	-	-	58
901827	06-12-90	2235	31°52';152°53'	31°54';152°52'	49-50	89-92	1.7	-	-	41
901828	06-12-90	2340	31°55';152°52'	31°57';152°52'	52-55	95-101	2.8	-	-	36
Newcastle Inshore										
901901	10-12-90	1345	32°53';151°49'	32°52';151°49'	05-08	09-15	-	0.1	-	14
901902	10-12-90	1435	32°51';151°51'	32°51';151°52'	09-10	16-19	-	-	-	20
901903	10-12-90	1525	32°50';151°52'	32°51';151°51'	09-11	16-20	-	-	-	18
901904	10-12-90	1615	32°52';151°50'	32°52';151°49'	09-12	16-22	-	-	-	7
901905*	10-12-90	2050	32°53';151°48'	32°52';151°50'	08-09	14-16	1.0	0.8	-	28
901906*	10-12-90	2140	32°51';151°51'	32°50';151°52'	08-10	14-19	0.4	0.2	-	36
901907	11-12-90	1340	32°53';151°48'	32°52';151°49'	07-09	12-17	0.1	1.6	-	31
901908	11-12-90	1440	32°51';151°51'	32°51';151°52'	10-12	18-22	-	-	-	8
901909	11-12-90	1530	32°51';151°52'	32°51';151°51'	10-12	18-22	-	0.1	-	10
901910	11-12-90	1625	32°52';151°50'	32°53';151°49'	07-09	12-17	-	0.1	-	19
901915	12-12-90	1455	32°53';151°48'	32°52';151°50'	08-09	14-17	0.3	3.7	-	31
901916	12-12-90	1555	32°51';151°51'	32°50';151°52'	09-10	16-19	0.2	6.0	-	34
901917	12-12-90	1645	32°50';151°53'	32°51';151°51'	09-11	16-20	0.1	5.4	-	25
901918	12-12-90	1755	32°52';151°50'	32°53';151°49'	08-10	14-19	0.1	3.4	-	31
Newcastle Offshore										
901801	03-12-90	2200	32°55';151°56'	32°54';151°57'	38-40	69-73	1.2	-	0.4	24
901802	03-12-90	2300	32°54';151°58'	32°53';151°59'	33-35	60-64	2.1	-	-	34
901803	03-12-90	2355	32°52';152°00'	32°51';152°01'	35-37	64-68	13.0	-	-	87
901804	04-12-90	0055	32°52';152°01'	32°52';152°00'	34-37	62-68	12.5	-	-	68
901911	11-12-90	2050	32°55';151°56'	32°55';151°57'	39-42	71-77	0.8	-	0.2	22
901912	11-12-90	2145	32°54';151°58'	32°53';151°59'	39-41	71-75	1.1	-	0.4	30
901913	11-12-90	2245	32°53';151°59'	32°52';152°01'	35-37	64-68	5.0	-	-	42
901914	11-12-90	2340	32°52';152°01'	32°53';152°00'	37-40	67-73	4.3	-	0.1	39
901920	12-12-90	2310	32°52';152°02'	32°53';152°01'	37-42	67-77	2.8	-	0.1	34
901921	13-12-90	0005	32°52';152°02'	32°51';152°03'	39-40	71-73	2.3	-	0.1	38
901922	13-12-90	0100	32°52';152°02'	32°53';152°01'	40-42	73-77	2.3	-	0.1	45
901923	13-12-90	0155	32°53';152°00'	32°54';151°59'	37-40	67-73	3.8	-	0.1	20

Appendix 2(g): Operational data, prawn catches and by-catch totals for trawling conducted on the northern NSW grounds during Survey IV. (* night-time tow.)

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Total Bycatch (kg)
Brunswick Heads Inshore									
910128	16-02-91	1320	28°37';153°35'	28°36';153°34'	07-08	12-15	-	0.1	124
910129	16-02-91	1550	28°35';153°34'	28°36';153°35'	09-11	16-21	-	-	168
910130	16-02-91	1655	28°35';153°34'	28°36';153°35'	05-08	09-15	-	0.1	114
910131	16-02-91	1745	28°36';153°35'	28°34';153°34'	06-08	11-15	-	0.1	99
910137	17-02-91	1510	28°36';153°35'	28°35';153°34'	07-09	12-17	-	0.1	33
910138	17-02-91	1555	28°35';153°35'	28°37';153°35'	08-10	14-19	-	-	115
910139	17-02-91	1645	28°37';153°35'	28°36';153°35'	08-10	14-19	-	-	80
910140	17-02-91	1745	28°36';153°35'	28°34';153°36'	06-07	11-13	-	0.1	31
910145	18-02-91	1505	28°36';153°35'	28°35';153°34'	07-09	12-17	-	-	66
910146	18-02-91	1600	28°35';153°34'	28°36';153°35'	09-10	16-19	0.1	-	65
910147	18-02-91	1650	28°36';153°35'	28°35';153°34'	05-07	09-13	-	-	47
910148	18-02-91	1740	28°35';153°34'	28°36';153°35'	05-07	09-13	-	0.1	54
Brunswick Heads Offshore									
910133	16-02-91	2330	28°26';153°41'	28°25';153°41'	29-31	53-57	5.7	-	106
910134	17-02-91	0025	28°25';153°40'	28°24';153°40'	30-31	55-57	5.8	-	173
910135	17-02-91	0120	28°23';153°40'	28°22';153°39'	29-30	53-55	5.5	-	191
910136	17-02-91	0220	28°23';153°39'	28°25';153°39'	27-28	49-52	1.6	-	141
910141	17-02-91	2040	28°26';153°40'	28°24';153°39'	27-28	49-52	1.4	-	70
910142	17-02-91	2140	28°24';153°39'	28°22';153°38'	27-28	49-52	2.4	-	118
910143	17-02-91	2235	28°23';153°38'	28°24';153°38'	26-28	47-52	4.3	-	125
910144	17-02-91	2340	28°25';153°39'	28°26';153°40'	28-29	51-53	3.8	-	67
910149	18-02-91	2040	28°26';153°41'	28°25';153°41'	29-32	53-59	3.0	-	79
910150	18-02-91	2135	28°24';153°40'	28°24';153°41'	30-31	54-57	9.0	-	113
910151	18-02-91	2235	28°23';153°40'	28°21';153°40'	30-31	54-57	2.2	-	124
910152	18-02-91	2335	28°22';153°40'	28°24';153°40'	29-30	53-55	2.7	-	111
Clarence River Inshore									
910102	13-02-91	1105	29°22';153°23'	29°24';153°23'	10-15	18-27	-	0.3	32
910103	13-02-91	1200	29°24';153°23'	29°25';153°23'	09-12	17-22	-	1.3	71
910104	13-02-91	1420	29°24';153°23'	29°23';153°23'	10-13	18-24	0.2	1.5	58
910105	13-02-91	1510	29°22';153°23'	29°21';153°24'	13-15	24-27	0.1	0.2	56
910106*	13-02-91	2015	29°21';153°23'	29°23';153°23'	12-13	22-24	1.0	6.7	99
910107*	13-02-91	2110	29°23';153°23'	29°24';153°23'	10-13	18-24	1.0	12.4	85
910112	14-02-91	1525	29°23';153°23'	29°24';153°23'	12-13	22-24	0.1	0.1	71
910113	14-02-91	1615	29°24';153°23'	29°23';153°23'	13-14	24-26	0.1	0.1	84
910114	14-02-91	1705	29°24';153°23'	29°22';153°24'	14-15	25-27	0.1	-	71
910115	14-02-91	1755	29°22';153°24'	29°23';153°23'	15-16	27-30	0.1	-	85
910120	15-02-91	1445	29°24';153°23'	29°23';153°23'	11-13	20-24	0.1	-	81
910121	15-02-91	1535	29°23';153°22'	29°24';153°23'	09-10	16-19	-	0.1	59
910122	15-02-91	1625	29°24';153°23'	29°23';153°22'	09-11	16-21	-	0.1	62
900123	15-02-91	1715	29°22';153°23'	29°21';153°24'	12-15	22-28	-	0.1	79
Clarence River Offshore									
910108	13-02-91	2345	29°22';153°36'	29°21';153°36'	37-38	67-70	5.0	-	50
910109	13-02-91	0045	29°21';153°37'	29°19';153°37'	37-40	67-73	6.7	-	71
910110	13-02-91	0155	29°20';153°36'	29°21';153°35'	36-38	66-70	5.0	-	97
910111	13-02-91	0250	29°22';153°35'	29°23';153°34'	38-39	70-71	5.4	-	61
910116	14-02-91	2040	29°22';153°34'	29°21';153°35'	36-37	65-67	4.1	-	35
910117	14-02-91	2135	29°21';153°36'	29°20';153°37'	38-41	69-75	1.4	-	14
910118	14-02-91	2235	29°21';153°36'	29°22';153°36'	38-40	69-74	5.8	-	116
910119	14-02-91	2330	29°23';153°35'	29°24';153°34'	37-38	67-70	3.2	-	43
910124	15-02-91	2045	29°23';153°36'	29°21';153°36'	38-39	69-72	4.3	-	33
910125	15-02-91	2145	29°22';153°36'	29°23';153°35'	37-38	67-70	5.5	-	65
910126	15-02-91	2245	29°24';153°34'	29°26';153°34'	35-37	64-68	3.4	-	33
910127	15-02-91	2345	29°26';153°34'	29°25';153°35'	38-40	69-74	2.0	-	35

Appendix 2(h): Operational data, prawn catches and by-catch totals for trawling conducted on the central NSW grounds during Survey IV. (# tow not included in analysis.)

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Racek Prawn (kg)	Total Bycatch (kg)
Tuncurry Inshore										
910301#	12-03-91	0815	32°09';152°31'	32°08';152°31'	11-12	20-22	-	-	-	190
910302#	12-03-91	0910	32°08';152°31'	32°07';152°31'	08-10	14-18	-	-	-	123
910303#	12-03-91	1005	32°07';152°31'	32°08';152°31'	07-09	12-17	-	0.1	-	125
910304#	12-03-91	1125	32°08';152°31'	32°09';152°31'	09-10	16-19	-	-	-	109
910502	09-04-91	0830	32°10';152°31'	32°09';152°31'	09-12	16-21	-	-	-	74
910503	09-04-91	0920	32°08';152°30'	32°07';152°31'	06-07	11-12	-	0.1	-	33
910504	09-04-91	1020	32°06';152°31'	32°07';152°30'	07-08	12-15	-	-	-	51
910505	09-04-91	1120	32°08';152°30'	32°09';152°30'	05-07	09-13	-	-	-	53
910601	16-04-91	0915	32°10';152°31'	32°09';152°31'	05-07	09-13	-	-	-	60
910602	16-04-91	1005	32°08';152°31'	32°07';152°31'	07-08	12-15	-	0.1	-	79
910603	16-04-91	1055	32°07';152°31'	32°08';152°32'	09-10	16-19	-	0.1	-	84
910604	16-04-91	1150	32°08';152°31'	32°10';152°31'	06-08	11-15	-	-	-	56
910609	17-04-91	1055	32°10';152°30'	32°09';152°31'	05-07	09-13	-	-	-	66
910610	17-04-91	1145	32°08';152°30'	32°06';152°31'	08-10	14-18	-	-	-	62
910611	17-04-91	1335	32°06';152°31'	32°07';152°30'	07-09	12-17	-	0.1	-	58
910612	17-04-91	1425	32°07';152°31'	32°09';152°30'	07-08	12-15	-	-	-	48
Tuncurry Offshore										
910506	09-04-91	2010	31°56';152°51'	31°55';152°55'	49-51	89-94	5.0	-	-	23
910507	09-04-91	2105	31°54';152°51'	31°53';152°52'	47-49	86-90	0.5	-	-	9
910508	09-04-91	2210	31°53';152°52'	31°55';152°53'	48-51	87-94	10.5	-	-	31
910509	09-04-91	2310	31°56';152°52'	31°57';152°52'	51-54	93-99	6.1	-	-	32
910605	16-04-91	1910	31°58';152°49'	31°57';152°50'	49-51	89-94	1.3	-	-	50
910606	16-04-91	2010	31°56';152°51'	31°55';152°52'	50-51	91-94	7.6	-	-	27
910607	16-04-91	2110	31°54';152°53'	31°53';152°55'	51-54	93-99	7.2	-	-	50
910608	16-04-91	2225	31°53';152°53'	31°54';152°52'	48-50	87-92	8.5	-	-	53
910613	17-04-91	1855	31°59';152°50'	31°57';152°51'	51-52	93-95	0.5	-	-	66
910614	17-04-91	2000	31°55';152°52'	31°54';152°52'	49-51	89-94	7.5	-	-	20
910615	17-04-91	2100	31°54';152°52'	31°55';152°52'	49-51	89-94	9.6	-	-	23
910616	17-04-91	2205	31°56';152°52'	31°58';152°52'	52-54	95-99	7.7	-	-	50
Newcastle Inshore										
910205	05-03-91	0720	32°51';151°51'	32°51';151°52'	07-09	12-17	0.1	0.1	-	10
910206	05-03-91	0820	32°51';151°53'	32°51';151°51'	10-12	18-22	-	-	-	7
910207	05-03-91	0930	32°52';151°50'	32°52';151°49'	08-10	14-19	-	0.1	-	11
910208	05-03-91	1030	32°53';151°49'	32°52';151°50'	07-08	12-15	0.1	0.1	-	45
910213	06-03-91	0725	32°51';151°52'	32°53';151°51'	07-08	12-15	-	0.1	-	23
910214	06-03-91	0815	32°52';151°49'	32°52';151°50'	07-10	12-19	-	0.1	-	15
910215	06-03-91	0915	32°52';151°50'	32°53';151°49'	06-07	11-13	-	-	-	35
910216	06-03-91	1015	32°53';151°49'	32°52';151°50'	08-10	14-19	0.1	-	-	10
910221	07-03-91	0725	32°53';151°49'	32°52';151°50'	10-11	18-20	0.1	0.1	-	22
910222	07-03-91	0815	32°52';151°50'	32°53';151°50'	09-10	16-19	-	0.1	-	14
910223	07-03-91	0910	32°53';151°50'	32°52';151°50'	08-09	14-17	-	0.1	-	8
910224	07-03-91	1000	32°52';151°50'	32°53';151°49'	10-12	18-22	-	0.1	-	32
Newcastle Offshore										
910201	05-03-91	0010	32°56';151°57'	32°54';151°57'	38-39	69-72	15.5	-	0.1	19
910202	05-03-91	0140	32°53';151°58'	32°52';151°59'	34-39	62-72	8.1	-	0.1	21
910203	05-03-91	0235	32°53';151°59'	32°54';151°58'	36-40	65-74	12.5	-	0.2	20
910204	05-03-91	0340	32°54';151°58'	32°53';151°59'	36-42	65-77	2.0	-	0.2	44
910209	06-03-91	0040	32°54';151°57'	32°54';151°58'	38-41	69-75	7.4	-	0.2	16
910210	06-03-91	0140	32°53';151°59'	32°52';152°00'	35-37	64-68	16.0	-	-	27
910211	06-03-91	0240	32°53';152°00'	32°54';151°59'	37-39	67-72	7.8	-	0.6	20
910212	06-03-91	0340	32°54';151°58'	32°55';151°57'	39-41	71-75	2.7	-	0.1	23
910217	07-03-91	0005	32°55';151°56'	32°54';151°58'	38-40	69-74	9.6	-	0.1	13
910218	07-03-91	0055	32°53';151°58'	32°52';151°59'	30-34	54-62	15.2	-	-	43
910219	07-03-91	0230	32°53';152°00'	32°54';151°59'	38-40	69-74	16.4	-	0.1	21
910220	07-03-91	0325	32°54';151°58'	32°55';151°56'	35-37	64-68	11.6	-	-	30

Appendix 3(a): List of fish species and their frequency of occurrence (presence per 12 tows; + 11 for Clarence R. Survey I) for the Clarence River and Brunswick Heads inshore grounds. (* commercial and/or angling species; # new record for NSW.)

	Area:	Clarence R.				Brunswick Hds			
	Survey:	I+	II	III	IV	I	II	III	IV
ORECTOLOBIDAE	* *Orectolobus maculatus*	2	2	1	–	–	–	2	–
CARCHARHINIDAE	* *Carcharhinus brevipinna*	1	–	–	–	–	–	–	–
	* *Carcharhinus plumbeus*	3	–	2	–	–	–	–	–
SPHYRNIDAE	* *Sphyrna zygaena*	–	–	–	–	–	–	–	1
RHYNCHOBATIDAE	*Rhynchobatus djiddensis*	1	–	–	–	1	1	–	–
RHINOBATIDAE	* *Aptychotrema rostrata*	8	–	12	8	12	12	12	11
TORPEDINIDAE	*Hypnos monopterygium*	1	12	8	5	7	6	8	6
DASYATIDIDAE	*Dasyatis fluviorum*	3	5	–	–	–	–	–	–
	D. kuhlii	3	2	5	3	7	9	7	4
	Pastinachus sephen	1	–	–	–	–	–	–	–
UROLOPHIDAE	*Trygonoptera testaceus*	11	12	10	12	12	12	12	12
	Urolophus sp.	1	5	1	2	–	1	–	–
MYLIOBATIDIDAE	*Aetobatus narinari*	2	–	–	–	–	–	–	–
	Rhinoptera neglecta	–	–	1	–	–	–	–	–
CLUPEIDAE	*Etrumeus teres*	–	2	1		–	–	–	–
	Herklotsichthys castelnaui	11	–	9	3	–	–	–	–
	Hyperlophus vittatus	4	2	1	–	–	–	–	–
	* *Sardinops sagax neopilchardus*	–	4	5	–	–	–	7	–
SYNODONTIDAE	*Trachinocephalus myops*	–	–	1	–	–	–	–	–
HARPADONTIDAE	*Saurida undosquamis*	1	–	–	12	12	5	12	12
ARIIDAE	*Arius graeffei*	1	–	–	–	–	–	–	–
PLOTOSIDAE	*Cnidoglanis macrocephalus*	1	1	2	–	6	2	1	–
	Euristhmus lepturus	1	1	2	–	6	6	3	3
	Plotosus lineatus	1	–	2	1	12	2	–	–
ANTENNARIIDAE	*Antennarius striatus*	–	–	–	12	–	–	–	12
TRACHICHTHYIDAE	*Optivus* sp.	–	–	–	–	1	–	–	–
	Trachichthys australis	–	–	–	–	–	–	1	–
ZEIDAE	* *Zeus faber*	1	1	–	–	–	–	–	–
FISTULARIIDAE	*Fistularia commersonii*	–	–	–	8	–	–	1	5
SCORPAENIDAE	*Centropogon australis*	2	3	1	8	5	12	3	1
	Dendrochirus zebra	–	–	–	1	–	–	–	–
	# *Inimicus caledonicus*	–	–	–	–	1	–	–	–
	Notesthes robusta	11	1	–	–	5	–	–	–
TRIGLIDAE	* *Chelidonichthys kumu*	–	2	9	10	5	9	12	8
	Lepidotrigla argus	–	–	–	1	4	–	–	–
	L. umbrosa	2	2	3	12	12	12	12	12
PLATYCEPHALIDAE	*Platycephalus arenarius*	1	–	–	11	1	4	1	8
	* *P. caeruleopunctatus*	5	12	12	12	12	12	12	12
	* *P. fuscus*	9	2	2	11	1	–	3	4
	P. longispinnis	8	12	3	12	12	12	12	12
	Suggrundus jugosus	–	–	–	3	–	–	1	–
DACTYLOPTERIDAE	# *Dactyloptena papilio*	–	–	–	–	5	2	5	–
SERRANIDAE	* *Epinephelus ergastularius*	1	–	–	–	–	1	–	–
	Triso dermopterus	–	–	7	1	–	–	1	–
TERAPONTIDAE	*Pelates quadrilineatus*	9	1	3	10	2	2	–	1
	Terapon theraps	3	1	–	–	–	–	–	–
PRIACANTHIDAE	*Priacanthus macracanthus*	10	3	11	6	11	5	8	7
APOGONIDAE	*Apogon fasciatus*	5	3	6	4	–	5	1	–
	A. nigripinnis	1	–	3	1	–	1	–	5
SILLAGINIDAE	* *Sillago bassensis*	–	11	6	9	3	2	6	6
	* *S. ciliata*	–	–	–	1	–	–	–	–
	* *S. maculata*	–	–	1	–	–	–	–	–
	* *S. robusta*	11	11	12	12	12	12	12	12
POMATOMIDAE	* *Pomatomus saltatrix*	10	8	9	3	3	1	3	4
RACHYCENTRIDAE	* *Rachycentron canadus*	–	–	1	–	1	1	–	–

Appendix 3(a) (continued)

	Area:	Clarence R.				Brunswick Hds			
	Survey:	I	II	III	IV	I	II	III	IV
CARANGIDAE	*Alectis ciliaris*	–	–	–	1	–	–	–	5
	Alepes sp.	–	–	–	1	3	–	–	4
	# *Atule mate*	–	–	–	–	3	–	–	–
	Carangoides chrysophrys	–	–	–	–	3	1	–	5
	# *C. coeruleopinnatus*	–	–	–	1	4	–	–	–
	# *C. equula*	–	–	–	1	–	–	–	–
	# *C. fulvoguttatus*	–	–	–	–	–	–	–	1
	# *C. malabaricus*	1	–	–	1	1	1	–	8
	* *Caranx sexfasciatus*	2	1	–	1	5	–	–	8
	Decapterus macrosoma	–	–	–	–	1	–	–	–
	# *D. russelli*	–	–	–	–	3	1	–	–
	Megalaspis cordyla	–	–	–	–	4	–	–	1
	* *Pseudocaranx dentex*	–	–	–	–	–	1	–	–
	# *Selar crumenophthalmus*	–	–	–	–	1	–	–	1
	# *Selaroides leptolepis*	–	–	–	–	–	2	–	–
	* *Seriola hippos*	–	–	2	–	1	–	7	–
	S. rivoliana	–	–	–	–	–	–	1	–
	Trachurus novaezelandiae	11	12	12	6	9	12	12	10
MENIDAE	*Mene maculata*	1	–	–	–	–	–	–	–
LEIOGNATHIDAE	*Equulites mortoniensis*	2	–	–	1	–	4	11	5
	Gazza sp.	–	5	–	–	–	–	–	–
LUTJANIDAE	*Lutjanus malabaricus*	1	–	–	–	3	–	–	–
GERREIDAE	*Gerres subfasciatus*	10	3	9	8	3	2	7	6
SPARIDAE	* *Pagrus auratus*	1	1	9	12	1	4	4	5
	* *Rhabdosargus sarba*	4	–	–	2	–	1	2	2
SCIAENIDAE	* *Argyrosomus hololepidotus*	10	4	5	–	1	–	–	–
	* *Atractoscion aequidens*	11	3	8	2	1	–	–	–
	Johnius vogleri	–	–	–	1	–	–	–	–
MULLIDAE	* *Parupeneus signatus*	–	–	–	–	–	–	–	1
	* *Upeneichthys lineatus*	–	2	1	7	–	3	3	3
	Upeneus tragula	–	–	–	5	1	3	1	1
MONODACTYLIDAE	*Schuettea scalaripinnis*	–	–	–	–	–	–	–	1
PEMPHERIDIDAE	*Pempheris analis*	–	–	–	–	–	–	2	–
	P. affinis	1	1	–	–	–	–	–	–
SCORPIDIDAE	*Atypichthys strigatus*	–	–	–	2	1	–	1	2
	Microcanthus strigatus	–	–	–	4	2	–	1	–
	* *Scorpis lineolatus*	–	–	–	–	–	–	2	2
EPHIPPIDIDAE	*Platax teira*	–	–	–	–	1	–	–	–
CHAETODONTIDAE	*Chaetodon guntheri*	–	–	–	–	–	–	–	1
	Heniochus diphreutes	–	–	–	–	1	–	1	3
ENOPLOSIDAE	*Enoplosus armatus*	–	–	1	4	–	–	–	1
CHEILODACTYLIDAE	*Cheilodactylus vestitus*	–	–	–	3	–	–	1	–
SPHYRAENIDAE	*Sphyraena africana*	10	8	12	5	4	10	12	6
POLYNEMIDAE	*Polydactylus multiradiatus*	–	–	–	–	–	–	–	1
PINGUIPEDIDAE	*Parapercis nebulosa*	–	–	–	–	–	1	–	–
CALLIONYMIDAE	*Callionymus calcaratus*	–	1	–	12	3	6	9	12
ACANTHURIDAE	*Prionurus microlepidotus*	–	–	–	–	1	–	–	1
SIGANIDAE	* *Siganus fuscescens*	–	–	1	–	–	–	–	–
TRICHIURIDAE	* *Trichiurus lepturus*	7	3	8	–	–	–	1	–
SCOMBRIDAE	* *Scomber australasicus*	7	–	5	5	2	–	11	–
NOMEIDAE	*Psenes whiteleggi* ?	–	–	1	–	–	4	–	2
BOTHIDAE	*Arnoglossus fisoni*	–	–	–	–	–	3	1	11
	Bothus myriaster	–	–	–	–	–	–	1	–
	Engyprosopon bleekeri	–	–	–	–	–	–	–	1
PARALICHTHYIDAE	* *Pseudorhombus arsius*	4	3	1	12	7	12	7	11
	* *P. jenynsii*	2	–	11	12	4	7	3	3
	* *P. tenuirastrum*	4	1	2	12	3	9	–	3

Appendix 3(a) (continued)

		Area:	Clarence R.				Brunswick Hds			
		Survey:	I	II	III	IV	I	II	III	IV
SOLEIDAE		*Synaptura nigra*	10	7	8	9	–	–	1	–
		Aseraggodes macleayanus	7	8	10	12	5	9	12	12
		Pardachirus hedleyi	2	–	–	–	3	–	–	–
		Zebrias fasciatus	1	–	–	–	–	–	–	–
CYNOGLOSSIDAE		*Paraplagusia unicolor*	1	2	6	11	9	11	12	12
TRIACANTHIDAE		*Tripodichthys angustrifrons*	1	–	–	–	–	–	–	–
MONACANTHIDAE		*Brachaluteres jacksonianus*	–	–	–	–	–	–	–	2
	*	*Eubalichthys mosaicus*	–	–	4	–	–	–	2	–
		Laputa sp.	–	–	–	2	–	1	–	–
	*	*Meuschenia trachylepis*	–	–	–	3	–	–	–	–
	*	*Nelusetta ayraudi*	–	–	3	–	–	–	2	–
		Paramonacanthus otisensis	–	–	3	1	1	–	–	
		Pseudaluteres nasicornis	–	–	–	–	2	–	2	
OSTRACIIDAE		*Anoplocapros robustus*	8	11	5	1	–	1	–	–
TETRAODONTIDAE		*Arothron manillensis*	1	–	–	–	–	–	–	–
		Lagocephalus cheesemani	6	1	–	5	1	3	–	7
		L. inermis	–	–	–	–	–	–	–	1
		L. sceleratus	–	–	–	–	2	–	2	5
		Reicheltia halsteadi	6	12	9	12	12	12	12	12
		Tetractenos hamiltoni	–	–	–	–	–	–	–	3
		Torquigener altipinnis	–	–	–	–	–	–	–	5
		T. pleurogramma	–	–	–	–	2	–	–	4
DIODONTIDAE		*Chilomycterus reticulatus*	–	–	–	1	–	–	–	–
		Diodon holocanthus	–	1	1	–	–	1	–	–

Appendix 3(b): List of fish species and their frequency of occurrence (presence per 12 tows) for the Clarence River and Brunswick Heads offshore grounds. (* commercial and/or angling species; # new record for NSW.)

		Area:	Clarence R.				Brunswick Hds			
		Survey:	I	II	III	IV	I	II	III	IV
HETERODONTIDAE		*Heterodontus galeatus*	–	1	–	–	–	–	–	–
BRACHAELURIDAE	#	*Brachaelurus* cf *colcloughi*	–	–	–	–	2	–	–	
STEGOSTOMATIDAE		*Stegostoma fasciatum*	–	–	–	–	–	1	–	–
TRIAKIDAE		*Hemitriakis* sp.	–	–	–	–	–	–	–	1
	*	*Mustelus antarcticus*	–	–	5	5	5	9	10	8
CARCHARHINIDAE		*Hemigaleus microstoma*	–	–	–	–	–	1	–	–
RHINOBATIDAE	*	*Aptychotrema rostrata*	–	3	–	1	3	5	4	2
	*	*Trygonorrhina* sp.nov.	–	–	–	–	–	1	5	–
TORPEDINIDAE		*Hypnos monopterygium*	3	2	5	12	–	–	5	8
RAJIDAE		*Raja polyommata*	1	–	1	1	–	–	–	
DASYATIDIDAE		*Dasyatis thetidis*	–	–	–	–	–	–	1	–
UROLOPHIDAE		*Urolophus paucimaculatus*	–	1	–	–	–	–	–	–
		Urolophus sp.	2	1	–	–	–	4	1	
CONGRIDAE		*Gnathophis* sp.	12	12	9	12	12	12	12	12
CLUPEIDAE		*Etrumeus teres*	–	2	–	–	–	–	–	–
	*	*Sardinops sagax neopilchardus*	6	–	5	–	–	–	2	–
ENGRAULIDIDAE		*Engraulis australis*	2	4	6	–	–	–	–	–
AULOPIDAE		*Aulopus purpurissatus*	–	–	–	1	–	–	–	–
SYNODONTIDAE	#	*Synodus indicus*	–	–	1	–	–	–	–	–
		Trachinocephalus myops	5	4	2	12	12	12	12	12
HARPADONTIDAE		*Saurida filamentosa*	8	11	12	12	2	–	–	–
		S. undosquamis	–	–	–	–	4	10	7	12
GONORYNCHIDAE		*Gonorynchus greyi*	12	12	5	12	11	12	11	12
BATRACHOIDIDAE		*Batrachomoeus dubius*	1	1	3	6	2	–	2	8
LOPHIIDAE		*Lophiomus setigerus*	–	–	1	2	–	1	–	–
ANTENNARIIDAE		*Antennarius striatus*	11	8	4	11	7	3	9	12
OGCOCEPHALIDAE		*Halieutaea brevicauda*	2	1	–	3	–	–	–	–
MORIDAE		*Pseudophycis breviuscula*	2	–	–	1	–	–	–	–
OPHIDIIDAE		*Ophidion* sp.	–	1	–	–	–	–	–	–
		Sirembo sp.	–	–	1	–	–	–	–	–
BELONIDAE		*Ablennes hians*	1	–	–	–	–	–	–	1
TRACHICHTHYIDAE		*Aulotrachichthys novaezelandiae*	–	1	–	–	–	–	–	–
		Optivus sp.	10	3	–	3	12	11	10	9
BERYCIDAE	*	*Centroberyx affinis*	–	4	–	–	–	1	1	–
MONOCENTRIDIDAE		*Cleidopus gloriamaris*	–	–	–	–	–	–	2	–
ZEIDAE	*	*Zeus faber*	1	3	1	–	–	–	–	–
CAPROIDAE		*Antigonia rubicunda*	–	–	–	1	–	–	–	1
VELIFERIDAE		*Velifer multiradiatus*	–	–	–	–	–	–	1	–
FISTULARIIDAE		*Fistularia commersonii*	–	–	–	–	–	–	–	9
		F. petimba	6	–	–	–	3	1	–	–
MACRORAMPHOSIDAE		*Macroramphosus gracilis*	8	1	10	–	–	–	–	–
		M. scolopax	7	12	12	12	–	–	–	–
SYNGNATHIDAE		*Hippocampus whitei*	–	–	–	–	–	–	–	1
SCORPAENIDAE	#	*Apistus carinatus*	–	–	–	–	1	–	–	–
		Centropogon australis	–	–	–	–	2	–	5	–
		Dendrochirus brachypterus	–	–	–	1	–	2	–	8
		D. zebra	1	–	1	–	1	–	5	–
	#	*Erosa erosa*	–	1	–	–	3	2	8	6
		Maxillicosta whitleyi	12	11	11	12	12	12	12	12
		Neosebastes incisipinnis	5	12	10	6	1	2	1	4
		Scorpaena cardinalis	–	1	–	–	–	–	1	–
TRIGLIDAE	*	*Chelidonichthys kumu*	2	9	4	4	4	11	8	5
		Lepidotrigla argus	12	12	12	12	12	12	12	12
		L. papilio	3	4	1	–	3	2	–	1

Appendix 3(b): (continued)

	Area:	Clarence R.				Brunswick Hds			
	Survey:	I	II	III	IV	I	II	III	IV
APLOACTINIDAE	*Aploactis aspersa*	–	–	–	–	1	–	3	–
PLATYCEPHALIDAE	*Platycephalus longispinis*	12	12	12	12	12	12	12	12
	* *P. caeruleopunctatus*	–	2	4	–	10	10	12	5
	* *P. marmoratus*	2	5	–	–	3	7	3	4
	Suggrundus jugosus	–	–	–	–	5	1	–	–
	Ratabulus diversidens	6	4	3	11	8	6	3	10
DACTYLOPTERIDAE	*Dactyloptena orientalis*	–	–	–	–	–	1	–	1
	# *D. papilio*	5	12	1	1	1	7	9	4
SERRANIDAE	* *Epinephelus ergastularius*	–	–	1	2	–	–	–	3
GLAUCOSOMATIDAE	* *Glaucosoma scapulare*	1	–	2	1	–	1	6	5
TERAPONTIDAE	*Terapon theraps*	–	–	–	–	–	–	–	1
BANJOSIDAE	# *Banjos banjos*	–	–	4	3	–	–	–	–
PRIACANTHIDAE	*Priacanthus macracanthus*	1	1	–	–	–	–	4	4
	# *Pristigenys niphonia*	3	1	1	1	–	–	–	2
APOGONIDAE	*Apogon nigripinnis*	–	–	–	–	1	2	–	–
SILLAGINIDAE	* *Sillago bassensis*	7	12	5	5	–	–	8	–
	* *S. robusta*	–	–	–	–	–	–	5	–
POMATOMIDAE	* *Pomatomus saltatrix*	2	–	–	–	–	1	–	–
RACHYCENTRIDAE	*Rachycentron canadus*	–	–	–	–	–	–	1	–
CARANGIDAE	# *Carangoides equula*	1	3	12	12	–	–	5	–
	Seriolina nigrofasciata	–	–	–	–	–	2	–	–
	Trachurus declivis	–	–	3	–	1	–	–	–
	T. novaezelandiae	12	12	9	8	3	–	12	1
NEMIPTERIDAE	*Nemipterus aurifilum*	–	1	–	–	–	–	–	–
	N. theodorei	6	2	1	3	1	–	5	–
SPARIDAE	* *Allotaius spariformes*	6	–	8	8	–	–	–	–
	* *Pagrus auratus*	–	1	–	1	–	–	3	–
	* *Rhabdosargus sarba*	1	1	–	–	–	–	–	–
SCIAENIDAE	*Argyrosoma hololepidotus*	1	–	–	–	–	–	–	–
MULLIDAE	* *Parupeneus signatus*	–	–	–	–	–	–	–	1
	* *Upeneichthys lineatus*	12	–	7	3	10	–	6	3
	Upeneus filifer	1	–	4	–	–	–	–	–
	U. tragula	4	–	–	–	–	–	–	–
PEMPHERIDIDAE	*Pempheris affinis*	1	–	–	–	4	–	–	–
SCORPIDIDAE	*Atypichthys strigatus*	–	–	–	–	1	1	–	–
ENOPLOSIDAE	*Enoplosus armatus*	1	–	–	–	–	–	–	–
POMACENTRIDAE	*Chromis abyssicola*	–	1	–	–	–	–	–	–
SPHYRAENIDAE	*Sphyraena africana*	–	–	1	–	9	1	2	–
LABRIDAE	*Choerodon frenatus*	8	2	4	–	–	–	–	–
	Xyrichtys sp.	–	–	–	–	1	–	–	–
OPISTOGNATHIDAE	*Opistognathus jacksoniensis*	1	1	–	–	–	–	–	–
PINGUIPEDIDAE	*Parapercis nebulosa*	–	–	–	–	7	–	1	5
	P. ramsayi	–	–	–	–	–	1	–	–
	P. sp.	2	–	2	–	–	–	–	–
URANOSCOPIDAE	*Ichthyscopus* sp.	–	–	–	–	3	–	–	1
	Uranoscopus sp.2	1	4	3	1	–	–	–	–
CHAMPSODONTIDAE	*Champsodon* sp.	–	–	5	–	–	–	–	–
BLENNIIDAE	*Xiphasia setifer*	–	–	–	–	1	–	–	–
CALLIONYMIDAE	*Callionymus moretonensis*	–	–	2	4	–	–	–	–
	C. japonicus scaber	9	–	8	12	–	–	4	11
	Repomucenus calcaratus	7	1	–	–	12	12	12	11
	Synchiropus calauropomus	12	12	12	12	11	11	6	8
	S. rameus	–	–	–	–	–	–	–	1
SIGANIDAE	* *Siganus fuscescens*	–	–	–	–	–	–	1	–
TRICHIURIDAE	* *Trichiurus lepturus*	–	2	–	–	–	–	–	–
SCOMBRIDAE	* *Scomber australasicus*	1	–	5	5	–	–	2	–

Appendix 3(b) (continued)

	Area:	Clarence R.				Brunswick Hds			
	Survey:	I	II	III	IV	I	II	III	IV
BOTHIDAE	*Crossorhombus azureus*	–	2	–	–	–	–	6	12
	Engyprosopon grandisquama	10	11	10	12	5	6	12	10
	E. maculipinnis	–	4	3	5	–	–	1	–
	Grammatobothus pennatus	1	–	–	–	–	–	4	8
	Lophonectes gallus	12	12	12	12	12	12	12	12
	Psettina gigantea	–	–	–	1	–	–	–	–
PARALICHTHYIDAE	* *Pseudorhombus tenuirastrum*	3	12	11	12	12	11	12	12
	* *P. dupliciocellatus*	–	–	–	–	1	1	–	–
SOLEIDAE	*Aesopia cornuta*	–	–	–	–	1	–	–	–
	Zebrias fasciatus	7	4	–	2	8	9	12	12
CYNOGLOSSIDAE	*Cynoglossus maculipinnis*	4	3	8	7	–	1	4	3
MONACANTHIDAE	*Aluterus monoceros*	–	–	–	–	1	–	–	–
	Cantheschenia longipinnis	1	1	–	2	1	–	–	–
	* *Eubalichthys mosaicus*	–	1	–	1	–	–	1	–
	Laputa sp.	–	–	–	–	4	1	12	10
	* *Meuschenia trachylepis*	–	2	1	–	–	2	–	–
	* *Nelusetta ayraudi*	–	1	–	2	–	–	–	4
	Paramonacanthus otisensis	4	2	4	9	8	7	–	12
	Thamnaconus modestoides	–	–	–	–	–	–	–	1
	T. harpargyreus	–	–	1	–	–	–	–	–
OSTRACIIDAE	*Anoplocapros robustus*	1	10	12	10	–	12	11	–
	Lactoria diaphana	–	–	–	–	1	–	1	–
	L. fornasini	–	–	–	–	1	–	–	–
	Trioris reipublicae	12	12	10	12	10	12	12	12
TETRAODONTIDAE	*Anchisomus multistriatus*	–	–	–	–	1	–	–	–
	Arothron firmamentum	–	–	–	–	2	–	–	–
	Canthigaster callisterna	–	–	1	–	–	–	–	–
	Lagocephalus cheesemani	9	8	2	12	7	11	10	12
	L. sceleratus	–	–	–	–	1	–	–	2
	Torquigener altipinnis	8	10	4	12	12	12	12	12
DIODONTIDAE	*Diodon holocanthus*	–	5	1	–	–	–	–	1

Appendix 3(c): List of fish species and their frequency of occurrence (presence per 12 tows) for the Newcastle and Tuncurry inshore grounds. (* commercial and/or angling species; # new record for NSW.)

	Area:	Newcastle				Tuncurry			
	Survey:	I	II	III	IV	I	II	III	IV
HETERODONTIDAE	*Heterodontus portusjacksoni*	9	11	4	–	12	12	12	1
BRACHAELURIDAE	*Brachaelurus waddi*	–	4	3	–	–	–	–	–
TRIAKIDAE	* *Mustelus antarcticus*	–	–	–	–	1	–	–	–
CARCHARHINIDAE	* *Carcharhinus brevipinna*	–	–	–	5	–	–	–	–
SPHYRNIDAE	* *Sphyrna zygaena*	–	–	1	6	–	–	–	–
SQUATINIDAE	* *Squatina australis*	–	–	–	–	–	1	–	1
RHINOBATIDAE	* *Aptychotrema rostrata*	4	4	7	3	11	12	12	11
	* *Trygonorrhina* sp.	–	1	–	–	10	12	12	8
TORPEDINIDAE	*Hypnos monopterygium*	1	2	–	–	7	–	–	2
DASYATIDIDAE	*Dasyatis fluviorum*	–	–	–	–	–	3	–	–
	D. kuhlii	–	–	–	–	–	–	2	–
UROLOPHIDAE	*Trygonoptera testaceus*	8	10	9	2	12	12	12	12
	Urolophus sp.	2	9	5	–	8	9	10	2
MYLIOBATIDIDAE	*Myliobatis australis*	–	–	–	1	6	3	9	–
CLUPEIDAE	*Etrumeus teres*	2	–	–	–	3	–	–	–
	Hyperlophus vittatus	7	–	–	7	–	–	–	–
	Potamalosa richmondia	–	1	–	–	–	–	–	–
	Sardinella gibbosa	–	–	–	–	–	1	–	–
	* *Sardinops sagax neopilchardus*	1	–	–	1	3	–	–	–
ENGRAULIDIDAE	*Engraulis australis*	6	–	–	7	1	–	–	–
AULOPIDAE	*Aulopus purpurissatus*	–	1	–	–	–	–	–	–
SYNODONTIDAE	*Trachinocephalus myops*	2	1	1	3	–	–	–	–
HARPADONTIDAE	*Saurida undosquamis*	–	–	1	–	2	3	9	–
PLOTOSIDAE	*Cnidoglanis macrocephalus*	–	5	4	–	2	11	–	1
	Euristhmus lepturus	–	8	2	–	–	–	–	–
	Plotosus lineatus	–	7	5	2	9	9	–	2
ANTENNARIIDAE	*Antennarius striatus*	–	–	–	3	–	–	–	–
MORIDAE	*Pseudophycis breviuscula*	–	6	–	–	1	–	–	–
TRACHICHTHYIDAE	*Optivus* sp.	3	2	–	–	–	–	–	–
BERYCIDAE	* *Centroberyx affinis*	–	1	–	1	2	–	–	–
ZEIDAE	* *Zeus faber*	–	–	1	–	1	2	–	–
FISTULARIIDAE	*Fistularia commersonii*	–	–	–	–	–	–	–	9
	F. petimba	5	–	–	5	–	–	–	–
SYNGNATHIDAE	*Hippocampus abdominalis*	–	–	–	1	–	–	–	–
	Filicampus tigris	1	–	–	–	–	–	–	–
SCORPAENIDAE	# *Apistus carinatus*	1	–	–	–	–	–	–	–
	Centropogon australis	2	7	7	3	10	–	2	1
	Notesthes robusta	4	1	–	9	6	–	–	3
	Scorpaena cardinalis	–	1	–	–	–	–	–	–
TRIGLIDAE	* *Chelidonichthys kumu*	4	12	11	2	1	12	11	5
PATAECIDAE	*Pataecus fronto*	1	–	1	–	–	–	–	–
PLATYCEPHALIDAE	*Platycephalus arenarius*	–	7	1	–	1	5	1	2
	* *P. caeruleopunctatus*	12	12	11	11	12	12	12	12
	* *P. fuscus*	–	1	3	3	3	1	2	2
	P. longispinis	5	12	10	12	5	12	12	10
	* *P. marmoratus*	1	–	–	–	–	–	–	–
DACTYLOPTERIDAE	*Dactyloptena orientalis*	–	–	1	–	–	–	–	–
	# *D. papilio*	–	–	–	–	1	–	–	1
SERRANIDAE	*Acanthistius ocellatus*	–	–	–	–	1	–	–	–
	* *Epinephelus ergastularius*	–	–	–	2	1	–	–	–
	E. undulostriatus	–	–	–	1	–	–	–	1
TERAPONTIDAE	*Pelates quadrilineatus*	2	–	–	6	7	7	–	2
PRIACANTHIDAE	*Priacanthus macracanthus*	1	–	–	11	2	1	–	10
APOGONIDAE	*Apogon nigripinnis*	–	–	–	–	3	2	1	–
	Siphamia cephalotes	–	–	–	–	3	–	–	–

Appendix 3(c) (continued)

	Area:	Newcastle				Tuncurry			
	Survey:	I	II	III	IV	I	II	III	IV
SILLAGINIDAE	* *Sillago bassensis*	3	10	11	12	12	11	4	12
	* *S. ciliata*	–	1	2	–	–	–	1	–
	* *S. maculata*	–	–	–	–	3	5	3	1
	* *S. robusta*	5	12	11	11	9	10	7	4
POMATOMIDAE	* *Pomatomus saltatrix*	6	4	5	2	12	8	1	7
RACHYCENTRIDAE	*Rachycentron canadus*	–	–	–	–	–	–	1	–
CARANGIDAE	*Alectis ciliaris*	–	–	–	2	–	–	–	–
	Alepes sp.	–	–	–	–	2	–	–	–
	Carangoides chrysophrys	–	–	–	–	–	–	–	1
	# *C. coeruleopinnatus*	–	–	–	–	–	–	–	9
	# *C. equula*	–	–	–	–	1	–	–	–
	# *C. malabaricus*	1	–	–	3	3	–	–	4
	Decapterus macrosoma	–	–	–	–	–	–	–	1
	* *Pseudocaranx dentex*	9	3	4	1	4	7	–	–
	# *Selar crumenophthalmus*	–	–	–	–	1	–	–	–
	* *Seriola hippos*	–	–	7	1	–	–	10	1
	Trachurus novaezelandiae	12	10	12	12	12	12	12	12
	# *Uraspis uraspis*	–	–	–	–	–	–	–	1
GERREIDAE	*Gerres subfasciatus*	3	3	6	6	6	–	9	1
SPARIDAE	* *Pagrus auratus*	4	–	2	3	6	–	1	6
	* *Rhabdosargus sarba*	2	–	3	1	5	–	5	7
	* *Acanthopagrus australis*	3	10	9	–	2	–	–	–
SCIAENIDAE	* *Argyrosomus hololepidotus*	7	10	4	–	10	8	–	–
	* *Atractoscion aequidens*	3	11	2	3	6	6	–	1
MULLIDAE	* *Parupeneus signatus*	1	–	–	–	–	–	–	1
	* *Upeneichthys lineatus*	–	–	–	1	2	1	–	–
	Upeneus tragula	2	1	–	2	1	6	–	1
MONODACTYLIDAE	*Schuettea scalaripinnis*	2	–	–	–	1	–	–	1
PEMPHERIDIDAE	*Pempheris analis*	–	–	–	–	1	–	–	–
	P. compressus	2	11	2	–	4	3	1	–
SCORPIDIDAE	*Atypichthys strigatus*	3	–	–	–	–	–	–	–
	Microcanthus strigatus	1	–	–	1	–	–	–	3
CHAETODONTIDAE	*Chaetodon auriga*	–	–	–	–	–	–	–	1
	Heniochus diphreutes	–	–	–	–	–	–	–	2
ENOPLOSIDAE	*Enoplosus armatus*	–	–	1	10	5	–	–	9
PENTACEROTIDAE	* *Paristiopterus labiosus*	1	–	–	–	–	–	–	–
CHIRONEMIDAE	*Chironemus marmoratus*	–	1	–	–	–	–	–	–
SPHYRAENIDAE	*Sphyraena africana*	10	8	7	11	11	11	10	12
	S. obtusata	–	–	–	–	1	–	–	–
BLENNIDAE	*Petroscirtes lupus*	–	–	–	3	–	–	–	2
CLINIDAE	*Cristiceps aurantiacus*	–	–	–	1	–	–	–	1
CALLIONYMIDAE	*Callionymus calcaratus*	–	1	–	1	–	–	–	1
SIGANIDAE	* *Siganus fuscescens*	2	–	–	–	–	–	–	1
TRICHIURIDAE	* *Trichiurus lepturus*	4	9	–	1	1	–	–	–
SCOMBRIDAE	* *Sarda australis*	–	–	–	2	–	–	–	1
	* *Scomber australasicus*	–	–	–	4	1	3	–	3
NOMEIDAE	*Psenes whiteleggi* ?	–	–	–	2	–	–	–	–
BOTHIDAE	*Arnoglossus fisoni*	–	1	–	–	–	–	–	–
PARALICHTHYIDAE	* *Pseudorhombus arsius*	10	9	8	6	11	11	10	12
	* *P. jenynsi*	3	3	3	2	8	7	1	5
	* *P. tenuirastrum*	–	–	–	–	–	4	–	2
SOLEIDAE	*Aseraggodes macleayanus*	8	12	12	8	9	6	8	7
	Pardachirus hedleyi	–	–	–	–	–	1	–	–
	Synaptera nigra	1	9	2	–	11	9	7	11
CYNOGLOSSIDAE	*Paraplagusia unicolor*	6	11	7	1	9	11	4	2

Appendix 3(c): (continued)

		Area:	Newcastle				Tuncurry			
		Survey:	I	II	III	IV	I	II	III	IV
MONACANTHIDAE		*Aluterus monoceros*	–	–	–	–	–	–	1	–
		Brachaluteres jacksonianus	–	–	–	2	1	–	–	2
	*	*Eubalichthys mosaicus*	–	–	2	–	–	–	10	–
	*	*Meuschenia trachylepis*	3	–	–	–	7	–	–	1
	*	*Nelusetta ayraudi*	–	–	4	–	–	–	7	–
		Paramonacanthus otisensis	–	–	–	–	–	2	–	1
		Penicipelta vittiger	–	–	–	–	1	–	–	1
OSTRACIIDAE		*Anoplocapros robustus*	5	8	5	2	12	12	12	12
		Lactoria fornasini	–	–	–	–	–	1	–	–
		Ostracion meleagris	–	–	–	1	–	1	–	–
TETRAODONTIDAE		*Arothron aerostaticus*	–	–	–	1	–	–	–	–
		Lagocephalus cheesemani	–	2	3	–	1	–	–	–
		L. sceleratus	–	–	1	–	–	–	–	–
		Reicheltia halsteadi	6	6	5	12	12	12	12	12
		Tetractenos hamiltoni	4	6	–	–	1	–	–	1
		Torquigener pleurogramma	–	–	1	–	–	–	–	1
DIODONTIDAE		*Allomycterus pilatus*	1	–	–	–	–	–	1	–
		Dicotylichthys punctulatus	6	6	5	–	10	12	11	11
		Diodon holocanthus	–	–	–	–	–	–	1	–
		D. nicthemerus	–	–	–	–	–	–	1	–

Appendix 3(d): List of fish species and their frequency of occurrence (presence per 12 tows) for the Newcastle and Tuncurry offshore grounds. (* commercial and/or angling species; # new record for NSW.)

		Area:	Newcastle				Tuncurry			
		Survey:	I	II	III	IV	I	II	III	IV
HETERODONTIDAE		*Heterodontus portusjacksoni*	5	9	–	1	–	–	–	–
ORECTOLOBIDAE	*	*Orectolobus maculatus*	3	2	3	–	–	3	1	–
		Parascyllium collare	–	–	–	–	4	12	7	3
SCYLIORHINIDAE		*Asymbolus* sp.	–	–	–	–	1	10	–	3
TRIAKIDAE	*	*Mustelus antarcticus*	–	–	–	1	1	12	–	–
CARCHARHINIDAE	*	*Carcharhinus obscurus*	–	–	–	–	1	–	–	–
SQUALIDAE	*	*Squalus megalops*	–	–	–	–	–	12	–	–
	*	*S. mitsukurii*	–	–	–	–	–	7	–	1
PRISTIOPHORIDAE	*	*Pristiophorus* sp.	–	2	1	–	–	10	3	4
SQUATINIDAE	*	*Squatina* sp.	–	–	1	1	–	8	3	2
RHINOBATIDAE	*	*Aptychotrema rostrata*	12	6	1	1	1	6	1	–
	*	*Trygonorrhina* sp.	5	–	–	–	–	3	–	–
TORPEDINIDAE		*Hypnos monopterygium*	12	8	11	7	1	–	–	–
		Torpedo macneilli	1	3	–	–	–	–	–	–
RAJIDAE		*Raja australis*	–	–	–	–	9	9	12	7
DASYATIDIDAE		*Dasyatis brevicaudata*	–	–	–	2	–	–	–	–
		D. thetidis	–	4	2	7	–	3	1	–
UROLOPHIDAE		*Trygonoptera testaceus*	4	1	–	1	–	–	–	–
		Urolophus bucculentus	–	–	–	–	–	12	7	2
		U. paucimaculatus	–	–	–	–	1	2	–	–
		U. sufflavus	1	–	–	–	2	12	9	5
		U. viridis	–	–	–	–	–	12	12	7
MYLIOBATIDIDAE		*Myliobatis australis*	–	2	–	–	–	–	–	–
MURAENOSOCIDAE		*Oxyconger leptognathus*	1	–	–	–	–	–	–	–
	#	*Muraenesox cinereus*	2	–	–	–	–	–	–	–
CONGRIDAE		*Conger verreauxi*	–	–	–	1	–	–	–	–
		Gnathophis sp.	10	5	7	12	10	10	12	12
		Poeciloconger kapala	–	–	–	–	–	–	1	–
	#	*Uroconger lepturus*	2	12	6	4	–	–	1	–
OPHICHTHIDAE		*Ophisurus serpens*	–	–	–	2	–	–	–	–
CLUPEIDAE		*Etrumeus teres*	–	–	–	3	–	–	–	2
	*	*Sardinops sagax neopilchardus*	–	2	6	1	–	–	–	–
ENGRAULIDIDAE		*Engraulis australis*	–	–	–	–	–	–	–	2
ARGENTINIDAE		*Argentina australiae*	–	–	–	–	–	–	–	3
AULOPIDAE		*Aulopus purpurissatus*	–	4	1	–	2	1	4	12
HARPADONTIDAE		*Saurida filamentosa*	12	5	7	6	11	4	11	8
CHLOROPHTHALMIDAE		*Chlorophthalmus nigripinnis*	–	–	–	–	–	–	–	1
GONORYNCHIDAE		*Gonorynchus greyi*	–	4	5	–	7	10	11	10
PLOTOSIDAE		*Euristhmus lepturus*	–	–	1	–	–	–	–	–
LOPHIIDAE		*Lophiomus setigerus*	–	2	1	5	–	1	–	2
ANTENNARIIDAE		*Antennarius striatus*	5	2	1	2	4	–	–	5
		Kuiterichthys furcipilis	–	–	–	–	–	–	–	1
OGCOCEPHALIDAE		*Halieutaea brevicauda*	–	–	–	–	–	1	–	8
MORIDAE		*Pseudophycis breviuscula*	10	12	12	12	6	6	5	11
OPHIDIIDAE		*Neobythites* sp.	–	1	8	4	–	–	1	3
		Ophidion sp.	–	–	–	1	–	–	–	–
BELONIDAE		*Ablennes hians*	–	–	–	–	1	–	–	2
TRACHICHTHYIDAE		*Aulotrachichthys novaezelandiae*	–	–	–	–	1	2	–	–
		Optivus sp.	10	1	–	5	1	2	–	–
BERYCIDAE	*	*Centroberyx affinis*	4	10	8	10	12	7	8	5
MONOCENTRIDIDAE		*Cleidopus gloriamaris*	–	6	–	–	–	–	1	–
HOLOCENTRIDAE		*Ostichthys kaianus*	4	1	–	3	2	–	–	1
ZEIDAE	*	*Zeus faber*	10	8	12	9	5	5	9	12
CAPROIDAE		*Antigonia rhomboidea*	1	2	–	2	–	–	–	2
		A. rubicunda	9	–	–	–	1	–	2	–

Appendix 3(d) (continued)

	Area:	Newcastle				Tuncurry			
	Survey:	I	II	III	IV	I	II	III	IV
VELIFERIDAE	*Velifer multiradiatus*	–	–	–	–	1	–	–	–
FISTULARIIDAE	*Fistularia petimba*	–	–	–	–	10	4	1	2
MACRORAMPHOSIDAE	*Macroramphosus scolopax*	–	–	–	2	12	12	12	12
SCORPAENIDAE	* *Helicolenus percoides*	2	1	–	7	–	–	1	2
	Maxillicosta whitleyi	4	1	–	1	12	6	5	11
	Neosebastes incisipinnis	–	–	1	1	6	2	3	11
TRIGLIDAE	* *Chelidonichthys kumu*	–	2	1	1	2	6	3	5
	Lepidotrigla argus	12	12	12	12	8	7	8	12
	L. grandis	–	–	–	–	–	–	1	1
	L. mulhalli	–	–	–	4	12	12	12	10
	L. papilio	3	–	–	3	–	–	–	1
	* *Pterygotrigla polyommata*	1	–	–	–	–	5	–	–
PLATYCEPHALIDAE	* *Platycephalus fuscus*	5	1	–	1	–	–	–	–
	* *P. caeruleopunctatus*	9	3	1	–	3	–	–	–
	P. longispinis	2	1	2	–	–	–	–	–
	* *P. marmoratus*	1	–	–	–	8	6	5	9
	* *P. richardsoni*	8	12	11	12	12	12	12	12
	Ratabulus diversidens	2	8	10	12	5	11	11	12
HOPLICHTHYIDAE	*Hoplichthys ogilbyi*	–	–	–	–	–	–	1	–
DACTYLOPTERIDAE	*Dactyloptena orientalis*	–	–	–	–	1	–	–	–
SERRANIDAE	*Ellerkeldia macculochi*	–	–	–	1	–	–	–	–
	* *Epinephelus ergastularius*	1	9	5	2	1	–	1	–
PRIACANTHIDAE	*Cookeolus japonicus*	–	–	–	–	2	1	–	1
	Priacanthus macracanthus	5	–	1	–	3	–	1	1
	Priacanthus sp.2	–	–	–	–	–	–	–	3
	Priacanthus sp.3	–	–	–	–	–	–	–	1
	# *Pristigenys niphonia*	–	–	–	–	–	–	–	3
APOGONIDAE	*Siphamia cephalotes*	–	–	1	–	–	–	–	–
ACROPOMATIDAE	*Apogonops anomalus*	–	12	12	2	1	–	1	–
SILLAGINIDAE	* *Sillago bassensis*	12	10	10	12	12	6	9	10
BRANCHIOSTEGIDAE	* *Branchiostegus wardi*	10	9	10	10	–	–	–	–
CARANGIDAE	# *Carangoides equula*	–	–	–	–	1	–	8	4
	Decapterus macrosoma	–	–	–	–	–	–	–	4
	* *Pseudocaranx dentex*	3	–	–	–	–	–	–	–
	Trachurus declivis	5	1	–	–	4	5	7	11
	T. novaezelandiae	11	12	12	12	8	4	1	5
	# *Uraspis uraspis*	–	–	–	1	–	–	–	–
CORYPHAENIDAE	* *Coryphaena hippurus*	–	–	–	–	–	–	1	–
NEMIPTERIDAE	*Nemipterus theodorei*	1	–	–	1	–	–	–	–
SPARIDAE	* *Allotaius spariformes*	–	1	–	1	11	2	9	11
	* *Pagrus auratus*	5	–	–	–	–	–	–	–
SCIAENIDAE	* *Argyrosomus hololepidotus*	–	–	–	–	1	–	–	–
MULLIDAE	* *Upeneichthys lineatus*	5	–	–	4	2	–	2	1
SCORPIDIDAE	*Atypichthys strigatus*	7	1	2	–	4	–	–	–
ENOPLOSIDAE	*Enoplosus armatus*	3	–	–	–	–	–	–	–
PENTACEROTIDAE	* *Paristiopterus labiosus*	–	–	–	–	–	1	–	–
	Zanclistius elevatus	3	1	–	1	1	2	–	–
CHEILODACTYLIDAE	* *Nemadactylus douglasii*	–	–	–	–	1	4	–	–
CEPOLIDAE	*Cepola australis*	5	1	3	7	–	–	–	–
SPHYRAENIDAE	*Sphyraena africana*	–	–	1	–	–	4	5	–
PINGUIPEDIDAE	*Parapercis allporti*	3	2	6	1	–	–	–	–
	P. binivirgata	3	3	4	2	–	–	–	–
	P. macrophthalma	2	1	2	–	–	–	–	–
	Parapercis sp.nov.	4	4	4	8	4	1	4	–
URANOSCOPIDAE	*Gnathagnus innotabilis*	–	–	4	1	–	–	–	–
	Uranoscopus sp.1	4	5	8	11	–	–	–	–

Appendix 3(d): (continued)

		Area: Newcastle				Tuncurry			
	Survey:	I	II	III	IV	I	II	III	IV
CHAMPSODONTIDAE	*Champsodon* sp.	5	6	8	11	–	–	1	–
CALLIONYMIDAE	*C. moretonensis*	–	–	3	–	–	–	10	–
	Repomucenus calcaratus	1	–	–	–	–	–	–	–
	Synchiropus calauropomus	2	4	1	2	–	–	–	–
GOBIIDAE	*Oxyurichthys* sp.	1	–	–	–	–	–	–	–
TRICHIURIDAE	*Lepidotus caudatus* (juv.)	–	–	1	–	–	–	–	–
	* *Trichiurus lepturus*	1	2	3	8	–	1	–	–
SCOMBRIDAE	* *Scomber australasicus*	–	2	–	6	–	–	12	–
BOTHIDAE	*Lophonectes gallus*	12	12	12	12	12	12	12	12
PARALICHTHYIDAE	* *Pseudorhombus arsius*	10	–	3	–	–	–	–	–
	* *P. tenuirastrum*	2	1	1	–	3	5	8	5
PLEURONECTIDAE	*Plagiopsetta glossa*	–	–	–	–	–	1	–	–
SOLEIDAE	*Aseraggodes macleayanus*	11	4	3	–	–	–	–	–
MONACANTHIDAE	* *Eubalichthys mosaicus*	1	–	1	–	–	1	2	1
	* *Meuschenia scaber*	1	1	–	–	–	–	–	–
	* *Nelusetta ayraudi*	2	–	–	–	–	1	–	5
	Thamnaconus harpargyreus	–	–	–	–	–	–	5	4
OSTRACIIDAE	*Anoplocapros robustus*	3	3	5	–	2	9	10	–
	Lactoria diaphana	–	–	1	–	–	–	–	–
	Trioris reipublicae	–	–	–	–	–	–	–	1
TETRAODONTIDAE	*Canthigaster callisterna*	1	–	–	–	–	–	–	–
	Lagocephalus cheesemani	–	–	–	3	5	–	3	5
	L. inermis	–	–	–	–	–	–	–	1
	Sphoeroides pachygaster	–	–	–	–	–	8	–	1
	Torquigener altipinnis	–	–	–	3	–	–	–	–
DIODONTIDAE	*Allomycterus pilatus*	–	–	–	–	–	4	4	–
	Diodon holocanthus	–	–	–	–	–	–	1	1

Appendix 4: List of crustaceans and cephalopods identified in catches during Surveys I to IV. The data indicate the percentage of total tows on each ground in which the species was recorded: 1= < 25%; 2 = 25–49%; 3 = 50–74%; 4 = 75–99%; 5 = 100%). (BH=Brunswick Heads; CR=Clarence River; T=Tuncurry; N=Newcastle; + Australian record; * NSW record.)

		INSHORE				OFFSHORE			
		BH	CR	T	N	BH	CR	T	N
CRUSTACEA									
STOMATOPODA									
HARPIOSQUILLIDAE									
Harpiosquilla melanoura		–	–	–	–	–	1	–	1
HEMISQUILLIDAE									
Hemisquilla ensigera australiensis		–	–	–	–	–	–	–	1
SQUILLIDAE									
Alima laevis		1	4	1	2	1	1	–	1
Anchisquilloides mcneilli		–	–	–	–	–	–	3	4
Kempina mikado		–	–	–	–	–	–	–	1
+*Lenisquilla lata*		–	–	–	–	–	–	–	1
**Lophosquilla costata*		–	1	–	–	–	–	–	–
**Oratosquilla gonypetes*		–	–	–	–	–	1	–	–
+*Oratosquilla imperialis*		–	–	–	–	–	2	1	0
Oratosquilla woodmasoni		1	–	–	–	–	–	–	1
LYSIOSQUILLIDAE									
Lysiosquilla sp. nov.		–	–	–	–	1	–	1	1
DECAPODA: PENAEIDEA									
SOLENOCERIDAE									
Solenocera choprai	Ridgeback prawn	–	–	–	–	–	–	4	4
Solenocera sp.		–	–	–	–	1	3	2	2
PENAEIDAE									
Metapenaeopsis mogiensis	Velvet prawn	–	–	–	–	2	–	–	–
M. novaeguineae	Velvet prawn	–	–	–	–	–	2	3	–
M. cf *wellsi*	Velvet prawn	–	–	–	–	–	–	1	–
Metapenaeus bennettae	Greasy back prawn	–	1	–	–	–	–	–	–
M. macleayi	School prawn	3	4	2	3	–	–	–	–
Parapenaeus australiensis	Racek prawn	–	–	–	–	–	–	–	3
?*Parapenaeus* sp.	Slender prawn	–	–	–	–	–	–	1	3
Penaeus esculentis	Tiger prawn	1	1	1	–	1	–	–	1
P. merguiensis	Banana prawn	1	1	–	–	–	–	–	–
P. monodon	Leader prawn	–	1	–	–	–	–	–	–
P. plebejus	King prawn	1	2	1	2	5	5	5	5
Trachypenaeus curvirostris	Hard-back prawn	1	3	1	2	4	5	1	1
SICYONIDAE									
Sicyonia cristata	Ridgeback rock prawn	–	–	–	–	1	–	–	–
DECAPODA: CARIDEA									
PANDALIDAE									
Plesionika spinipes	Redstriped carid prawn	–	–	–	–	–	1	1	1
Plesionika ortmani	Carid prawn	–	–	–	–	–	1	1	4
DECAPODA: PALINURA									
PALINURIDAE									
Jasus verreauxii	Eastern rock lobster	–	1	–	–	–	1	–	1
Linuparus trigonus	Barking lobster	–	–	–	–	–	–	–	1
SCYLLARIDAE									
Ibacus brucei	Red (Bruce's) bug	–	–	–	–	–	–	1	–
Ibacus peronii	Balmain bug	1	1	–	1	2	1	1	–
Ibacus sp.nov.	Smooth bug	–	1	–	–	4	5	4	2
Scyllaris sordidus		–	–	–	–	–	–	1	1
DECAPODA: BRACHYURA									
CALAPPIDAE									
Calappa lophus		–	–	–	–	1	1	–	–
C. philargius		–	1	–	–	1	1	–	–
Matuta planipes		2	1	1	2	–	–	–	–
Mursia curtispina		–	–	–	–	–	–	2	–
CORYSTIDAE									
Jonas luteanus		–	–	–	–	–	1	–	–

Appendix 4: (continued)

		INSHORE				OFFSHORE			
		BH	CR	T	N	BH	CR	T	N
GONEPLACIDAE									
Carcinoplax meridionalis		–	–	–	–	–	–	–	1
Ommatocarcinus macgillivrayi		–	1	–	–	–	–	–	1
HOMOLIDAE									
Homola orientalis		–	–	–	–	–	–	–	3
LATREILLIDAE									
Latreilla philargium		–	–	–	–	–	–	2	–
LEUCOSIIDAE									
Arcania undecimspinosa		–	–	–	–	–	1	1	–
Philyra undecimspinosa		–	1	–	1	–	–	–	–
Randallia eburnea ?		–	–	–	–	–	–	1	–
MAJIDAE									
Hyastenus elatus		1	–	–	–	1	–	1	–
Leptomithrax waitei		–	–	–	–	–	–	1	–
Leptomithrax tuberculatus		–	–	–	–	1	1	1	3
Naxioides robillardi		–	–	–	–	–	–	1	2
PARTHENOPIDAE									
Eumedonus villosus		1	–	–	–	1	1	–	–
Parthenope longimanus		–	–	–	–	1	–	–	–
PORTUNIDAE									
Charybdis bimaculata		–	–	1	1	–	1	3	5
C. cruciata	Coral crab	2	1	1	1	1	1	1	1
C. miles		–	–	–	–	–	2	1	5
C. natator		1	1	1	–	2	1	–	–
C. orientalis		–	–	1	1	–	–	–	–
C. truncata		–	–	1	–	–	–	–	–
Lupocyclas sp.		–	–	–	–	–	1	–	–
Ovalipes australiensis	Two-spotted crab	1	1	3	4	–	–	–	–
O. molleri		–	–	–	–	–	–	1	–
Portunus argentatus		–	–	–	–	1	2	–	–
P. orbitosinus		–	1	–	–	1	–	–	–
P. pelagicus	Blue-swimmer crab	2	1	4	3	2	1	–	2
P. pubescens		–	–	1	–	–	–	–	–
P. rubromarginatus		4	2	–	–	4	2	–	–
P. sanguinolentus	Three-spotted crab	4	4	2	4	1	1	–	–
Scylla serrata	Mud crab	–	–	1	–	–	–	–	–
Thalamita sima		1	1	1	–	–	–	–	–
RANINIDAE									
Lyreidus tridentatus		–	–	–	–	–	1	–	4
Ranina ranina	Commercial spanner crab	2	1	1	–	–	1	–	–
XANTHIDAE									
Pilumnus sp.		–	–	–	–	–	–	–	1
MOLLUSCA									
CEPHALOPODA									
SEPIIDAE									
Sepia sp.	Cuttlefish	1	1	–	–	4	4	5	4
SEPIOLOIDIDAE									
Sepioloidea lineolata	Lined dumpling squid	1	1	–	–	3	1	–	1
LOLIGINIDAE									
Loligo chinensis	Broad squid	3	3	4	4	–	–	–	–
Loliolus noctiluca	Bottle squid	4	4	3	5	–	–	–	–
Loligo sp.	Slender squid	1	2	1	2	3	3	2	1
Loliolus noctiluca	Bottle squid	4	4	3	5	–	–	–	–
Sepioteuthis australis	Southern calamary	1	1	2	1	3	3	2	2
OMMASTREPHIDAE									
Nototodarus gouldi	Gould's (arrow) squid	–	–	–	1	1	2	4	2
OCTOPODIDAE									
Octopus maorum	Common octopus	1	1	–	–	1	1	1	1
Octopus sp.2	Plain octopus	2	1	2	1	4	4	1	1
Octopus sp.3	Long-armed octopus	1	–	–	–	1	1	2	1
Hapalochlaena fasciata	Blue-ringed octopus	–	–	–	1	–	–	–	–

Appendix 5: Operational and catch data for exploratory trawling conducted during Cruises 90-08 to 91-05.

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	Shot Time (mins)	King Prawn (kg)	Comm. Spp. (kg)	Trash (kg)
Brunswick Hds - Ballina										
900813	03-05-90	0105	28°23';153°50'	28°20';153°50'	74-75	135-137	80	0.8	15	60
900836	06-05-90	1910	29°00';153°49'	29°03';153°49'	83-85	152-156	60	0.2	10	75
901227	01-09-90	1830	28°25';153°50'	28°22';153°50'	84-92	153-165	60	23.0	15	40
901246	04-09-90	0015	28°24';153°50'	28°30';153°51'	75-85	137-156	120	3.0	30	70
910132	16-02-91	2050	28°27';153°50'	28°24';153°49'	65-75	118-138	60	-	5	70
Coffs Harbour										
900857	09-05-90	0010	30°29';153°21'	30°31';153°20'	76-83	140-152	60	28.0	26	120
901255	05-09-90	1645	32°22';153°24'	30°24';153°23'	75-82	137-150	60	-	30	120
910101	12-02-91	2215	30°33';153°19'	30°31';153°20'	77-81	140-148	60	-	20	135
Cape Hawke										
901001	05-06-90	0435	32°23';152°42'	32°20';152°44'	53-55	96-101	90	8.0	160	120
910501	07-04-91	0415	32°16';152°40'	32°13';152°41'	44-47	80-86	90	1.0	65	160
Newcastle										
901105	13-06-90	0400	32°56';152°02'	32°54';152°06'	60-62	109-114	75	23.0	6	27
Broken Bay										
901501	16-10-90	2045	33°38';151°28'	33°37';151°29'	41-42	73-77	30	0.2	25	33
901502	16-10-90	2155	33°35';151°29'	33°34';151°30'	36-38	65-70	30	0.3	65	55
901503	16-10-90	2300	33°33';151°29'	33°32';151°29'	31-32	56-59	30	0.1	50	70
901504	16-10-90	0010	33°32';151°28'	33°32';151°29'	30-31	54-57	30	0.1	45	95
901505	17-10-90	0115	33°34';151°28'	34°35';151°27'	30-33	54-61	30	0.1	70	60
901506	17-10-90	0210	33°37';151°28'	33°38';151°28'	36-40	65-73	30	0.1	40	60
Sydney										
901507	18-10-90	1950	33°46';151°28'	33°45';151°29'	64-66	117-121	30	-	20	45
901508	18-10-90	2055	33°44';151°30'	33°43';151°31'	64-65	117-119	30	-	30	75
901509	18-10-90	2155	33°42';151°31'	33°41';151°32'	66-67	120-123	30	-	50	35
Bate Bay										
901601	29-10-90	2010	34°02';151°19'	34°04';151°18'	68-71	124-130	30	0.1	44	50
901602	29-10-90	2220	34°04';151°19'	34°05';151°16'	68-69	124-126	30	0.2	46	30
901603	30-10-90	0135	34°06';151°14'	34°07';151°13'	61-65	111-119	30	0.1	23	35
901604*	30-10-90	0235	34°09';151°12'	34°10';151°12'	62-64	113-117	30	-	-	-
Shoalhaven Bight										
901605	30-10-90	2150	34°54';150°53'	34°53';150°53'	36-37	65-68	30	0.1	70	35
901606	30-10-90	2240	34°52';150°52'	32°52';150°52'	33-36	60-66	30	0.1	55	30
901607	30-10-90	2340	34°52';150°50'	34°53';150°50'	24-28	43-51	30	-	105	40
901608	31-10-90	0035	34°52';150°49'	34°51';150°49'	21-23	38-42	30	0.1	80	35
901609	31-10-90	0130	34°51';150°49'	34°49';150°49'	20-21	36-39	30	0.1	85	65
901610	31-10-90	0225	34°49';150°49'	34°50';150°48'	18-19	32-35	30	0.2	110	50

* muddy catch; not sorted

Appendix 6: List of fish and invertebrate species caught during exploratory trawling off Brunswick Heads and Ballina (BH), Coffs Harbour (CHb), Cape Hawke (CHk), Broken Bay (BB), Sydney and Bate Bay (Syd) and Shoalhaven Bight (SB). The data show the number of tows from which each species was recorded. (+ Australian record; # NSW record.)

		BH	CHb	CHk	New	BB	Syd	SB
	Total no. of tows:	5	3	2	1	6	6	6
	Depth range (m):	118–165	137–152	80–101	109–114	54–77	111–130	32–68
HEXANCHIDAE	+ *Hexanchus nakamurai*	1	–	–	–	–	–	–
HETERODONTIDAE	*Heterodontus portusjacksoni*	–	–	–	–	5	2	5
ORECTOLOBIDAE	*Orectolobus maculatus*	–	–	1	–	1	–	–
	Parascyllium collare	2	3	1	–	–	–	2
SCYLIORHINIDAE	*Asymbolus* sp.	2	2	1	–	1	3	2
	Galeus boardmani	1	3	–	–	–	–	–
TRIAKIDAE	*Mustelus antarcticus*	3	1	1	–	2	4	1
CARCHARHINIDAE	*Carcharhinus altimus*	1	–	–	–	–	–	–
SQUALIDAE	*Squalus megalops*	2	3	–	–	–	4	–
	S. mitsukurii	–	1	–	–	–	–	–
PRISTIOPHORIDAE	*Pristiophorus* sp.	–	1	–	–	–	4	–
SQUATINIDAE	*Squatina australis*	–	–	–	–	–	–	3
	Squatina sp.	–	2	–	–	1	–	1
RHINOBATIDAE	*Aptychotrema rostrata*	–	–	1	1	–	1	–
	Trygonorrina sp.	–	–	–	–	1	–	5
TORPEDINIDAE	*Hypnos monopterygium*	1	–	–	–	2	–	1
	Narcine tasmaniensis	–	3	–	–	–	2	–
RAJIDAE	*Raja polyommata*	4	–	–	–	–	–	–
	Raja australis	2	1	2	–	2	6	3
DASYATIDIDAE	*Dasyatis thetidis*	–	–	–	–	1	–	–
UROLOPHIDAE	*Trygonoptera testaceus*	–	–	–	–	2	–	3
	Urolophus bucculentus	1	1	–	1	1	1	4
	Urolophus paucimaculatus	–	–	–	–	4	–	4
	Urolophus sufflavus	3	2	1	1	3	3	1
	Urolophus viridis	3	3	1	–	–	6	1
	Urolophus sp.	–	–	–	–	2	–	2
MYLIOBATIDIDAE	*Myliobatis australis*	–	–	–	–	–	–	1
CONGRIDAE	*Gnathophis* sp.	4	1	2	–	6	3	6
	Poeciloconger kapala	1	–	–	–	–	–	–
AULOPIDAE	*Aulopus curtirostris*	4	3	–	–	–	–	–
	Aulopus purpurissatus	1	–	1	–	3	–	–
HARPADONTIDAE	*Saurida filamentosa*	3	–	–	1	–	–	–
CHLOROPHTHALMIDAE	*Chlorophthalmus nigripinnis*	–	1	–	–	–	5	–
GONORYNCHIDAE	*Gonorynchus greyi*	4	3	2	–	5	–	3
LOPHIIDAE	*Lophiomus setigerus*	2	1	–	–	–	–	–
OGCOCEPHALIDAE	*Halieutaea brevicauda*	2	2	–	–	–	–	–
MORIDAE	*Austrophycis* sp.	2	–	–	–	–	–	–
	Physiculus therosideros	1	–	–	–	–	–	–
	Pseudophycis breviuscula	1	1	1	1	2	4	–
OPHIDIIDAE	*Neobythites* sp.	1	1	–	–	–	–	–
	Ophidion sp.	4	–	–	–	–	–	–
	Sirembo sp.	4	–	–	–	–	–	–
MACROURIDAE	*Coelorinchus mirus*	–	3	–	–	–	–	–
TRACHICHTHYIDAE	*Aulotrachichthys novaezelandiae*	3	2	–	–	–	–	–
	Optivus sp.nov.	–	–	1	–	3	–	3
BERYCIDAE	*Centroberyx affinis*	2	–	2	1	6	6	5
HOLOCENTRIDAE	*Ostichthys* sp.	1	–	–	–	–	–	–
ZEIDAE	*Zenopsis nebulosus*	–	1	–	–	–	–	–
	Zeus faber	–	–	2	–	3	6	5
CAPROIDAE	*Antigonia rubicunda*	5	1	–	1	–	–	–
VELIFERIDAE	*Velifer multiradiatus*	2	–	1	–	–	–	–
FISTULARIIDAE	*Fistularia petimba*	2	1	1	–	–	–	–
MACRORAMPHOSIDAE	*Macroramphosus gracilis*	4	2	–	–	–	–	1
	M. scolopax	3	3	2	–	–	6	2

Appendix 6: (continued)

		BH	CHb	CHk	New	BB	Syd	SB
	Total no. of shots:	5	3	2	1	6	6	6
	Depth range (m):	118–165	137–152	80–101	109–114	54–77	111–130	32–68
SYNGNATHIDAE	*Solegnathus spinosissimus*	–	–	–	–	2	–	–
SCORPAENIDAE	# *Ebosia bleekeri*	4	–	–	–	–	–	–
	Helicolenus percoides	–	–	1	–	–	6	–
	Maxillicosta whitleyi	–	–	1	–	6	–	5
	Neosebastes incisipinnis	4	3	1	–	1	–	–
	Scorpaena cardinalis	–	–	–	–	1	–	–
TRIGLIDAE	*Chelidonichthys kumu*	4	2	1	–	3	–	5
	Lepidotrigla argus	5	–	2	–	6	–	6
	Ledidotrigla grandis	2	3	–	–	–	2	–
	Lepidotrigla modesta	1	–	1	–	–	3	–
	Lepidotrigla mulhalli	–	2	1	1	1	6	3
	Lepidotrigla papilio	–	–	–	–	–	–	3
	Lepidotrigla sp.	–	–	–	–	–	1	–
	Pterygotrigla picta	2	2	–	–	–	–	–
	Ptrygotrigla polyommata	–	–	–	–	–	–	1
PLATYCEPHALIDAE	*Platycephalus caeruleopunctatus*	–	–	1	–	5	–	3
	Platycephalus longispinis	–	–	1	–	–	–	4
	Platycephalus marmoratus	–	–	2	–	–	–	4
	Platycephalus richardsoni	–	2	2	1	6	6	6
	Ratabulus diversidens	4	3	2	–	4	–	–
HOPLICHTHYIDAE	*Hoplichthys ogilbyi*	–	1	–	–	–	2	–
DACTYLOPTERIDAE	*Dactyloptena papilio*	1	–	–	–	–	–	–
SERRANIDAE	*Epinephelus ergastularius*	1	–	–	–	2	–	–
	Lepidoperca pulchella	1	–	1	–	–	–	–
BANJOSIDAE	*Banjos banjos*	1	1	–	–	–	–	–
PRIACANTHIDAE	*Cookeolus boops*	2	1	–	–	–	–	–
ACROPOMATIDAE	*Apogonops anomalus*	1	1	–	1	6	6	–
SILLAGINIDAE	*Sillago bassensis*	–	–	1	–	6	–	6
BRANCHIOSTEGIDAE	*Branchiostegus serratus*	–	–	–	–	–	1	–
CARANGIDAE	*Pseudocaranx dentex*		–	–	1	–	1	––
	Trachurus declivis	1	1	2	–	5	2	5
	Trachurus novaezelandiae	–	–	–	1	6	–	3
EMMELICHTHYIDAE	*Emmelichthys struhsakeri*	2	–	–	–	–	–	–
NEMIPTERIDAE	*Nemipterus theodorei*		1	–	–	–	–	––
SPARIDAE	*Allotaius spariformes*	3	3	–	–	–	2	–
	Pagrus auratus	2	–	1	–	1	–	2
MULLIDAE	*Upeneichthys lineatus*	–	–	1	–	–	–	–
SCORPIDIDAE	*Atypichthys strigatus*	–	–	–	–	1	–	–
PENTACEROTIDAE	*Paristiopterus labiosus*	–	–	1	–	–	–	1
	Zanclistius elevatus	–	–	1	–	–	–	1
POMACENTRIDAE	*Chromis abyssicola*	3	–	–	–	–	–	–
CHEILODACTYLIDAE	*Nemadactylus douglasii*	1	–	1	–	4	–	–
SPHYRAENIDAE	*Sphyraena africana*	–	–	1	–	–	–	–
LABRIDAE	*Bodianus vulpinus*	1	–	–	–	–	–	–
PINGUIPEDIDAE	*Parapercis allporti*	–	1	1	1	–	6	–
	Parapercis binivirgata	1	–	–	–	–	–	–
	Parapercis macrophthalma	1	–	–	–	–	–	–
URANOSCOPIDAE	*Gnathagnus innotabilis*	–	–	–	1	–	4	–
	Kathetostoma laeve	–	–	–	–	5	1	3
	Uranoscopus sp.3	1	–	–	–	–	–	–
CHAMPSODONTIDAE	*Champsodon* sp.	–	–	–	1	–	–	–
CALLIONYMIDAE	*Callionymus calcaratus*	–	–	–	–	2	–	–
	Callionymus moretonensis	3	1	–	–	–	2	–
	Synchiropus calauropomus	–	–	1	–	6	–	–
GEMPYLIDAE	*Rexea antefurcata*	1	–	–	–	–	–	–
	R. solandri	–	3	–	–	–	–	–
SCOMBRIDAE	*Scomber australasicus*	–	–	1	–	–	–	–

Appendix 6: (continued)

	Total no. of tows: Depth range (m):	BH 5 118–165	CHb 3 137–152	CHk 2 80–101	New 1 109–114	BB 6 54–77	Syd 6 111–130	SB 6 32–68
CENTROLOPHIDAE	*Seriolella brama*	-	-	-	-	1	3	6
	S. punctata	-	-	-	-	2	2	6
BOTHIDAE	*Lophonectes gallus*	1	2	2	1	6	6	6
PARALICHTHYIDAE	*Pseudorhombus arsius*	-	-	-	-	2	-	-
	P. jenynsii	-	-	-	-	-	-	4
	P. tenuirastrum	-	-	1	-	5	-	6
PLEURONECTIDAE	*Ammotretis rostratus*	-	-	-	-	-	-	1
	Aseraggodes macleayanus	-	-	-	-	4	-	-
	Plagiopsetta glossa	4	1	-	-	-	-	-
	Zebrias fasciatus	-	-	-	-	4	-	4
MONACANTHIDAE	*Meuschenia freycineti*	-	-	-	-	-	-	2
	M. scaber	-	-	1	-	3	-	-
	M. trachylepis	1	-	-	-	-	-	2
	Nelusetta ayraudi	-	-	2	-	4	-	2
	Thamnaconus tesselatus	1	-	-	-	-	-	-
OSTRACIIDAE	*Anoplocapros robustus*	-	1	2	-	4	-	4
	Kentrocapros flavofasciatus	3	2	-	-	-	-	-
TETRAODONTIDAE	*Canthigaster callisterna*	-	-	1	-	-	-	-
	Lagocephalus cheesemani	2	-	1	-	-	-	-
	Sphoeroides pachygaster	3	3	-	1	-	1	-
DIODONTIDAE	*Allomycterus pilatus*	-	1	1	1	-	3	2
CRUSTACEA								
HARPIOSQUILLIDAE	# *Harpiosquilla annandalei*	-	-	-	-	1	-	-
HEMISQUILLIDAE	*Hemisquilla ensigera australiensis*	-	-	-	-	-	-	2
SQUILLIDAE	*Anchisquilloides mcneilli*	-	-	-	1	1	6	1
	Kempina mikado	-	-	-	1	-	3	-
	Lenisquilla lata	-	-	-	-	-	1	-
SOLENOCERIDAE	*Solenocera choprai*	2	-	-	1	-	1	-
PENAEIDAE	*Parapenaeus australiensis*	-	-	-	1	-	4	-
	?*Parapenaeus* sp.	-	-	-	1	-	-	-
	Penaeus plebejus	4	2	2	1	6	1	5
	Trachypenaeus curvirostris	-	-	-	-	3	-	-
PANDALIDAE	*Plesionika spinipes*	2	2	-	-	-	-	-
SCYLLARIDAE	*Ibacus brucei*	3	2	-	-	-	-	-
	Ibacus peronii	-	-	1	-	5	5	2
	Ibacus sp.nov.	2	1	2	-	4	5	2
	Scyllaris sordidus	-	-	-	-	1	-	-
CALAPPIDAE	*Mursia curtispina*	-	-	-	1	-	4	-
GONEPLACIDAE	*Carcinoplax meridionalis*	-	-	-	-	-	2	-
	?*Psopheticus* sp.	-	-	-	1	-	-	-
LEUCOSIDAE	*Arcania undecimspinosa*	-	-	-	-	-	4	-
MAJIDAE	*Leptomithrax waitei*	-	3	-	1	1	3	-
	Leptomithrax tuberculatus	-	-	-	-	5	-	-
	Naxioides robillardi	-	-	-	-	1	-	-
PORTUNIDAE	*Charybdis bimaculata*	-	-	-	1	5	5	4
	Charybdis miles	-	-	-	1	4	-	-
RANINIDAE	*Lyreidus tridentatus*	-	-	-	1	-	5	2
CEPHALOPODA								
SEPIIDAE	*Sepia* sp.	5	3	2	1	6	6	6
LOLIGINIDAE	*Loligo* sp.	2	-	-	-	-	-	-
	Sepioteuthis australis	4	-	2	-	6	1	3
OMMASTREPHIDAE	*Nototodarus gouldi*	2	3	2	1	6	6	4
OCTOPODIDAE	*Octopus maorum*	2	-	-	-	3	-	-
	Octopus sp.1	-	-	-	-	2	1	-
	Octopus sp.3	2	-	-	-	-	-	-

APPENDIX K

Preliminary report on the the by-catch of prawn trawling in the Clarence River and Lake Wooloweyah.

NSW Fisheries, Internal publication, 1992.

Kennelly, S.J. and G.W. Liggins.

Preliminary Report

The by-catch of prawn trawling in the Clarence River and Lake Wooloweyah

S.J. Kennelly & G.W. Liggins

NSW Fisheries

July, 1992

1.0 Introduction

This brief, preliminary report has been compiled so that some information from the Prawn-trawl By-catch project may be incorporated into the production of the Northern Rivers project report by July, 1992. Whilst the Prawn-trawl By-catch project began well after the Northern Rivers project and was not actually part of it, the results and research done during the past 3 years by the Prawn trawl By-catch team are clearly relevant and of interest to the same audience, particularly the fishers of the Clarence estuary.

1.1 The Prawn trawl by-catch project

In late 1989, we began our survey of the catches and by-catches of the estuarine prawn trawlers operating in Botany Bay, Port Jackson, the Hawkesbury and Clarence Rivers and Lake Woolooweyah. We also surveyed the oceanic prawn trawlers working out of the ports of Port Stephens, Coffs Harbour, Yamba/Iluka and Ballina. The aim of this work was to quantify the catches and by-catches of these prawn fleets to fill our void in the data on these aspects of the NSW prawn fisheries and so complete the first logical step in the eventual provision of management recommendations for these fisheries.

We would like to take this opportunity to acknowledge most sincerely the excellent co-operation that we have experienced with the prawn trawl fishers of NSW in doing this research. Quite simply, without their help over the past 3 years, we could not have done this work nor be in a position to present the data that is contained in this preliminary report. At the recent International Conference on Bycatch in the Shrimp Industry (held in Florida), the following point was made many times by fishermen, scientists and managers from around the world: that the NSW prawn trawl by-catch research project has enjoyed a level of industry-participation and good-will, the equal of any such project in the world. We believe that this conclusion from this very high-level conference speaks volumes for the attitude and courtesy of NSW's prawn trawlers.

Fig. 1 shows the north coast of NSW, encompassing the range of the prawn trawl fisheries in the state. These fisheries mainly target two species, the eastern king prawn (*Penaeus plebejus*) at night and the eastern school prawn (*Metapenaeus macleayi*) during the day. Estuarine prawn trawling occurs in 5 estuaries in NSW, mainly during the summer period. Oceanic prawn trawling occurs out of 11 ports along the coast in all seasons.

This preliminary report concerns an initial examination of the data generated by our sampling of the catch and by-catch of estuarine prawn trawling in the Clarence River and Lake Woolooweyah.

1.2 Previous studies

Glaister (1977), reporting on the "Clarence River school prawn study", listed 59 species of fish sampled by prawn trawl and beam trawl. While no quantitative description of the by-catch was presented, the species of commercial/recreational value that he reported as being most common were, in the river: yellowfin bream, jewfish and estuarine perch and, in Lake Woolooweyah: yellowfin bream, mullet and flathead.

An unpublished study of the by-catch in the Clarence River over the 1984-85 and 1985-86 seasons by John Virgona (NSW Fisheries) found that the most common by-catch species, of commercial/recreational value were yellowfin bream, tailor, sea mullet and tarwhine.

2.0 Methodology

2.1 Field sampling

In each month that prawn trawling has occurred since late 1989, we have attempted to place scientists aboard trawlers on 4 randomly-selected boat-trips on each of the Clarence River and Lake Woolooweyah. During these trips, the catch and by-catch from each tow were placed on the sorting tray and then sorted by the crew and our scientist, separating the various species. The weights of prawns from each tow were also recorded using scales during the first 3 months of the project, after which time our scientists estimated these weights based on the number and fractions of fish boxes of prawns that were caught in each tow. This was necessary as fishers wanted to ice their prawns as soon as possible and, in the hot summer weather of the district, weighing prawns with scales could have affected the quality of the trawler's product. All by-catch species of commercial and recreational importance were counted weighed and measured. Non-commercial species were counted. For each tow, we also recorded the time, duration, location of the tow, as well as the basic gear configuration used.

2.2 Calculation of catch and by-catch rates

Because boat-trips were randomly sampled each month, average catch rates and variances were calculated per month from replicate boat-trips rather than "replicate" tows. Whilst the latter method would have provided greater replication (and probably smaller variances), one cannot assume that individual tows were independent - in fact, usual fishing practices indicate the opposite. Further, estimates of effort by fleets (used in extrapolating by-catch rates to whole fleets) are only available in units of fisherman-days (boat-trips).

2.3 Calculation of total month/season catches and by-catches by the fleet

The catch rates per trip (and associated variances) for the river and lake for each month/season can be extrapolated to estimate catches by whole fleets for each location in each month/season using the total numbers of boat-trips done by the fleet (using rules for the derivation of standard errors of combination estimates, e.g. Mood, Graybill and Boes, 1974; Myers and Shelton, 1980). These estimates of trawling effort are available in NSW via reports that fishers are legally required to submit on a monthly basis. Whilst such effort data may be inaccurate due to many reasons (e.g. incorrect completion of forms by fishers and/or incomplete or inaccurate data entry), they are the best available.

As this effort data does not discriminate between effort on the river and lake, we assume that, during those months that trawling takes place in both locations (Dec-May), effort is split as 75% on the river and 25% in the lake.

To take into account these potential inaccuracies we assume that these data on fishing effort are accurate to within 10% of the true figure (i.e. standard error to mean ratio = 10%). This is effectively saying that we are 95% confident that the true effort was within +/- 20% of the estimate that we have available.

3.0 Results

3.1 Catch and by-catch rates

Figure 2.1 summarises the catch rates of prawns by trawlers fishing the river and lake in the 1989-90, 1990-91 and 1991-92 seasons. These catch rates are based on the total weight of prawns caught during a fishing trip (fisherman-day) and includes retained and riddled (discarded) prawns.

Figures 2.2 and 2.3 show the catch rates of combined by-catch species by weight and by number of individuals respectively. Figure 2.4 is equivalent to Figure 2.3 but only includes species of commercial/recreational value.

Figures 2.5 - 2.12 summarise the by-catch rates of bream, jewfish, tailor, dusky flathead, sand whiting, large-toothed flounder, sea mullet and tarwhine. A list of all species taken as by-catch on the river and lake over the 3 years of the survey is contained in Table 1.

It is also possible (although not presented in this report) to calculate catch per unit time (rather than catch per fisherman-day). Figure 3 shows trawl time per trip during for each month sampled in the river and lake. Because trawl-time per trip does not appear to be consistent between months, catch per unit time should be a more accurate means for comparing relative abundances of species across time and/or location, whilst catch per fisherman-day is the most appropriate figure to use in estimating monthly and seasonal catches by the fleet.

3.2 Extrapolation to total month/season catches and by-catches by the fleet

Fishing effort (number of fisherman-days) on the river and lake in the 1989-90 and 1990-91 seasons is shown in Figure 4. The source of these estimates was described in section 2.3. Because of a time-lag between the collection of the monthly catch returns and the entry of this data onto computer, no effort data is available for the 1991-92 season as yet.

For both the river and the lake, we have extrapolated monthly catch rates to total catches where we have a minimum of 3 sampled fishing trips in that month. These monthly total catches are then combined to give an estimate of the total catch or by-catch of a species or category of species across these months. These estimates are contained in the "Sampled months" columns of Table 2.1 and Table 2.2 (River and Lake respectively). If we assume that the sampled months are representative of all months in the season, then our combined estimate (across sampled months) can be further extrapolated to cover the whole season by multiplying by the factor: effort in whole season / effort in sampled months. These estimates are contained in the "Whole season" columns of Table 2.1 and Table 2.2.

3.3 Length-frequency distributions of by-catch species

Figures 5.1 - 5.8 summarise the relative length-frequencies of key species (bream, jewfish, tailor, dusky flathead, sand whiting, large-toothed flounder, sea mullet and tarwhine) for the 1989-90 and 1990-91 seasons in the river and lake. To generate each length-frequency plot, monthly size-frequency distributions were combined across the season after being weighted by the factor, monthly effort / no. sample trips. Accordingly, the distributions reflect the relative quantities of each size-class taken by the fleet across those months that were sampled. This was not possible for the 1991-92 season.

4.0 Discussion

Studies such as ours often assume that all discarded by-catch dies as a result of the trauma associated with capture, removal from the water and handling. Whilst our study has not examined the fate of discards, those few studies that have considered the mortality of such by-catch have concluded that a small but variable proportion of the by-catch survives. Survival of the "by-catch experience" depends on species-specific vulnerabilities, operational factors (soak time, sorting time) and the time of exposure on deck. Of particular relevance to our Clarence survey was the observation by Hyland (1985) on prawn trawlers in Moreton Bay that yellowfin bream swam actively when returned to the water. Our own observations have been mixed: for example, it does appear common for bream to swim more actively when returned to the water than jewfish. However, we also know from aquaculture research that it is not uncommon for even the most carefully-handled juvenile snapper and mulloway to die 2-3 weeks after any form of handling.

Even if all the juvenile finfish discarded by prawn trawlers die, this may mean very little to subsequent stocks of commercial and recreational fisheries for these species if most of these juveniles would have died of natural causes anyway (i.e. in the absence of prawn trawling). Only by incorporating estimates of the natural mortalities of by-catch species, their ages at legal size and our estimates of mortality due to prawn trawling, can we begin to estimate any causal effects of prawn trawl by-catch on subsequent stocks in fisheries for these species.

It is also clearly relevant to have some understanding of the relative proportion of the available biomass that by-caught species represent. For example, estimates of by-catches of particular species in particular areas that are in the order of hundreds of thousands of fish, may be negligible if the biomass of these fish in these places are orders of magnitude larger.

Despite these uncertainties however, we feel that the estimates of by-catches detected during our surveys indicate that it would be unwise not to explore ways of minimising the potentially deleterious effects of by-catch.

The catch rates derived from our study illustrate the utility of this type of data for the examination of temporal patterns in the magnitude of by-catch. Figures 2.2 - 2.12 and Tables 2.1 and 2.2 reveal that catch rates of principal commercial and recreational by-catch species vary markedly between species. Moreover, even within particular species there is considerable variability in the magnitude of by-catches across months and across years. Further, the pattern across months varies across years. There appear to be no obvious periods within the season when by-catch is consistently higher than at other times. This is an important observation to bear in mind if temporal closures are considered as a possible management option - if indeed it is considered that management is necessary. Of course, a different management option would involve a system of flexible closures in which access to the fishery is determined by ongoing monitoring of catch and by-catch.

On the completion of our study later this year, it will clearly be beneficial to compare the by-catches of the Clarence River and Lake Woolooweyah to the other surveyed locations. Our impressions of small/large by-catches of particular species (described in this report) may well be tempered by the scale of corresponding by-catches in other estuaries or on offshore grounds. Comparisons of by-catches on such spatial scales may identify "problem" estuaries / oceanic grounds or indeed problem areas within estuaries / oceanic grounds.

Experiments we have done in other locations (offshore and in the Hawkesbury River) suggest the potential utility of gear modifications in minimising negative aspects of prawn trawl by-catch. Data from these experiments and observations of different gears in other locations suggest that there is scope to reduce by-catch through the use of modified gears.

Fig. 1 - The range of prawn trawl fisheries in NSW and location of sample sites.

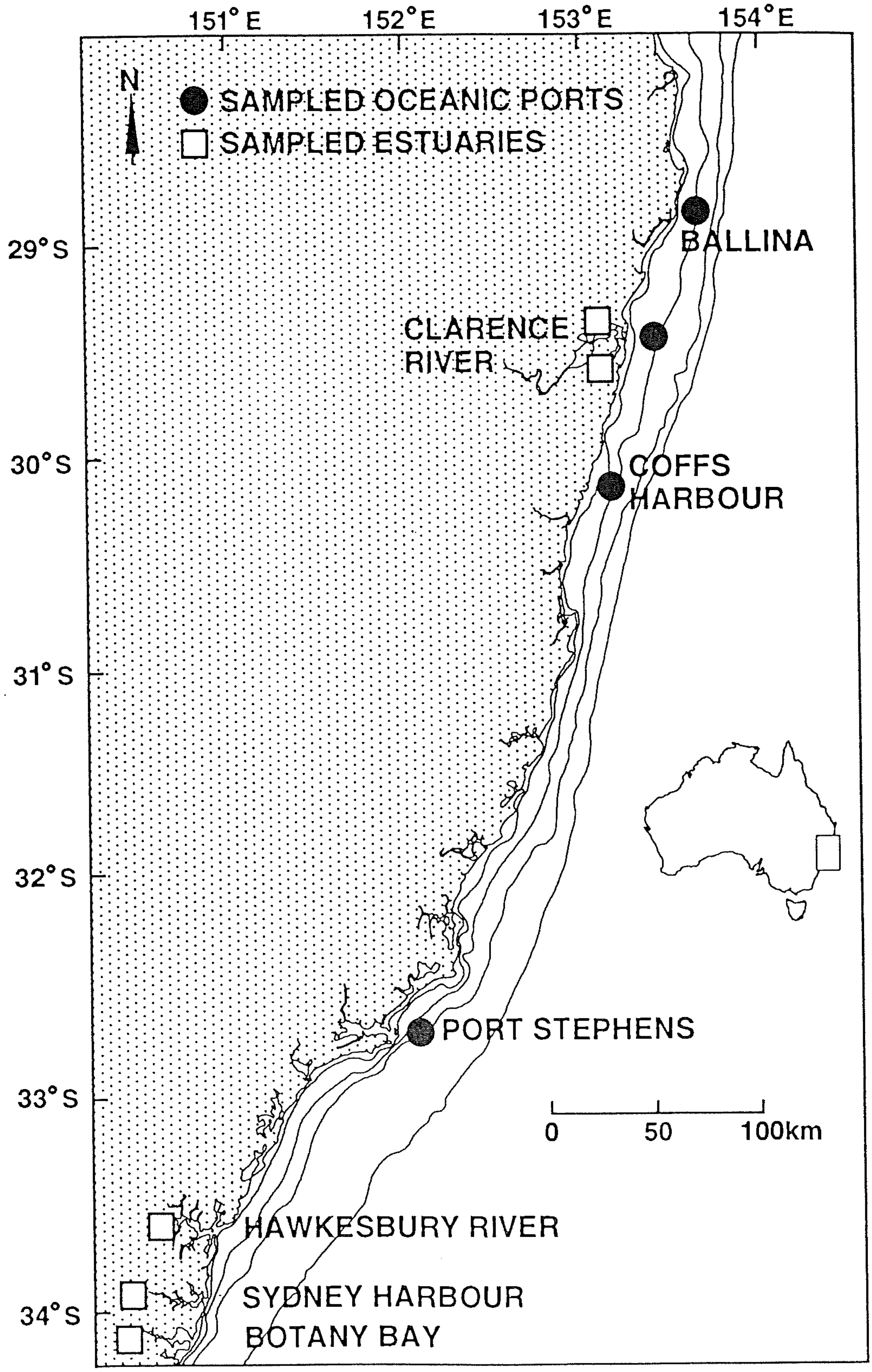


Fig. 2.1 Mean (+/-1se) catch of PRAWNS (kg.) per fisherman-day

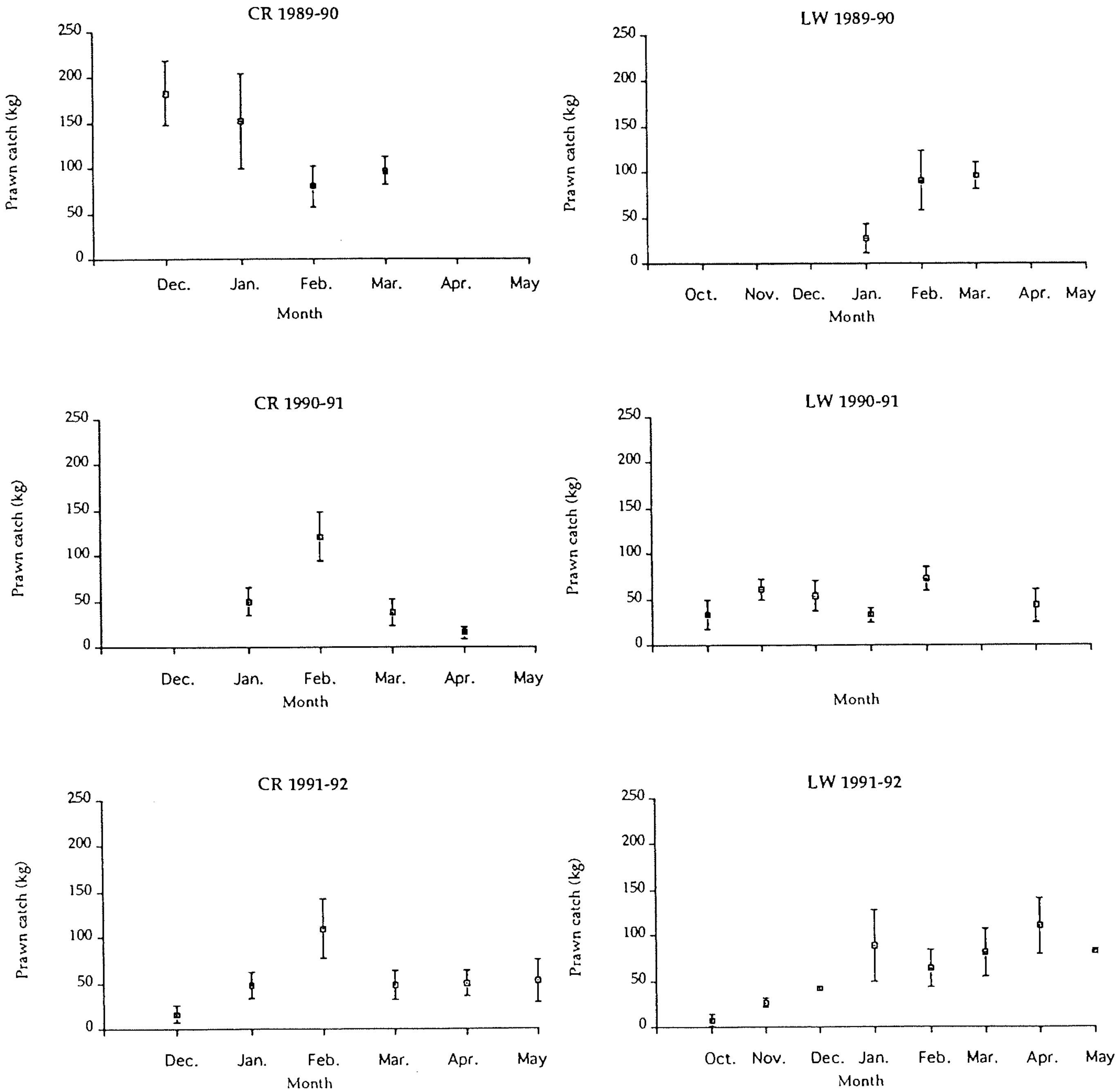


Fig. 2.3 Mean (+/-1se) TOTAL bycatch (no. individuals) per fisherman-day

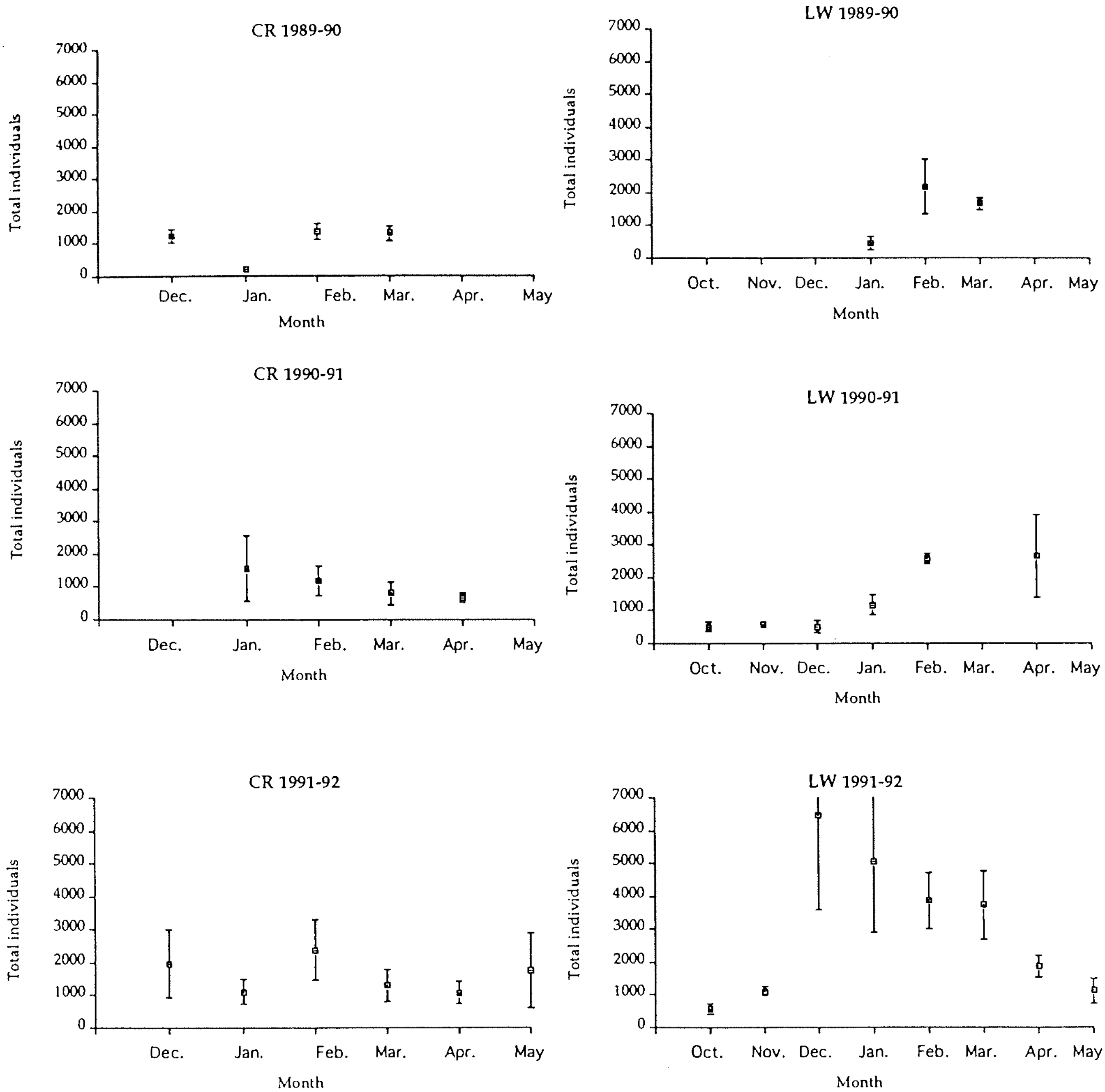


Fig. 2.4 Mean (+/-1se) bycatch of COMMERCIAL species (no. individuals) per fisherman-day

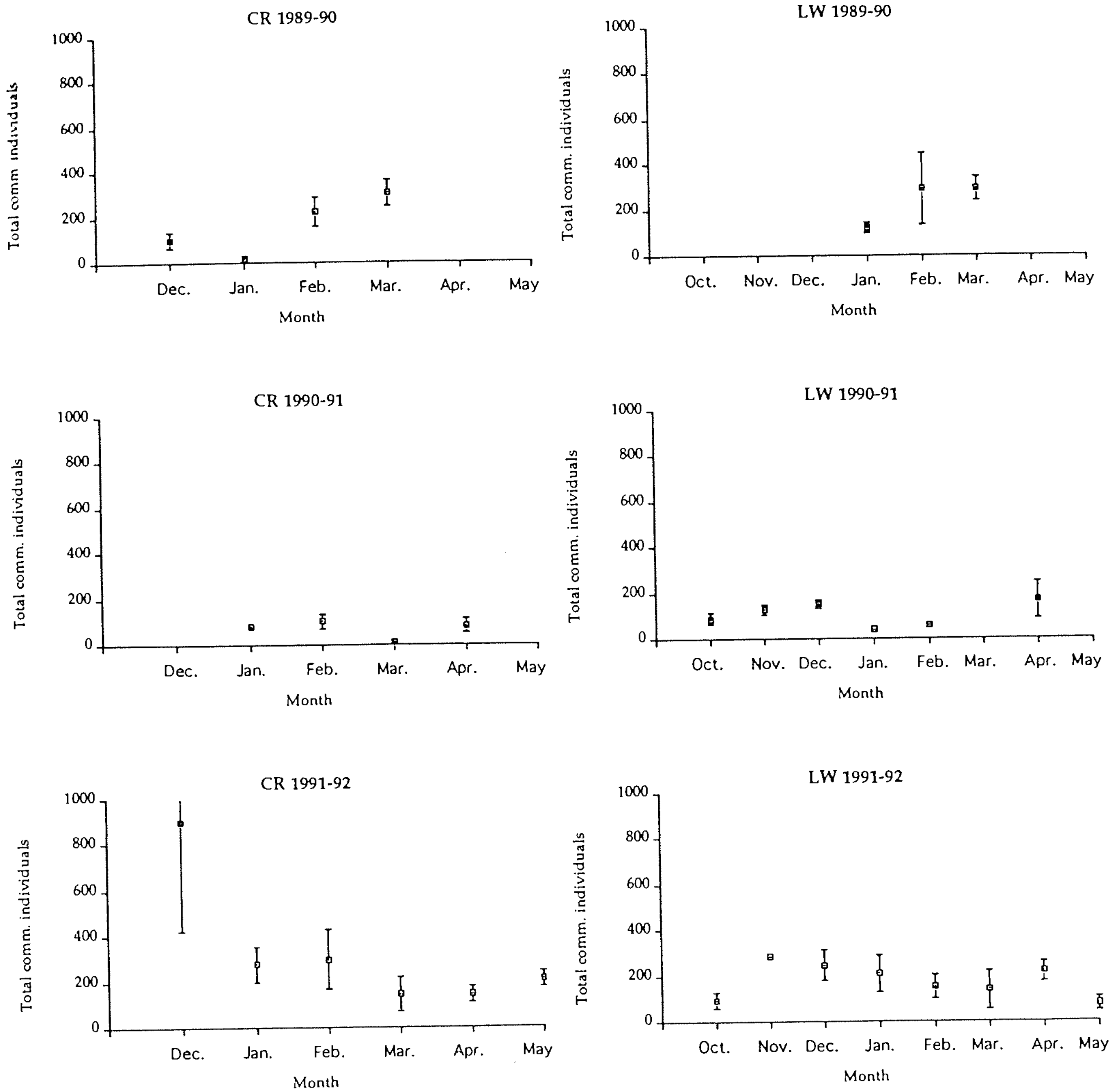


Fig. 2.5 Mean (+/-1se) bycatch of BREAM (no. individuals) per fisherman-day

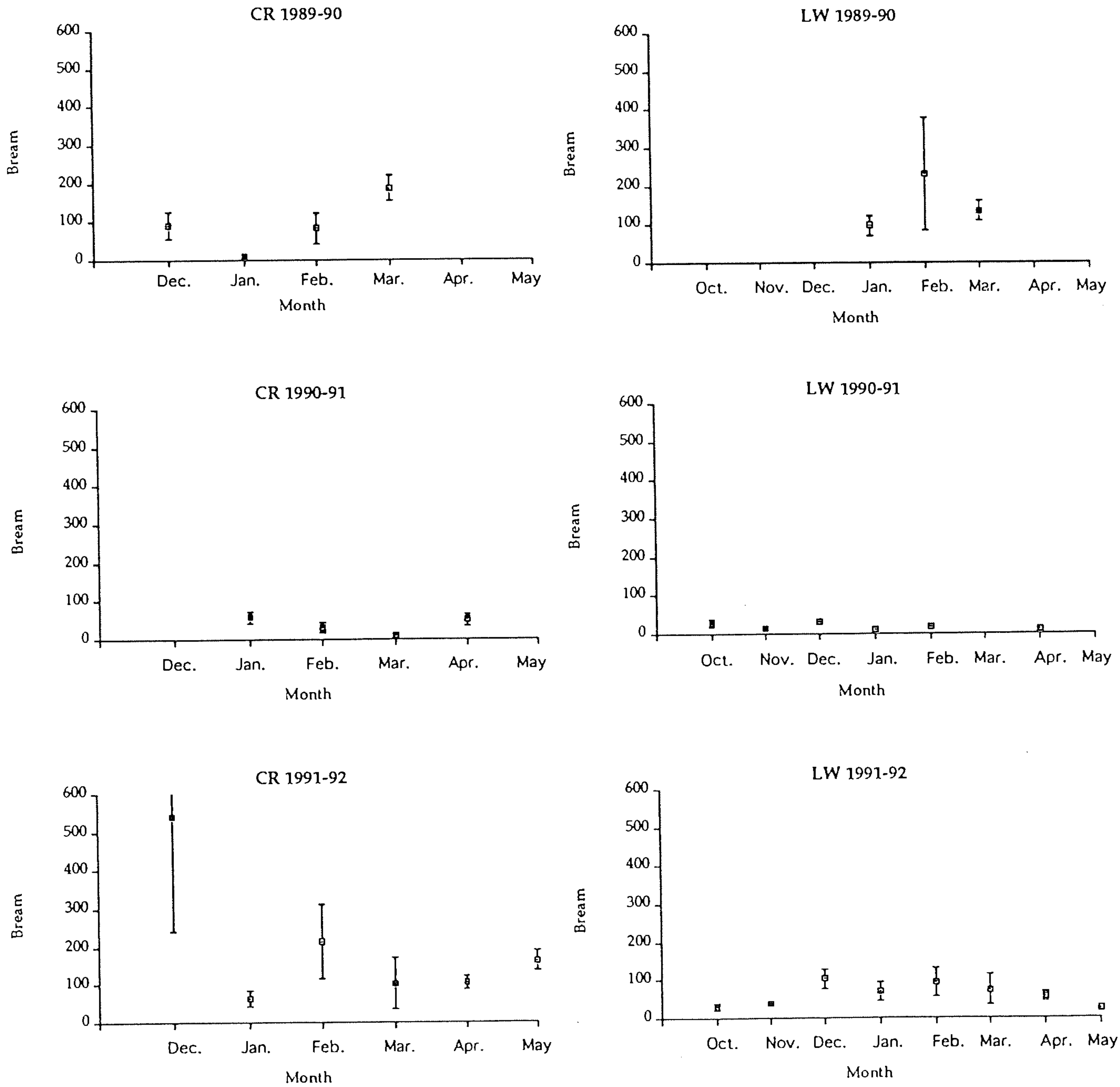


Fig. 2.6 Mean (+/-1se) bycatch of JEWFISH (no. individuals) per fisherman-day

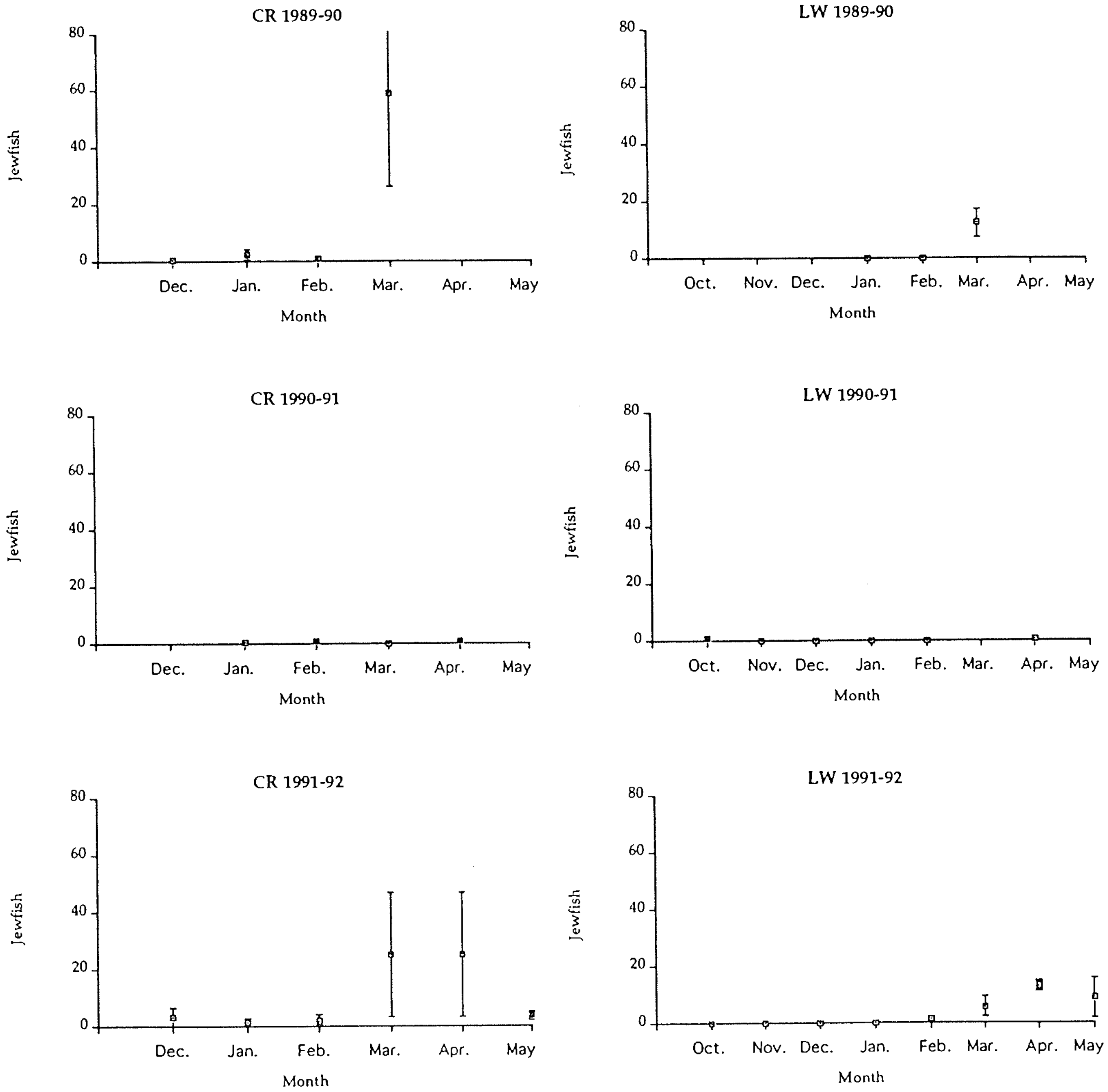


Fig. 2.7 Mean (+/-1se) bycatch of TAILOR (no. individuals) per fisherman-day

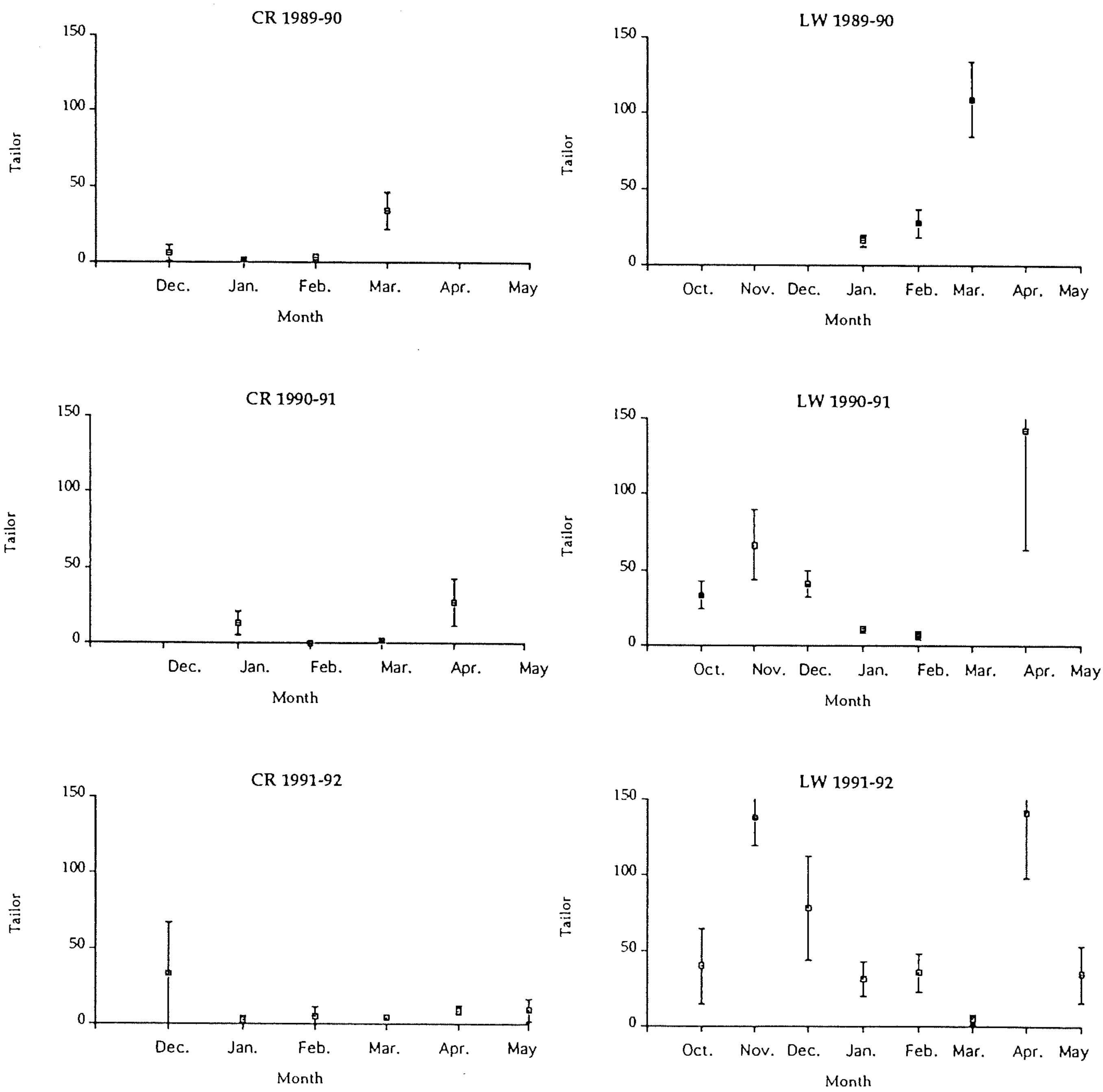


Fig. 2.8 Mean (+/-1se) bycatch of DUSKY FLATHEAD (no. individuals) per fisherman-day

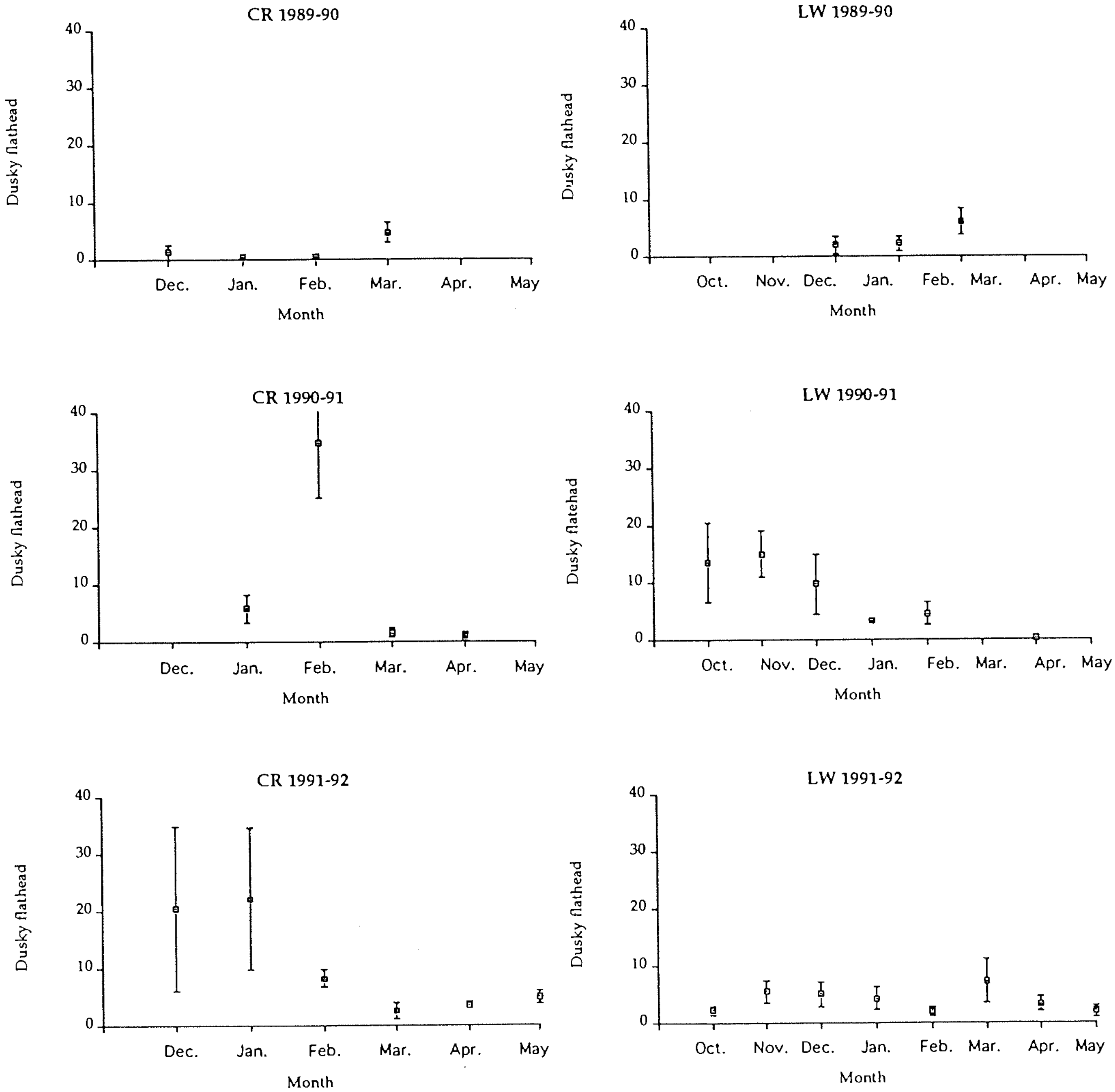


Fig. 2.9 Mean (+/-1se) bycatch of SAND WHITING (no. individuals) per fisherman-day

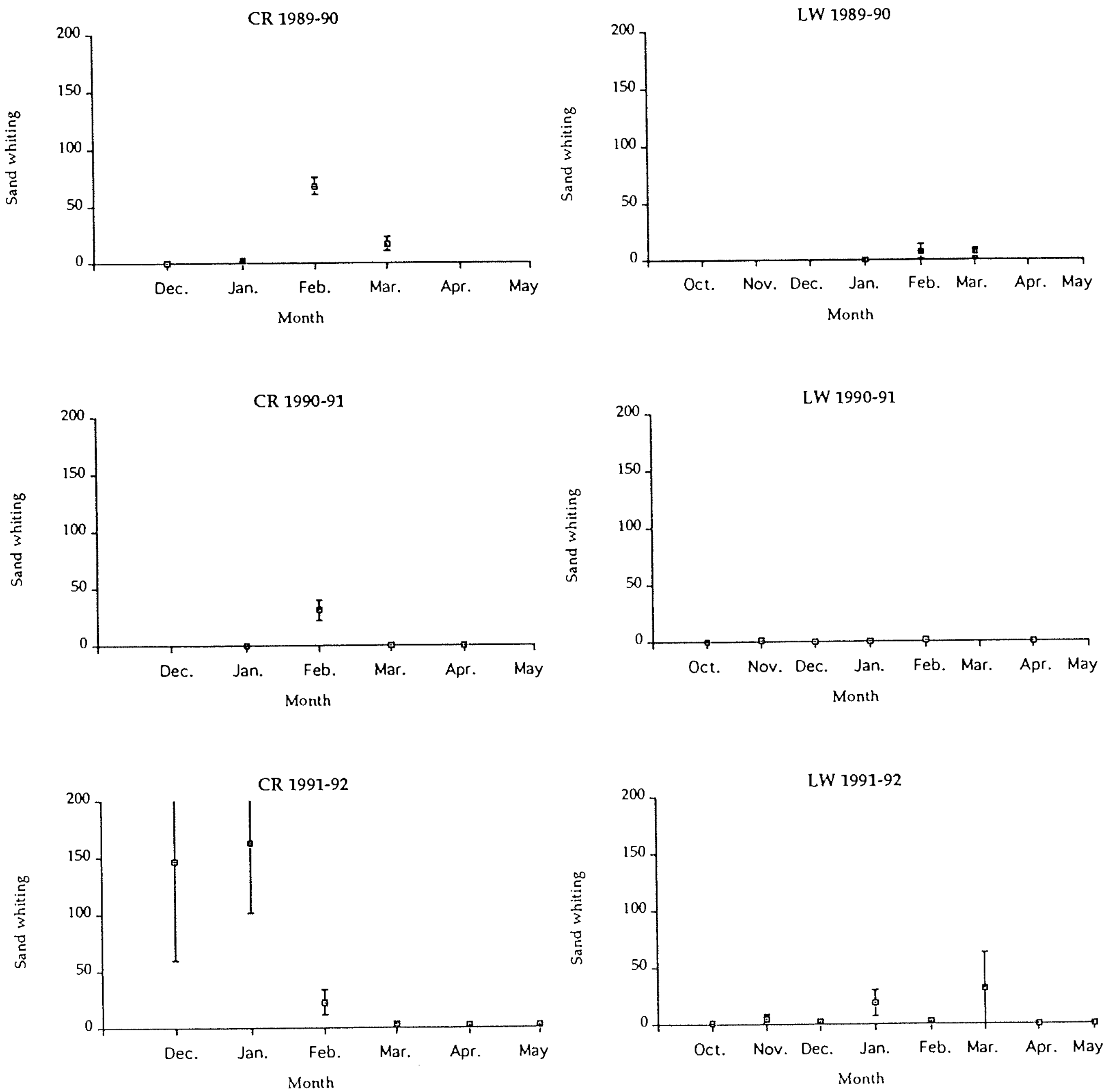


Fig. 2.10 Mean (+/-1se) bycatch of LARGE-TOOTHED FLOUNDER (no. individuals) per fisherman-day

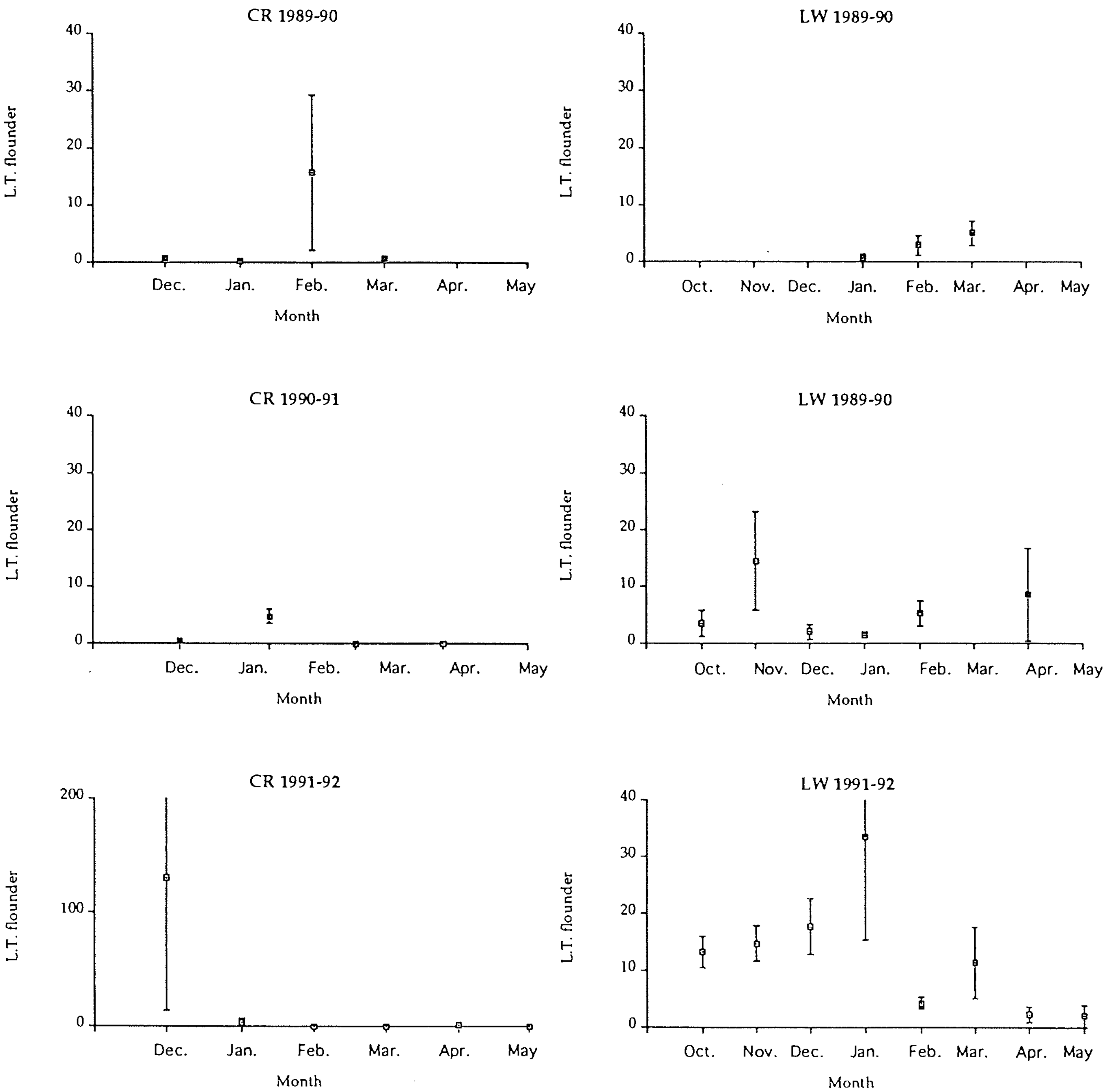


Fig. 2.11 Mean (+/-1se) bycatch of SEA MULLET (no. individuals) per fisherman-day

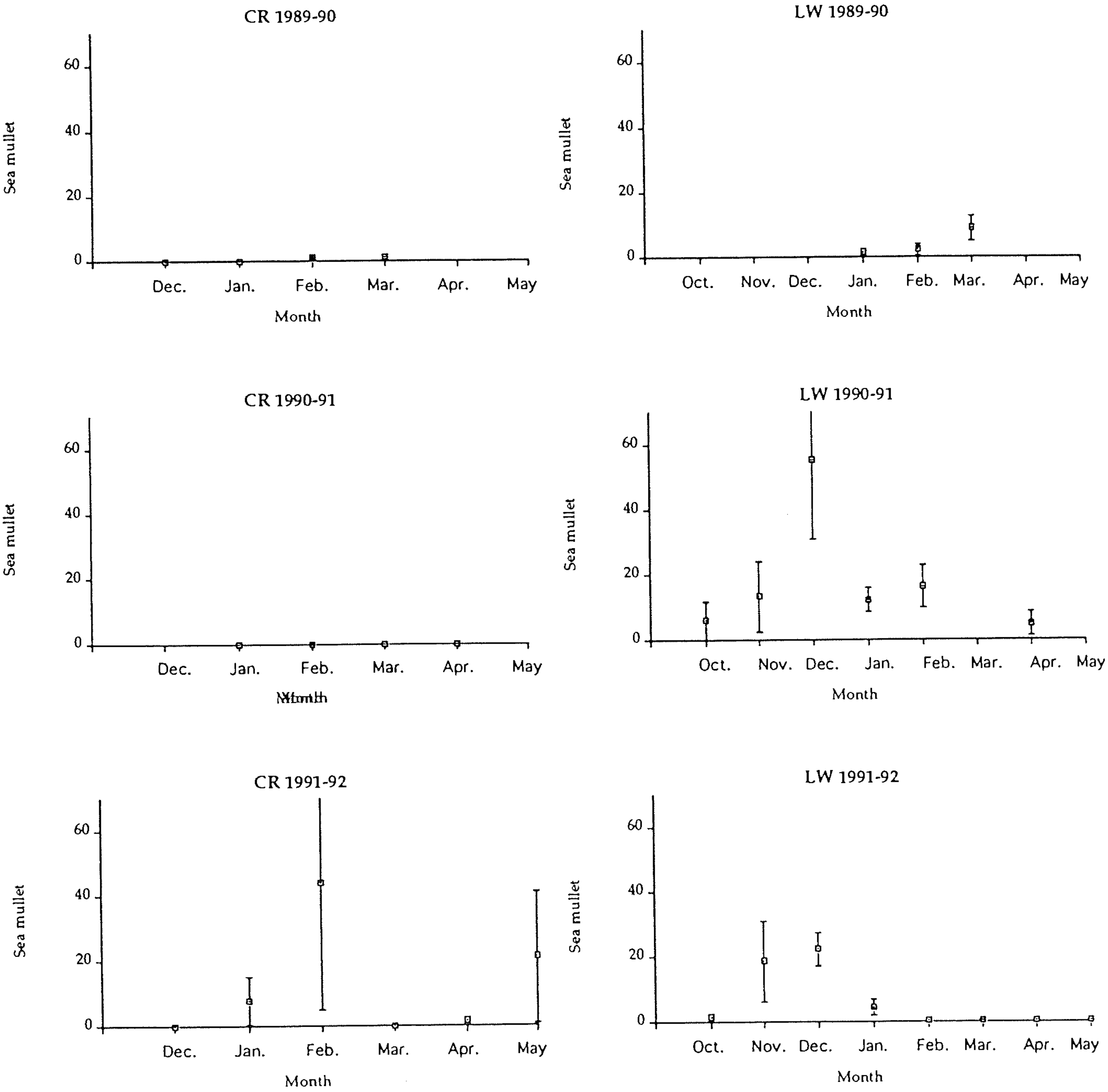


Fig. 2.12 Mean (+/-1se) bycatch of TARWHINE (no. individuals) per fisherman-day

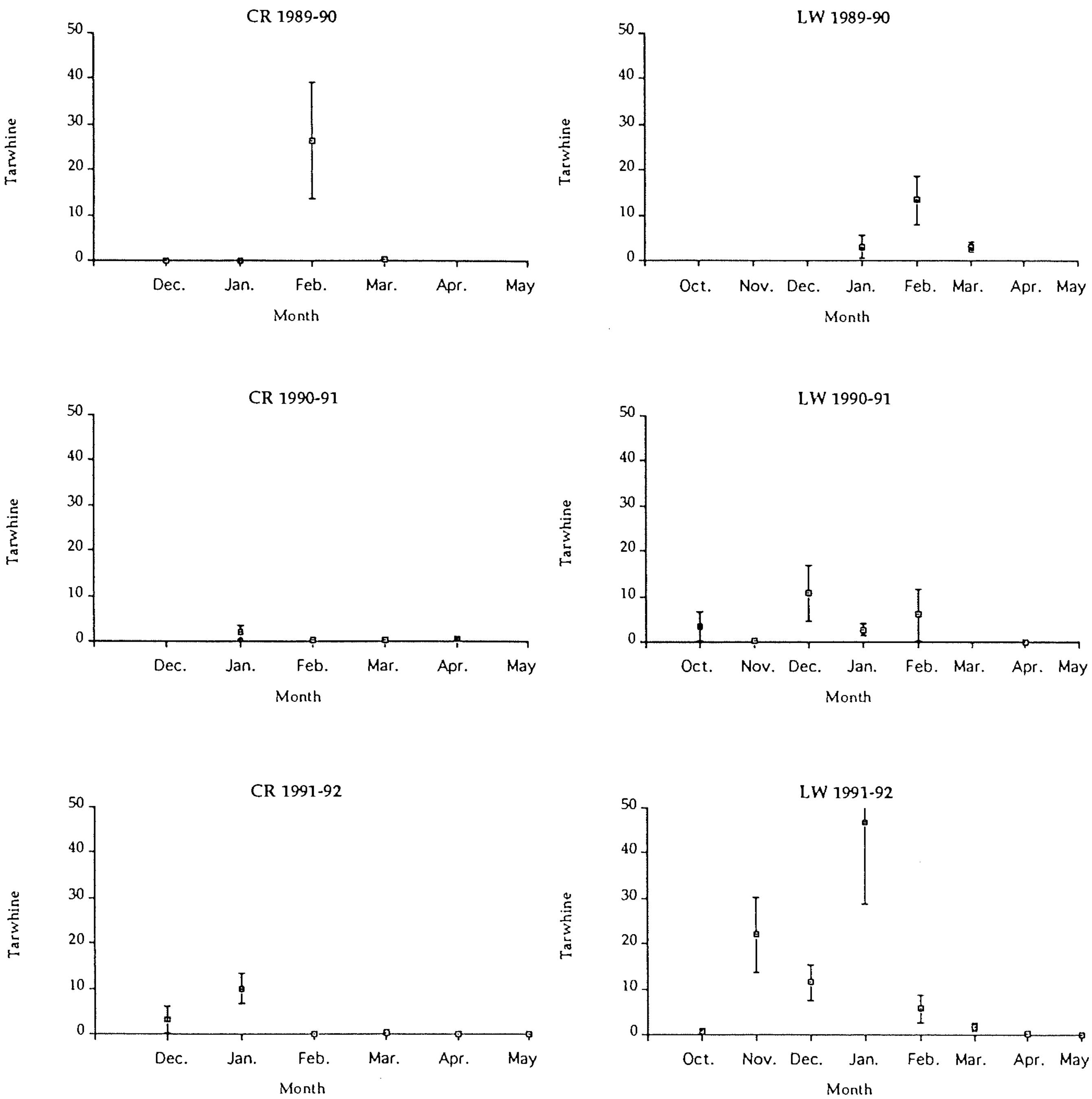


Fig. 3 Mean (+/-1se) TRAWL TIME (mins) per fisherman-day

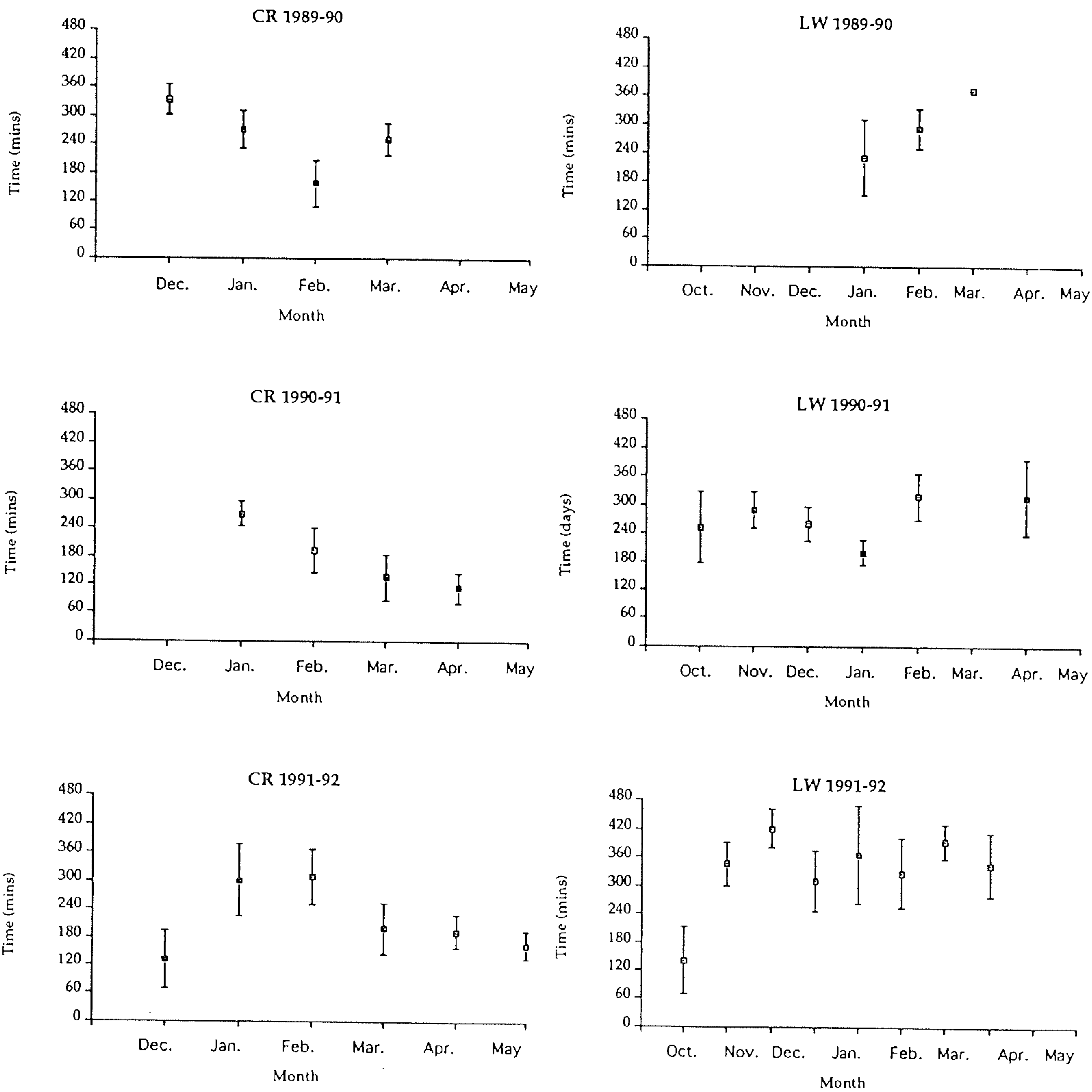
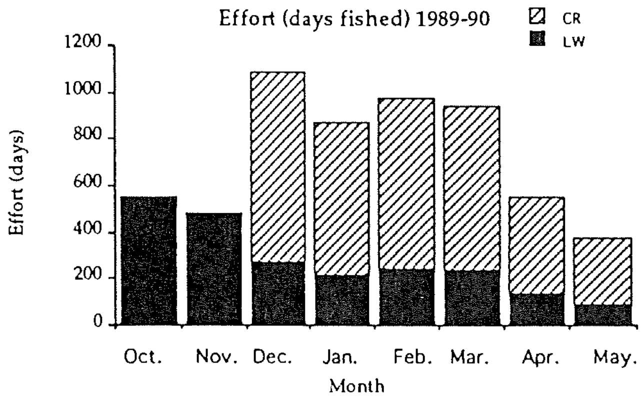
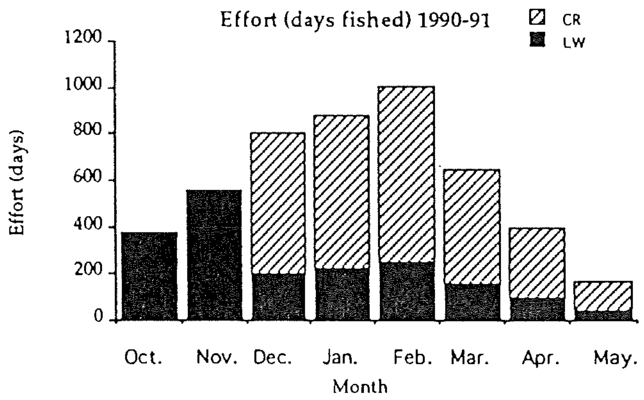


Fig. 4 EFFORT (fisherman-days)

[source: Fishermen's Catch Returns]

assumes 75%/25% split in effort between River/Lake in months Dec-May





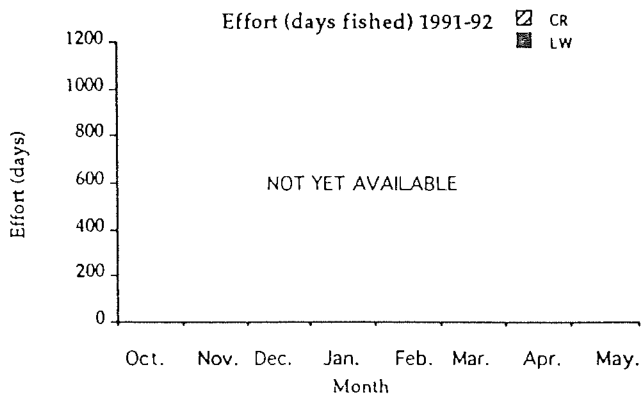


Fig. 5.1 Relative length-frequencies of BREAM bycatch

[0.5 cm bins]

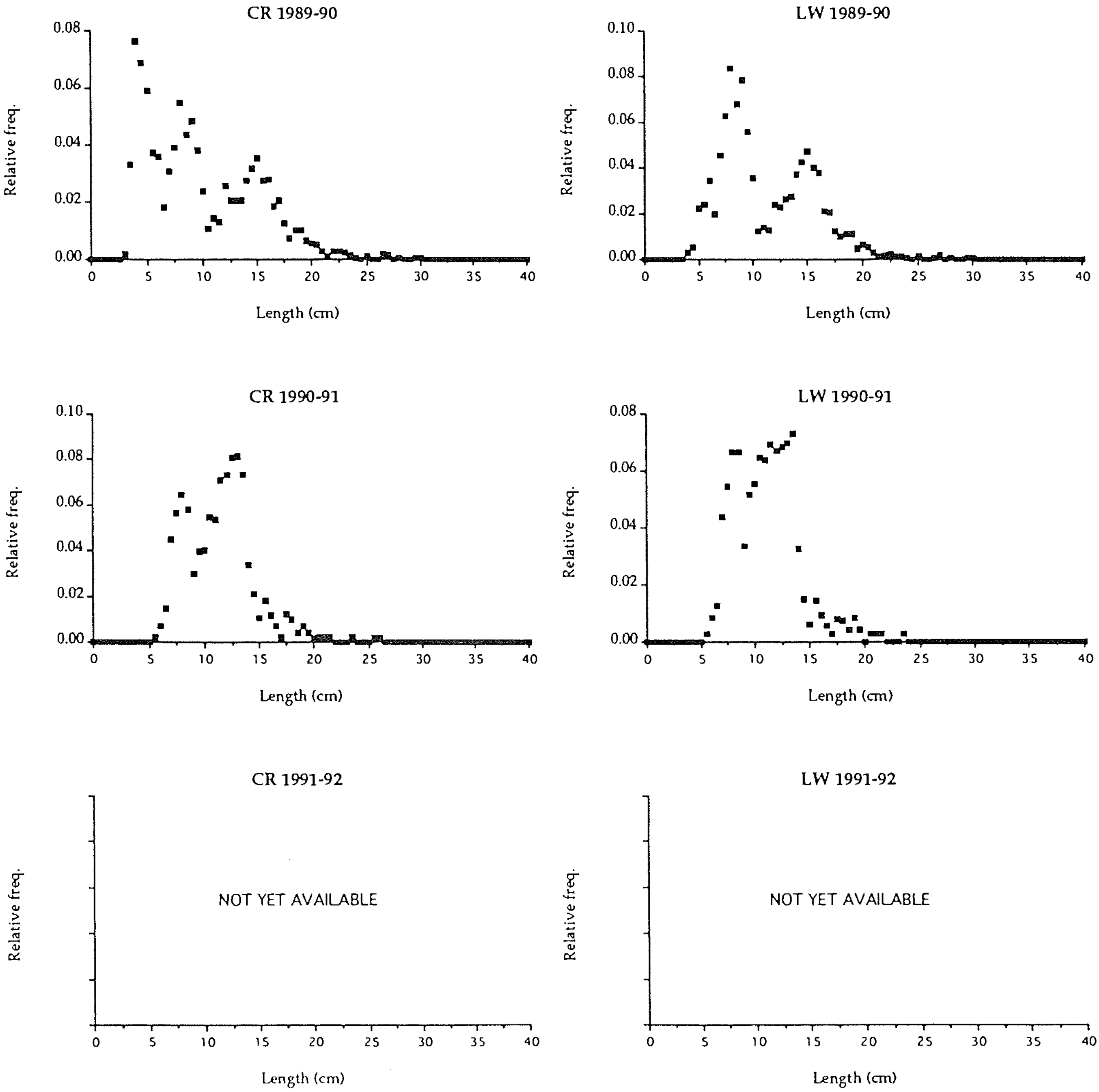


Fig. 5.2 Relative length-frequencies of JEWFISH bycatch

[0.5 cm bins]

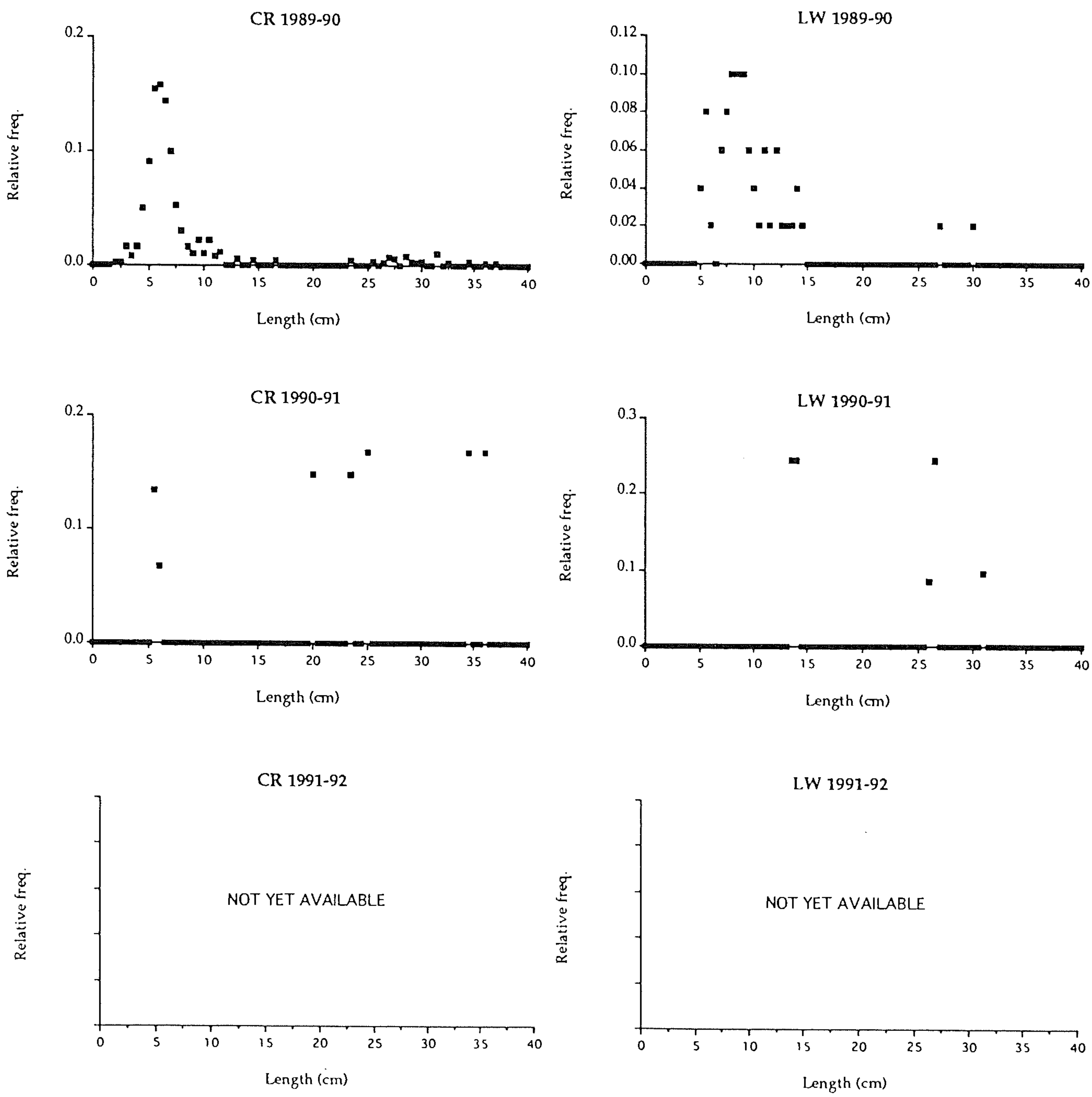


Fig. 5.3 Relative length-frequencies of TAILOR bycatch

[0.5 cm bins]

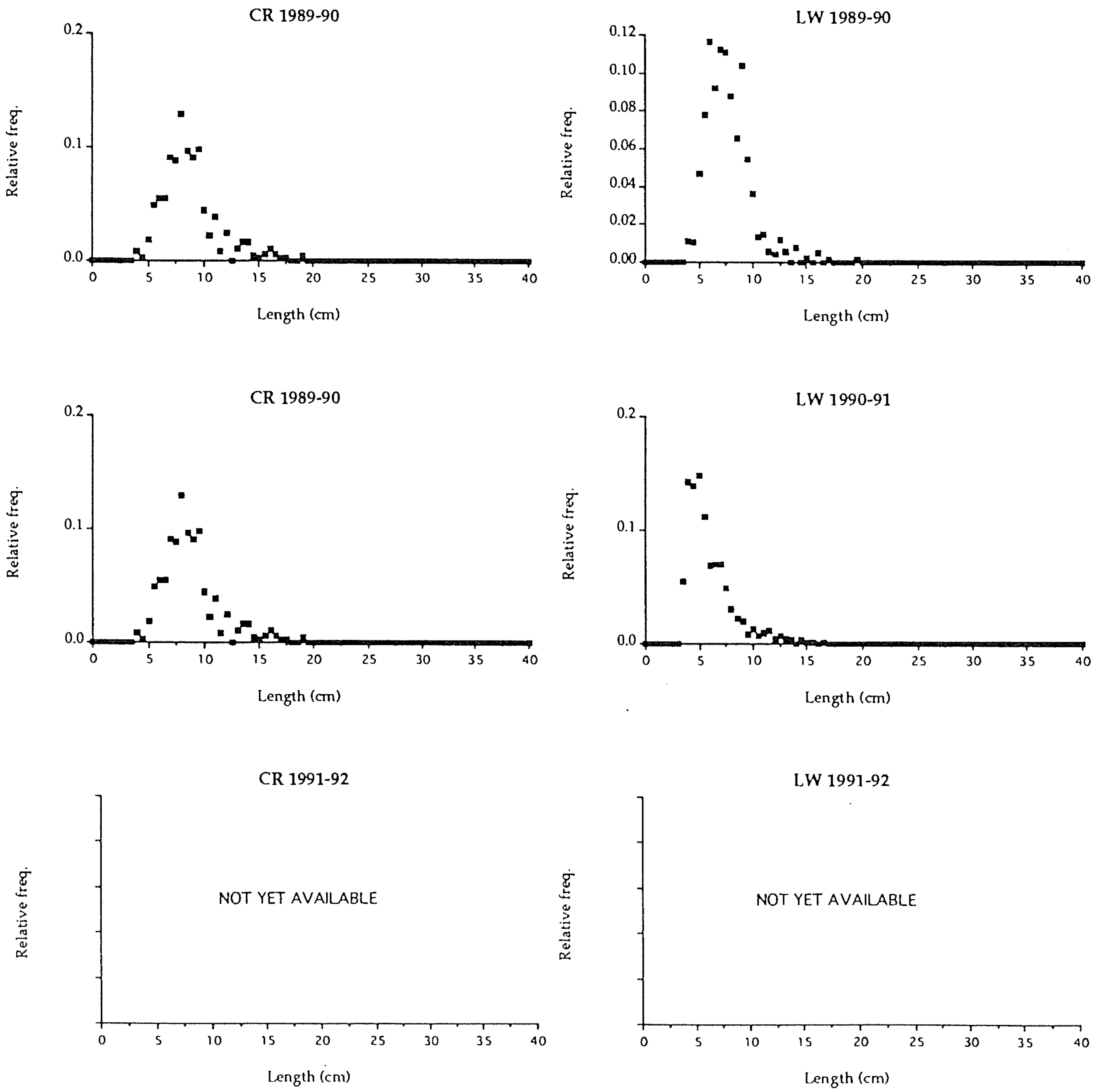


Fig. 5.4 Relative length-frequencies of DUSKY FLATHEAD bycatch

[0.5 cm bins]

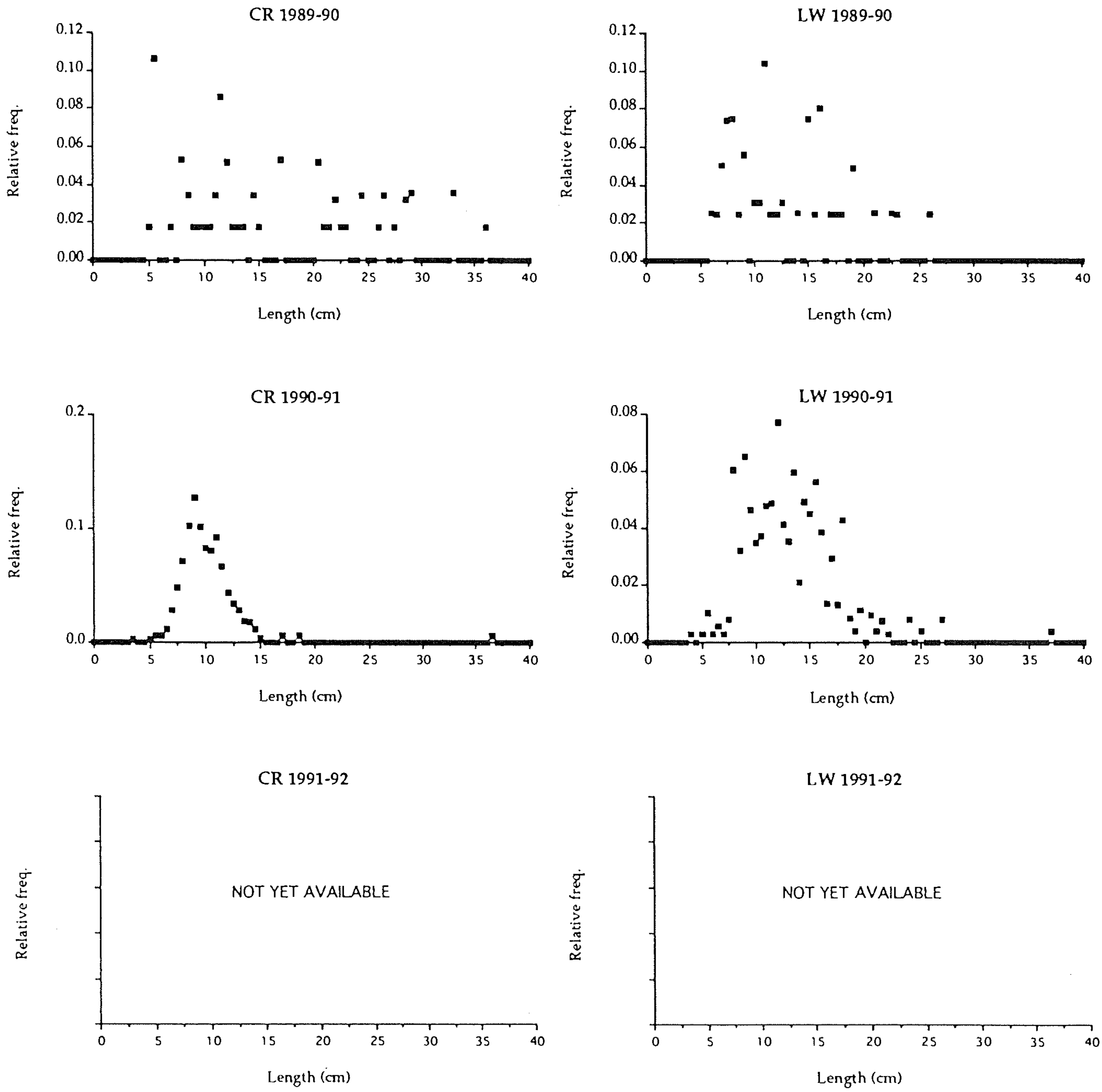


Fig. 5.5 Relative length-frequencies of SAND WHITING bycatch

[0.5 cm bins]

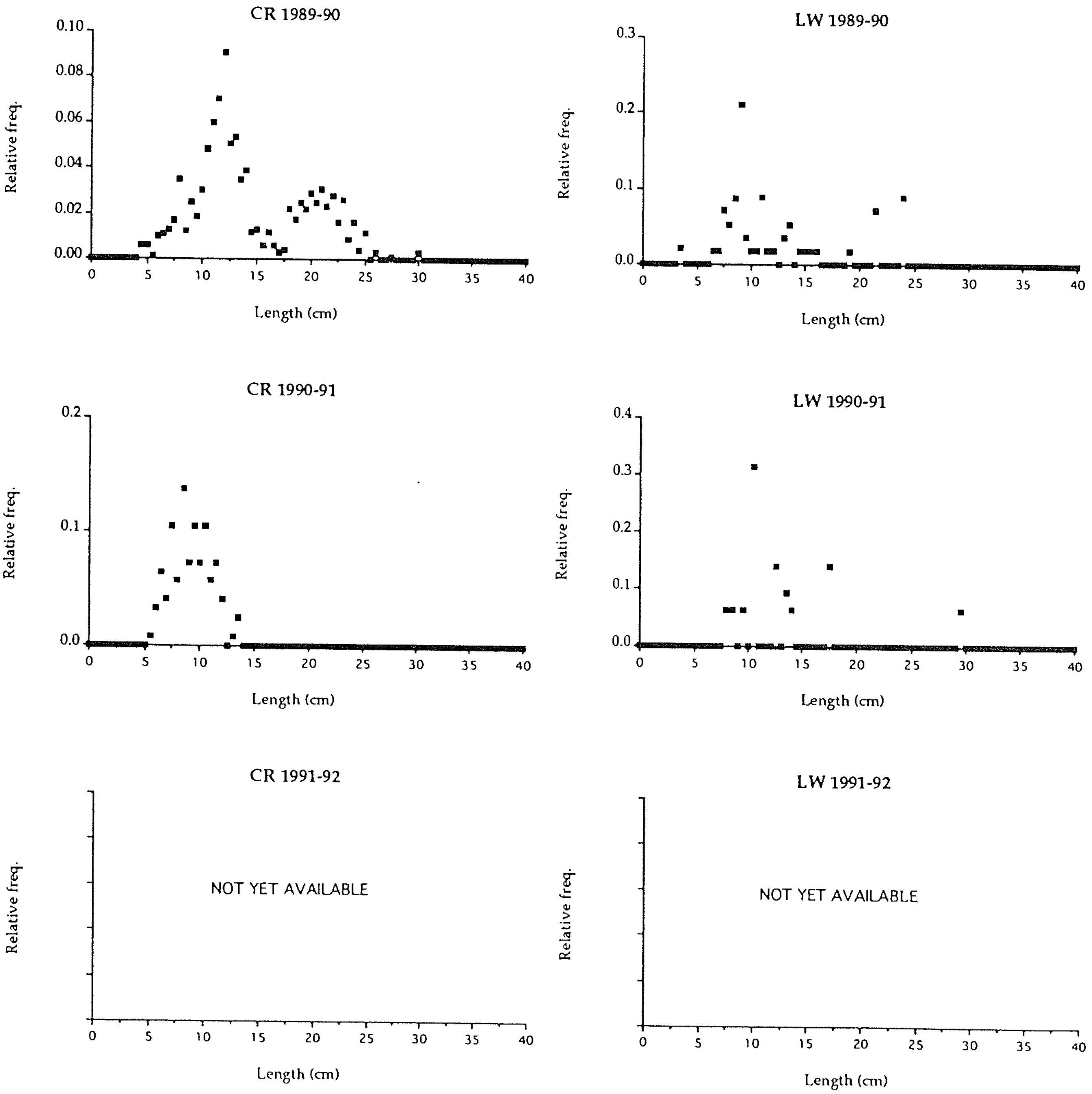


Fig. 5.6 Relative length-frequencies of LARGE-TOOTHED FLOUNDER bycatch

[0.5 cm bins]

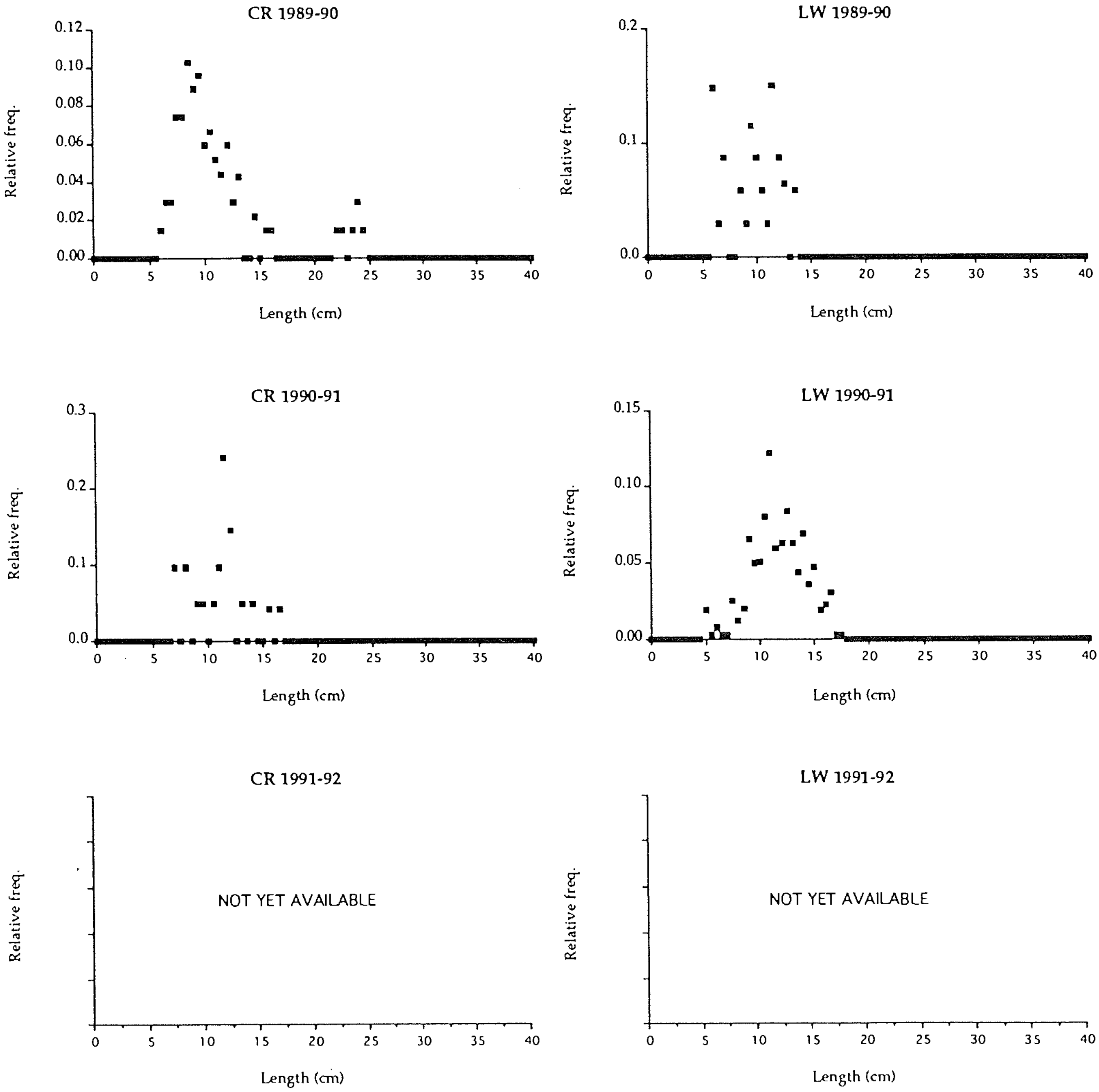


Fig. 5.7 Relative length-frequencies of SEA MULLET bycatch

[0.5 cm bins]

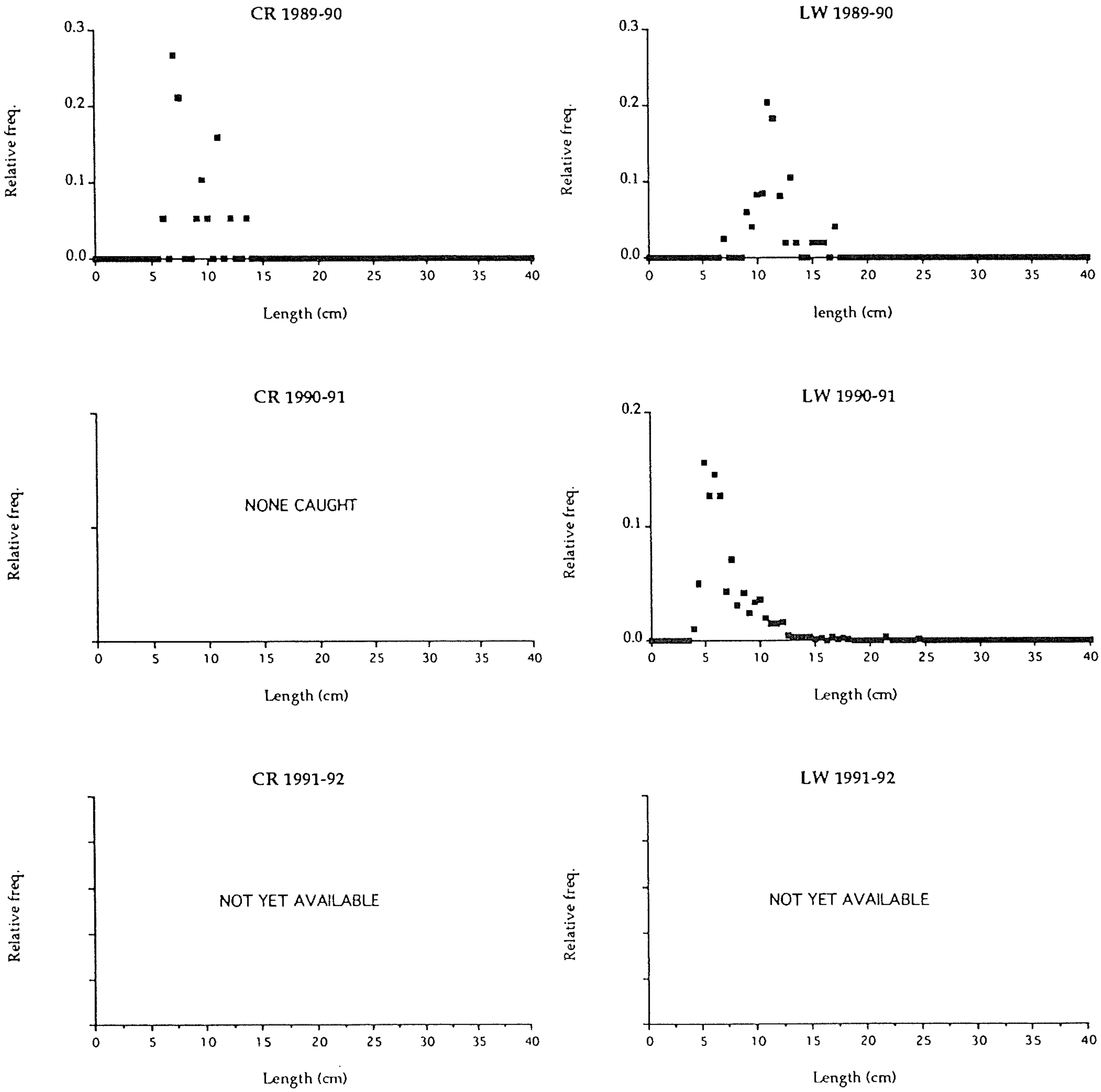
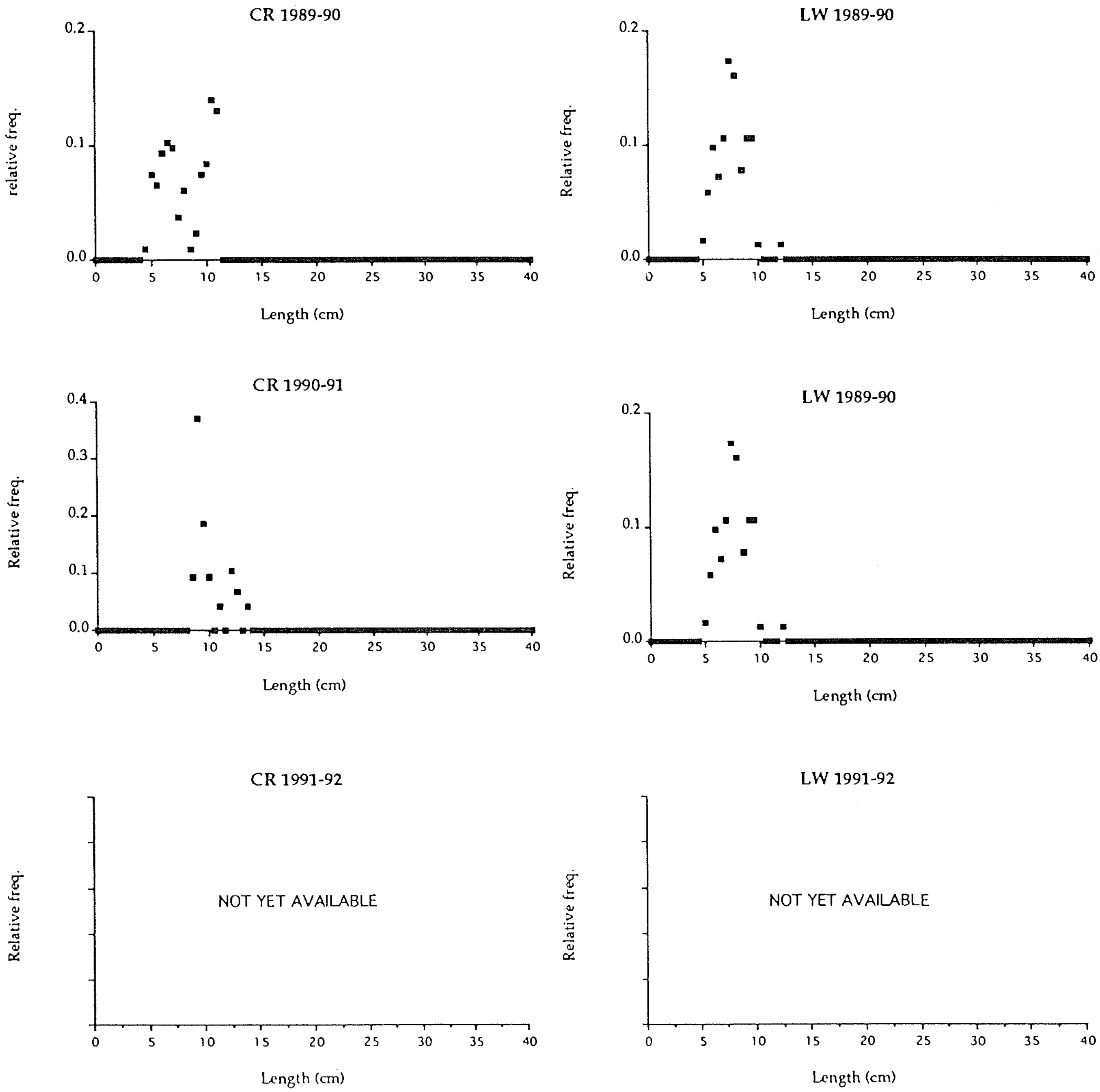


Fig. 5.8 Relative length-frequencies of TARWHINE bycatch

[0.5 cm bins]



- By-catch species list, Clarence R. (CR) and L. Woolooweyah (LW)

ily	Scientific name	Common name	CR	LW
MBASSIDAE	*Priopidichthys marianus*	Ramseys perchlet	X	X
	Velambassis jacksoniensis	Glassey perchlet	X	X
NGUILLIDAE	*Anguilla australis*	Short finned eel	X	X
	Anguilla reinhardt	Long finned eel	X	
POGONIDAE	*Siphamia roseigaster*	Pink breasted siphonfish	X	X
RIIDAE	*Neoarius australis*	Fork tailed catfish	X	X
OTHIDAE	*Pseudorhombus arsius*	Large toothed flounder	X	X
	Pseudorhombus jenynsii	Small toothed flounder	X	X
ALLIONYMIDAE	*Callionymus sp.*	Stinkfish	X	
ARANGIDAE	*Gnathanodan speciosus*	Golden trevally	X	X
	Pseudocaranx dentex	Silver trevally	X	
	Trachurus novaezelandiae	Yellowtail		X
ARCHARHINIDAE	*Carcharhinus spp.*	Whaler shark	X	
LUPEIDAE	*Harengula abbreviata*	Southern herring	X	X
	Hyperlophus vittatus	Sandy sprat	X	X
	Potamalosa richmondia	Freshwater herring	X	X
ASYATIDIDAE	*Dasyatus fluviorum*	Brown stingray	X	
IODONTIDAE	*Dicotylichthys mysersi*	Myer's porcupine fish	X	
ONGRIDAE	*Congor wilsoni*	Congor eel		X
INOLESTIDAE	*Dinolestes lewini*	Long-finned pike	X	X
LEOTRIDAE	*Gobiomorphus australis*	Striped gudgeon	X	
	Hypseleotris compressus	Empire gudgeon	X	X
	Philypnodon grandiceps	Large-headed gudgeon	X	X
LOPIDAE	*Elops machnata*	Giant herring		X
NGRAULIDIDAE	*Engraulis australis*	Australian anchovy	X	X
PHIPPIDAE	*Platax tiera*	Round faced batfish	X	
ERREIDAE	*Gerres ovatus*	Common silver biddy	X	X
IRELLIDAE	*Girella tricuspidata*	Blackfish	X	X
OBIIDAE	*Acanthogobius flavimanus*	Oriental goby	X	
	Arenigobius bifrenatus	Bridled goby	X	X
	Brachyambloypus coecus	Blind goby	X	X
	Favonigobis tamarensis	Tamar river goby	X	X
	Redigobius macrostomus	Large mouth goby	X	X
	Valenciennea longipinnis	Striped goby	X	
	??????????	Half bridled goby	X	X
	<unid. gobies>	Goby	X	
EMIRAMPHIDAE	*Arrhamphus sclerolepis*	Snub-nosed garfish	X	X
	Hyporhamphus ardelio	River garfish	X	X
ONACANTHIDAE	*Eubalichthys mosaicus*	Mosaic leatherjacket		X
	Meuschenia australis	Brown striped leatherjack	X	
	<unid. leatherjackets>	Leatherjacket	X	
ONODACTYLIDAE	*Monodactylus argenteus*	Diamond fish	X	X
UGILIDAE	*Liza argentea*	Flat-tail mullet	X	X
	Mugil cephalus	Sea mullet	X	X
	Myxus elongatus	Sand mullet	X	X
URAENESOCIDAE	*Muraenesox bagio*	Common pike eel	X	X
YLIOBATIDAE	*Myliobatis australis*	Eagle ray		X
ERCHICHTHYIDAE	*Macquaria novemaculeata*	Australian bass	X	
	Percalates colonorum	Australian perch		X
LATYCEPHALIDAE	*Platycephalus arenarius*	Northern sand flathead	X	X
	Platycephalus fuscus	Dusky flathead	X	X
LOTOSIDAE	*Euristhmus lepturus*	Long-tailed catfish	X	X
	Plotosis lineatus	Striped catfish	X	X

DAE	*Pomatomus saltatrix*	Tailor	X	X
NTHIDAE	*Priacanthus macracanthus*	Red bigeye	X	X
PHAGIDAE	*Selenotoca multifasciata*	Old maid	X	X
ENIDAE	*Argyrosomus hololepidotus*	Jewfish	X	X
RPAENIDAE	*Notesthes robusta*	Bullrout	X	X
LLAGINIDAE	*Sillago ciliata*	Sand whiting	X	X
	Sillago maculata	Trumpeter whiting	X	X
OLEIDAE	*Achlyopa nigra*	Black sole	X	X
	Aseraggodes macleayanus	Narrow banded sole	X	X
PARIDAE	*Acanthopagrus australis*	Bream	X	X
	Pagrus auratus	Snapper		X
	Rhabdosargus sarba	Tarwhine	X	X
ERAPONIDAE	*Pelates quadrilineates*	Trumpeter	X	X
ETRAODONTIDAE	<toadfish/pufferfish>	Toadfish/pufferfish	X	X
RANOSCOPIDAE	*Ichthyscopus lebeck*	Spotted stargazer	X	
ROLOPHIDAE	*Urolophus testaceus*	Common stingaree	X	X
ALAEMONIDAE	*Macrobrachium sp.*	Long armed prawn	X	
QUILLIDAE	*Squilla sp.*	Mantis shrimp		X
RAPSIDAE	*Scylla serrata*	Mud crab	X	X
ORTUNIDAE	*Portunus pelagicus*	Blue swimmer crab	X	X
unid. crabs>	<unidentified crabs>	Crabs-unidentified	X	
OLIGINIDAE	*Loliolus sp.*	Bottle squid		X

Table 2.1 - Estimates (+/-1se) of Catch & Bycatch for 1989-90 and 1990-91 seasons - Clarence River

	1989-90		1990-91	
	Sampled months [Dec-Mar]	Whole season [Dec-May]	Sampled months [Jan-Apr]	Whole season [Dec-May]
Prawns (kg.)	373,495 (53,243)	462,704 (65,961)	146,969 (25,636)	195,412 (34,085)
Total bycatch (kg.)	45,784 (3,752)	56,720 (4,648)	31,986 (7,431)	42,529 (9,880)
Total bycatch individuals. (no.)	3,031,761 (333,332)	3,755,898 (412,948)	2,509,777 (787,854)	3,337,026 (1,047,539)
Commercial spp. indivs. (no.)	472,071 (74,005)	584,825 (91,681)	161,168 (27,547)	214,291 (36,627)
Bream (no.)	271,701 (50,275)	336,597 (62,284)	81,447 (16,300)	108,293 (21,672)
Jewfish (no.)	43,802 (23,550)	54,264 (29,175)	1,119 (313)	1,487 (416)
Tailor (no.)	32,805 (10,117)	40,640 (12,533)	17,727 (7,217)	23,569 (9,595)
Dusky flathead (no.)	5,120 (1,722)	6,343 (2,134)	30,989 (7,977)	41,203 (10,606)
Sand whiting (no.)	62,355 (8,692)	77,249 (10,768)	23,343 (7,128)	31,037 (9,478)
Large-tooth. flounder (no.)	12,727 (10,007)	15,767 (12,397)	3,906 (1,065)	5,194 (1,416)
Sea mullet (no.)	1,700 (835)	2,106 (1,035)	0 (0)	0 (0)
Tarwhine (no.)	19,662 (9,543)	24,358 (11,822)	1,778 (974)	2,364 (1,295)

Table 2.2 - Estimates (+/-1se) of Catch & Bycatch for 1989-90 and 1990-91 seasons - Lake Woolooweyah

	1989-90 Sampled months [Jan-Mar]	1989-90 Whole season [Oct-May]	1990-91 Sampled months [Oct-Feb, Apr]	1990-91 Whole season [Oct-May]
Prawns (kg.)	50,839 (10,050)	162,581 (32,141)	87,477 (11,323)	98,003 (12,685)
Total bycatch (kg)	18,393 (5,975)	58,820 (19,108)	17,206 (2,440)	19,277 (2,734)
Total bycatch individuals (no.)	1,015,891 (224,778)	3,248,772 (718,829)	1,755,684 (189,894)	1,966,933 (212,743)
Commercial spp. indivs. (no.)	165,575 (42,454)	529,501 (135,766)	174,493 (20,944)	195,488 (23,464)
Bream (no.)	108,538 (37,124)	347,100 (118,719)	32,852 (5,373)	36,805 (6,019)
Jewfish (no.)	2,938 (1,999)	9,394 (3,833)	385 (199)	432 (223)
Tailor (no.)	35,993 (6,900)	115,104 (22,067)	76,326 (16,165)	85,509 (18,110)
Dusky flathead (no.)	2,395 (726)	7,659 (2,323)	17,226 (3,834)	19,298 (4,295)
Sand whiting (no.)	3,428 (1,908)	10,962 (6,103)	1,000 (619)	1,121 (694)
Large-tooth. flounder (no.)	2,052 (713)	6,563 (2,280)	12,293 (5,137)	13,772 (5,755)
Sea mullet (no.)	2,969 (1,059)	9,494 (3,387)	28,007 (8,386)	31,377 (9,395)
Tarwhine (no.)	4,592 (1,483)	14,685 (4,742)	5,698 (2,291)	6,384 (2,566)

Daytime Trawling on Offshore Grounds

Pairs of daytime tows were made on the Clarence River ground during Surveys VI–VIII and off Newcastle during all survey periods. Catch data are summarised in Table 10. Off the Clarence River, few prawns or bugs were caught during the day. Catches of other commercial species were generally smaller and the total weight of by-catch was about half that recorded for the night-time tows.

On the Newcastle ground, king prawn catches were very small except for tow no. 911513 when 3.2 kg were taken; this tow was made immediately after dawn and also caught 19.5 kg of striped carid prawns and about 3000 juvenile redfish. Compared to the night-time catches, pink tilefish was the only by-catch species caught in consistently greater numbers during the day; in contrast, the numbers of small tiger flathead taken were much smaller (Surveys V–VII).

Table 10: Catch data for the main species caught during daytime tows on offshore grounds.

	Tow no.	King prawn (no.)	Smooth bug (no.)	Slender squid (no./kg)	Cuttlefish (no./kg)	Redfish (no./kg)	Tile-fish (no./kg)	Comm. by-catch (kg)	Trash spp. (kg)	Total by-catch (kg)	Fish spp. (no.)
Clarence R											
VI	911239	0	0	4/0.1	30/2.0	29/0.2	0	3.0	12.0	15.0	21
	911240	1	1	53/1.0	26/2.0	2/0.1	0	6.8	25.0	31.8	23
VII	911643	3	6	0	5/0.3	5/0.4	0	4.9	25.0	29.9	29
	911644	1	1	3/0.1	9/0.7	0	0	4.8	20.0	24.8	26
VIII	920234	1	2	2/0.2	16/2.3	0	0	10.0	90.0	100.0	19
	920235	0	1	1/0.1	17/1.8	0	0	8.4	110.0	118.4	27
			Tiger flat-head(no./kg)								
Newcastle											
V	911115	5	6/0.1	-	0	81/0.2	8/1.0	2.4	13.0	15.4	23
	911116	17	40/1.0	-	2/0.4	90/0.2	36/6.3	11.1	11.5	22.6	28
VI	911513	161	67/2.4	0	22/1.6	3000/21.3	22/5.4	36.1	72.0	108.1	31
	911514	12	11/2.0	13/0.2	8/0.3	10/0.9	8/1.5	18.6	31.0	49.6	23
VII	911815	2	52/4.8	0	3/0.2	1/0.1	20/3.6	9.2	31.5	40.7	21
	911816	29	90/9.9	0	31/2.2	0	48/8.8	23.5	42.0	65.5	33
VIII	920409	0	4/0.3	6/0.8	0	0	12/1.4	7.3	65.0	72.3	26
	920410	16	1/0.1	6/0.9	2/0.2	0	18/5.5	13.9	30.0	43.9	26

SIZE COMPOSITION OF CATCHES

Prawns: Table 11 gives the counts for king and school prawns (no./kg) for each area and survey when significant quantities were caught. These indices are inversely proportional to the average size of the prawns in the sample.

School prawns caught off the Clarence River during Surveys VII (November) and VIII (February) were very small (195/kg). By comparison, school prawns taken off Brunswick Heads in Survey VIII were large (96/kg). On the Newcastle ground, school prawns caught during Surveys VII and VIII were also comparatively large (126/kg and 78/kg).

King prawns caught on the Brunswick Heads and Clarence River offshore grounds were consistently large (14–28/kg); the lowest count for each ground was recorded during Survey VIII (17/kg and 14/kg). Off Tuncurry, medium sized king prawns were caught during Surveys V (52/kg), Survey VI (38/kg) and Survey VIII (58/kg); few prawns were caught during Survey VII. Relatively large king prawns were taken on the Newcastle ground during Survey VII (36/kg); the prawns were appreciably smaller during Surveys V (65/kg), VI (58/kg) and VIII (69/kg).

King prawns caught on the inshore grounds, mainly during the night-time tows, were usually very small. Off the Clarence River, very small king prawns were present during Survey VII (196/kg), and medium sized prawns during Survey VIII (56/kg). Very small king prawns were also taken on the Newcastle ground during Surveys VII (205/kg) and VIII (121/kg).

Table 11: Mean counts (no./kg) of school and king prawns caught during Surveys V – VIII.
(* few prawns caught)

Survey:		V (May–June)		VI (Aug.–Sept.)		VII (Nov.–Dec.)		VIII (Feb.–April)	
		King	School	King	School	King	School	King	School
Brunswick Heads	inshore	–	155	–	*	–	*	–	96
	offshore	24	–	25	–	19	–	17	–
Clarence River	inshore	–	*	–	*	196	*	56	194
	offshore	23	–	28	–	21	–	14	–
Tuncurry	inshore	–	*	–	*	–	*	–	*
	offshore	52	–	38	–	*	–	58	–
Newcastle	inshore	–	*	–	*	205	126	121	78
	offshore	65	–	58	–	36	–	69	–

Fish: Length-frequency histograms for commercial species which were caught in significant numbers during Surveys V to VIII are presented in Appendix 3 (Figs 2–15). Length data for species caught on both inshore and offshore sites are combined on the same figure. Where catches were subsampled, the data have been scaled to represent total catch numbers. Minimum legal lengths are indicated on the histograms.

The catches of commercial fish species on the inshore grounds were mainly composed of small and/or juvenile fish. The length data for a number of these species show dominant modal peaks of juveniles. The large numbers of sand flathead taken on the four inshore grounds were mostly beneath the minimum legal length of 33 cm; the small number of sand flathead caught offshore were mostly larger than 33 cm. The data for stout whiting show dominant size modes of small fish less than 15 cm for most surveys; significant numbers of larger fish were caught off Brunswick Heads (Surveys V and VIII), the Clarence River (Survey V) and Tuncurry (Surveys V, VII and VIII).

Almost all redspot whiting from the inshore catches were less than 15 cm, in contrast to the offshore redspot whiting which were mostly larger (15–25 cm). Similarly, most red gurnard caught on the inshore grounds were small (less than 20 cm LCF); on offshore grounds off northern NSW, they were mainly between 15 and 27 cm, while off Tuncurry and Newcastle the size range was 22 to 44 cm.

Snapper caught on the Clarence River inshore ground during Survey VII were very small (5–10 cm FL); during Survey VIII on the same ground and inshore off Tuncurry during Surveys VII and VIII, the snapper were larger (11–22 cm). Mulloway caught off Newcastle during Survey VIII were also juveniles (4–16 cm).

The data for shovelnose rays show that the inshore Brunswick Heads catches were composed mainly of small size classes (20–50 cm) compared to the mainly large rays (60–90 cm) caught on the Tuncurry ground.

Tiger flathead caught off Tuncurry were mostly larger than the legal minimum length (32 cm FL), in contrast to the predominantly juvenile tiger flathead (7–28 cm) from the Newcastle ground (Fig. 13). Redfish were similar to this as the Tuncurry fish were on average much larger (12–29 cm) than the mainly juvenile redfish (3–10 cm) from Newcastle. The data for tiger flathead, redfish and ocean perch (inshore form) from Newcastle all show distinct modal peaks with increasing modal lengths from survey to survey indicating growth increments.

Crabs and Bugs: Length-frequency histograms for smooth bugs, blue swimmer crabs, three-spotted crabs and two-spotted crabs are shown in Appendix 3 (Figs 16–19).

The smooth bugs from off Brunswick Heads were mostly larger than 50 mm CL whereas those from the Clarence River catches show the presence of distinct size modes between 25 and 50 mm.

The majority of blue swimmer crabs caught off Tuncurry were larger than the minimum legal size of 60 mm carapace length whereas off Newcastle there were similar numbers of under- and over-sized crabs; on both grounds there were many more females than males (about 75% overall).

The data for three-spotted crabs showed that very few taken during these surveys were larger than a commercially acceptable size of approximately 60 mm carapace length. Most two-spotted crabs caught off Newcastle were larger than 50 mm CL.

Squids: Length-frequency histograms for bottle squid, broad squid (combined for Tuncurry and Newcastle surveys) and slender squid for the Brunswick Heads and Clarence River offshore grounds are presented in Appendix 3 (Figs 19–21).

The data for the small bottle squid from the Brunswick Heads, Clarence River and Newcastle inshore grounds showed similar patterns. Most bottle squid smaller than 60 mm mantle length were males. The maximum size for males was 65 mm and for females 89 mm.

The size range of the inshore broad squid from the Tuncurry and Newcastle grounds was 2 cm to 25 cm mantle length but were mostly smaller than 20 cm. The data for Survey VI showed evidence of an influx of small squid onto the grounds with a modal peak at 7 cm.

Slender squid from the northern NSW offshore grounds ranged from 4 cm to 36 cm mantle length. Almost all were sexually immature squid less than 20 cm ML.

Scallops: The size distributions of southern scallops caught off Newcastle are shown in Appendix 3 (Fig. 22). Almost all scallops were less than 60 mm shell length, smaller than an acceptable commercial size. The data show apparent annual cohorts and suggest an annual growth of 25–30 mm. This is similar to the 30 mm annual growth reported for southern scallops of the same size in Jervis Bay (Hamer 1987).

Faunal Assemblages

Fishes: Lists of all species caught during Surveys V-VIII are presented in Appendix 4. The lists show the frequency of occurrence of each species (no. of tows in which each species was recorded) for each ground and survey and include species captured during daytime tows on offshore grounds and night-time tows on inshore grounds.

In all, 312 species of fishes were identified from the eight survey grounds, 171 from the inshore sites and 223 from the offshore sites. The identification of the small flounder *Plagiopsetta glossa* has been confirmed by F. Chapleau (pers. comm.); the records of this species in Cruise Report No.110 and in this report are the first from Australian waters. With reference to Paxton et al. (1989) and Gunn (1990), five species (from families Heterodontidae to Carangidae) are new records for NSW waters; these species are *Synodus macrops* (Synodontidae), *Minous versicolor* (Scorpaenidae), *Epinephalus radiatus* (Serranidae), and *"Caranx" kleini* (see Gunn 1990) and *Parastromateus niger* (Carangidae).

Table 12 shows the total number of species recorded from each site, the number of species caught during each survey and the mean number per tow. The data show that the mean number of fish species per tow ranged from 18 to 38 for the inshore grounds and 23 to 37 for the offshore grounds. The number of species per survey was between 40 and 76 (inshore) and 52 and 78 (offshore).

<u>Table 12:</u> Total number of fish species recorded for each area and survey (only for daytime tows on inshore grounds and night tows on offshore grounds). The mean number per tow is shown in brackets.

		Inshore Surveys					Offshore Surveys			
	Total Spp.	V	VI	VII	VIII	Total Spp.	V	VI	VII	VIII
Brunswick Hds	97	48 (24)	40 (21)	47 (26)	76 (38)	113	63 (30)	56 (29)	62 (33)	78 (37)
Clarence R.	111	53 (18)	47 (18)	60 (28)	74 (35)	100	57 (28)	61 (31)	62 (31)	66 (34)
Tuncurry	100	60 (25)	56 (27)	59 (34)	59 (31)	95	60 (29)	65 (30)	61 (26)	59 (26)
Newcastle	103	59 (24)	44 (18)	55 (24)	67 (29)	112	67 (28)	52 (23)	68 (28)	64 (27)

On the Tuncurry inshore ground, the total number of species per survey (56-60) showed little variation. In contrast, the numbers of species recorded during Survey VIII (in March) on the Brunswick Heads and Clarence River inshore grounds, and to a lesser extent the Newcastle inshore ground (in April), were much higher than for Surveys V-VII. Catches on both northern grounds contained 25 species not recorded during the preceding three surveys; among these were 13 species of the family Carangidae, mostly juveniles of fishes with more tropical distributions. The Newcastle catches contained seven species of carangids recorded only during Survey VIII. On all inshore grounds the lowest number of fishes were caught during the August-September sampling period (Survey VI).

The total number of species per survey on the offshore grounds was relatively constant for all grounds apart from Survey VIII off Brunswick Heads when 78 species were recorded; 19 of these species were caught only during this survey but in contrast to the inshore grounds, most were demersal species. This high species count was made when the total by-catch, mainly trash fish, was much larger than for other surveys (see Table 6).

Twelve species of fishes were recorded from all eight grounds. Six were commercially exploited species: shovelnose ray, red gurnard, sand flathead, redspot whiting, red mullet and smooth-backed flounder; the non-commercial species were numbfish, red bullseye, yellowtail, slender scad, common seapike, and smooth boxfish. As shown in the catch data, redspot whiting were at times common on all grounds, and shovelnose rays, red gurnard and sand flathead were more numerous on inshore than offshore grounds. Red mullet and smooth-backed flounder were generally more common on the offshore grounds especially off Brunswick Heads and the Clarence River. Yellowtail, slender scad and seapike are primarily pelagic species and were occasionally caught in large numbers, especially inshore. Smooth boxfish were more common inshore and, off Tuncurry, formed a major part of the trash by-catch; numbfish and red bullseye were caught in small numbers on all the grounds.

Table 13 shows the degree of overlap in the geographic and depth distributions of the fish species. The data show that for the inshore sites, 83% of the species recorded from the Brunswick Heads ground were also caught off the Clarence River, and conversely 72% of the Clarence River species were taken in the Brunswick Heads catches. The degree of overlap was lower (65-67%) between the two southern sites off Tuncurry and Newcastle. The lowest percentage overlap (61-65%) was between Brunswick Heads and Newcastle, the two most distant sites.

For the offshore sites, the degree of overlap of the species distributions was 56-63% between Brunswick Heads and the Clarence River and 63-74% for the Tuncurry and Newcastle grounds. Between the two most distant sites (Brunswick Heads and Newcastle) the overlap was 36-37%. A comparison of the species assemblages between adjacent inshore and offshore sites showed the overlap ranged between 29% and 36%.

Table 13: Percentage similarity matrix showing the percentage overlap of species among the four inshore sites and four offshore sites, and between adjacent inshore and offshore sites. The table shows the number of species recorded at each site and the percentages of the total species at each site which were also recorded from the other sites. (BH=Brunswick Heads; CR=Clarence River; T=Tuncurry; N=Newcastle)

	No.of	INSHORE				OFFSHORE			
	Spp.	BH	CR	T	N	BH	CR	T	N
INSHORE									
Brunswick Hds	97	100	83	66	65	35			
Clarence R.	111	72	100	64	68		32		
Tuncurry	100	64	71	100	67			29	
Newcastle	103	61	73	65	100				32
OFFSHORE									
Brunswick Hds	113	30				100	56	35	36
Clarence R.	100		36			63	100	49	59
Tuncurry	95			31		41	52	100	74
Newcastle	112				30	37	46	63	100

Invertebrates

Appendix 5 lists the crustaceans and cephalopods recorded during Surveys V-VIII and shows the frequency of occurrence (percentage of total tows in which each was recorded) for each species. A total of 78 species of crustaceans was caught, 35 from inshore grounds and 62 from offshore. The main groups represented were prawns (19 spp.), portunid (swimmer) crabs (19 spp.) and mantis shrimps (10 spp.). Eleven species of cephalopods were caught including five species of squids and four species of octopuses.

Exploratory Trawling

Four exploratory tows for king prawns were made off northern NSW during the course of Surveys V-VIII; operational and catch data are included in Appendix 2. Few prawns were caught in any of the tows.

Prawn Tagging

Kapala was used to tag king prawns in Trial Bay (November 1991) and south of Newcastle (December 1991 and March 1992). The tagging sites are shown in Figure 1, and operational data and numbers of prawns tagged are included in Appendix 2. The tagging was part of a study by S. Montgomery (Fisheries Research Institute) into the rates of movements of eastern king prawns and to provide data for a model of the fishery.

A total of 3204 tagged king prawns were released in Trial Bay and 291 were subsequently recaptured. These recaptured prawns were at liberty for a maximum of 228 days, and travelled a maximum of 515 km (to about 45 n.miles north of Cape Moreton). At the Newcastle site, 5840 prawns were tagged and released; 323 were recaptured with a maximum time at liberty of 187 days and a maximum movement of 760 km (to 26 n.miles north of Cape Moreton). All recaptures were caught north of the tagging sites. Detailed results will be published separately.

DISCUSSION

The following discussion and summary figures refer to all data (including Surveys I-IV reported in Cruise Report No.110) collected during the two year study.

Inshore Grounds

Figures 23 and 24 show the rainfall data for the catchments adjacent to the sampling sites (from Australian Bureau of Meteorology Monthly Rainfall Reviews) and the mean catch rates (numbers or weights) of school prawns and important by-catch species taken on the inshore grounds during Surveys I-VIII. The results suggested a relationship between rainfall and the abundance of school prawns and some associated by-catch species.

The mean catch rates of school prawns on all grounds were low during most survey periods and their relative abundances did not exhibit a clear seasonal pattern. Further, for most of the two year survey, rainfall was below average and the few relatively large school prawn catches followed periods of seasonally high and/or much greater than average rainfall, eg. Surveys V and VIII on the Brunswick Heads ground, Surveys I and VIII off the Clarence River, Survey I off Tuncurry, and Survey VIII off Newcastle.

Such relationships between rainfall and school prawn catches have also been reported by Ruello (1973) for the Hunter (Newcastle) region, and Glaister (1978) for the Clarence River. Ruello stated that the ocean school prawn catch off Newcastle was generally small during average or dry weather conditions but large catches occurred after heavy rainfall because of the subsequent emigration of prawns from the river to the sea. Glaister (1978) found positive correlations (on weekly, monthly and annual time intervals) between the discharge of the Clarence river and the oceanic component of the school prawn landings.

Mulloway and teraglin were two important by-catch species associated with large catches of school prawns. Figures 23 and 24 show that significant numbers of juvenile mulloway and teraglin were caught on the Clarence River and Tuncurry grounds during Survey I, and on the Newcastle ground during Surveys I and VIII, implying that these species may have exited the adjacent rivers after heavy rain. Very few mulloway and teraglin were caught on the Brunswick Heads ground which is adjacent to a much smaller estuarine system than the other grounds.

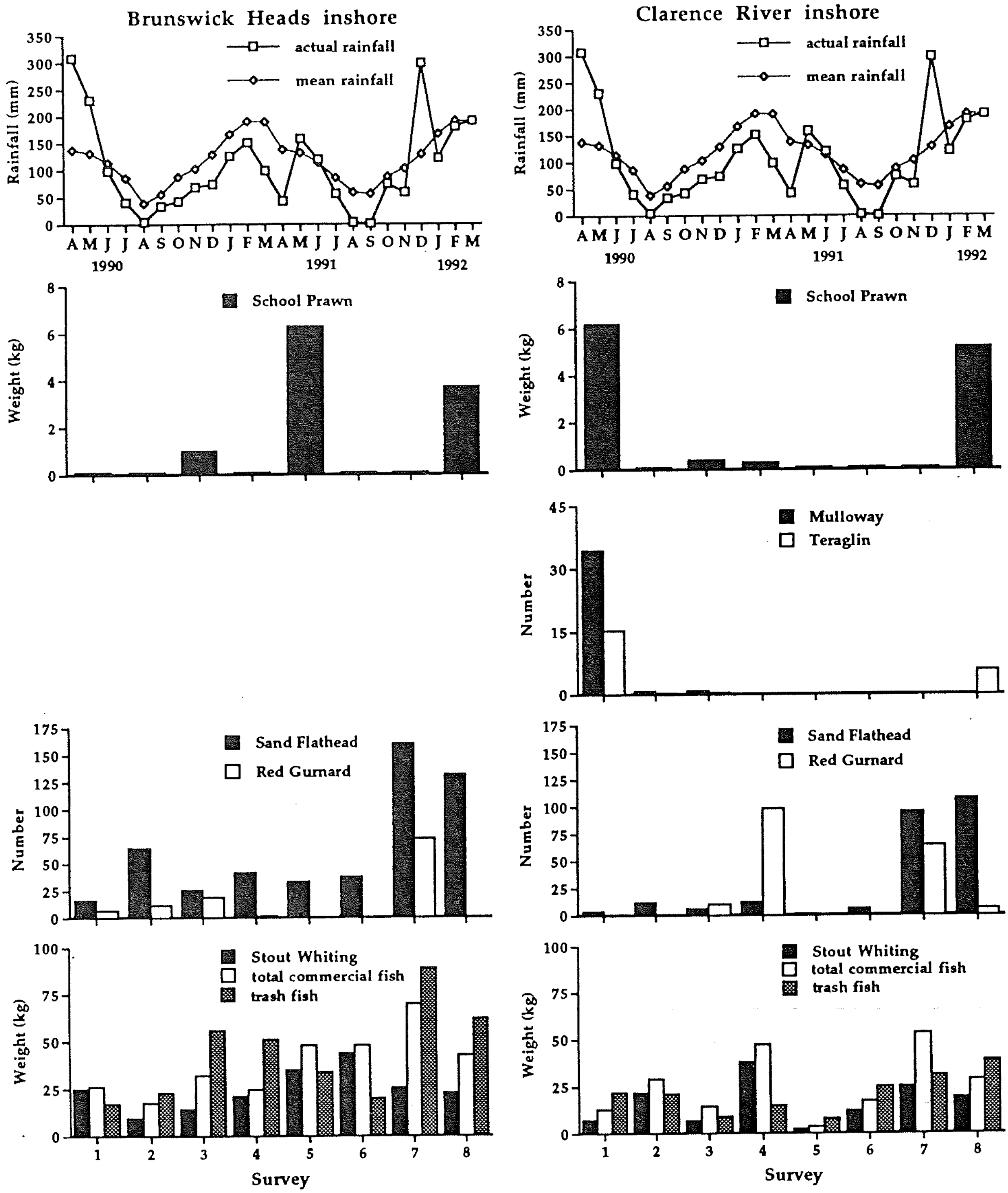


Figure 23: Rainfall data for the Upper North Coast catchment area and the mean catch rates (no. or kg per 30 min. tow) of school prawns, important by-catch species, and total commercial and trash fish during Surveys I-VIII on the Brunswick Heads and Clarence River inshore grounds.

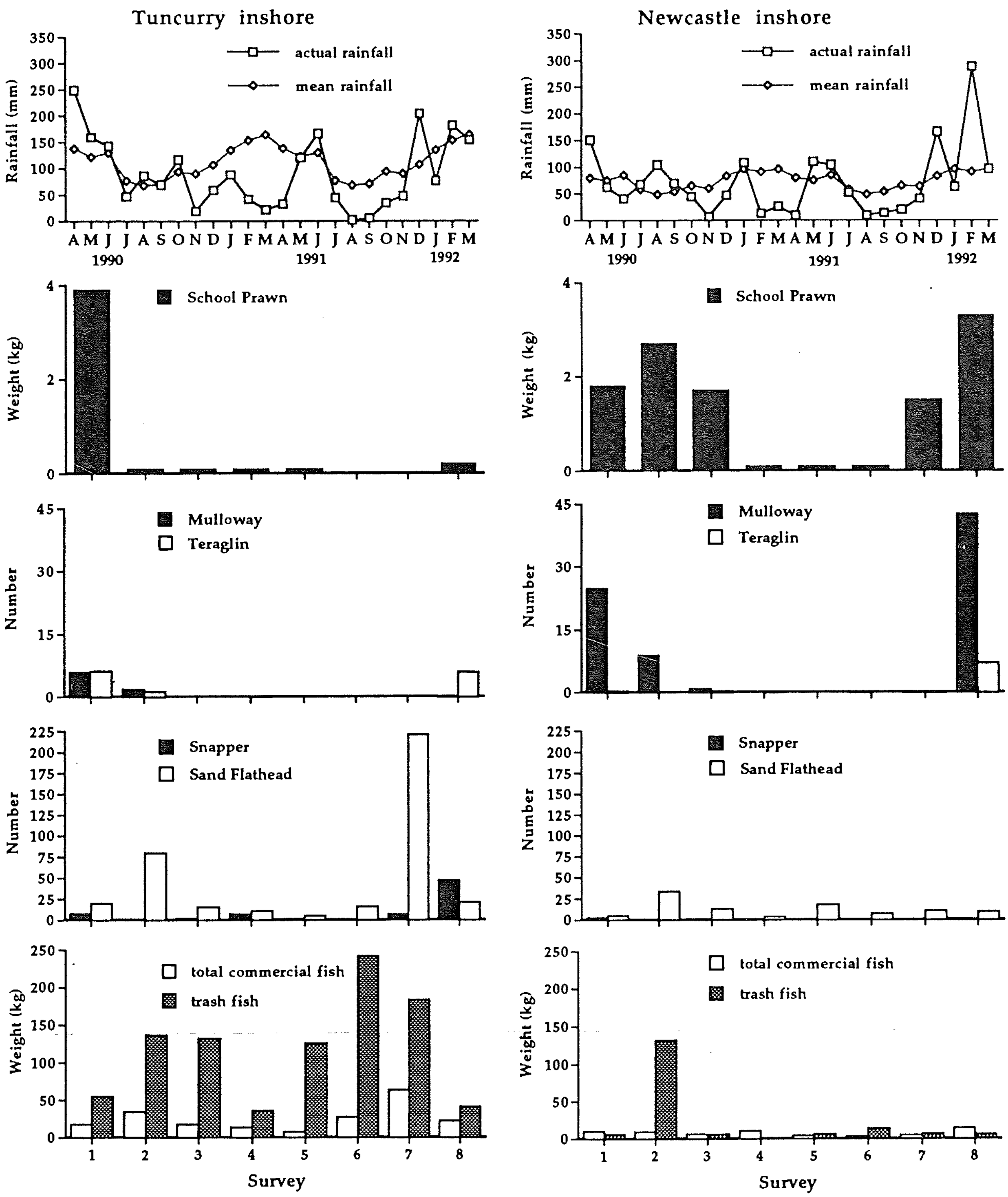


Figure 24: Rainfall data for the Manning (Tuncurry) and Hunter (Newcastle) catchment areas, and the mean catch rates (no. or kg per 30 min. tow) of school prawns, important by-catch species, and total commercial and trash fish during Surveys I-VIII on the Tuncurry and Newcastle inshore grounds.

Relatively large numbers of small sand flathead were caught on all grounds during all surveys with exceptionally high catch rates (>75/tow) during Surveys VII and VIII on the Brunswick Heads and Clarence River grounds and during Surveys II and VII on the Tuncurry ground. Large numbers (>45/tow) of small snapper were taken off the Clarence River (Surveys IV and VII) and Tuncurry (Survey VIII). On the Brunswick Heads and Clarence River grounds, stout whiting was the dominant commercial by-catch species with peaks of abundance during Survey VI (Brunswick Heads) and Survey IV (Clarence River). None of these three species showed any obvious seasonal pattern of abundance or relationship with rainfall.

Three-spotted crabs, two-spotted crabs and bottle squid, all of marginal commercial importance, were the only by-catch invertebrates caught in significant quantities during the study (see Tables 1-4 and Cruise Report No.110). Three-spotted crabs were more common on the two northern grounds although large numbers of juveniles were caught off Newcastle during Survey VIII; few three-spotted crabs of a commercially acceptable size (>60 mm carapace length) were caught on any ground. Two-spotted crabs were most common on the Newcastle ground; during Surveys I-IV few were larger than 60 mm CL (see Cruise Report No.110) but during Surveys V-VIII about half were more than 60 mm CL. The small bottle squid were common on all inshore grounds and showed peaks in abundances during the summer (November-December and February-April) survey periods.

Mean catch rates of trash fish were relatively high on the Brunswick Heads (17-89 kg/tow) and Tuncurry (36-243 kg/tow) inshore grounds where no trawler activity was observed. Trash catches on the Clarence River ground ranged from 7 kg/tow to 39 kg/tow and were lowest during Surveys III and V when all catches (prawns and by-catch) were small. On the Newcastle ground, the trash catch was always very low (<15 kg/tow) except for Survey II when large catches of Port Jackson sharks inflated the catch; this ground is continually fished by prawn and/or fish trawlers.

In summary, commercially important by-catch species were represented on the inshore grounds mainly by juveniles. During periods of relatively high school prawn catch rates (which usually followed high rainfall and increased river discharge), significant numbers of juvenile mulloway and teraglin were caught. Stout whiting, and juveniles of sand flathead, snapper, red gurnard and shovelnose rays were occasionally abundant but usually during times when school prawn catches were small and when little or no commercial prawn trawling was taking place.

Offshore Grounds

On the offshore grounds, the relative abundances of king prawns showed different patterns among the eight surveys on each ground (see Fig. 25). On the Brunswick Heads ground, the highest mean catch rates were during the summer surveys (III & IV and VII & VIII) with a maximum of 6.1 kg/tow (Survey III). Off the Clarence River, the mean catch rates of king prawns showed a general decrease over the course of the two year program. In each of the two years the highest catch rates were made during August (Surveys II and VI) when 6.1 and 3.6 kg/tow were recorded. The abundances of king prawns off Tuncurry was clearly seasonal with high catch rates during April and May (Survey I: 5.1 kg/tow; IV: 6.0 kg/tow; and VIII: 10.5 kg/tow). The Newcastle ground was the most productive of the four grounds with consistently moderate to high catch rates ranging from 3.1 kg/tow (Survey II) to 10.4 kg/tow (Survey IV) but with no apparent seasonal peak in abundance.

The size compositions of king prawns (as measured by the number per kg) on each offshore ground for the eight surveys are shown in Figure 26. Apart from catches on the Brunswick Heads ground during Survey IV (37/kg), prawns on the northern NSW grounds were consistently large (13-28/kg) and mostly reproductively mature. King prawns on the two southern grounds were smaller and mostly immature. The increase in the average size of king prawns on offshore grounds from south to north probably reflects their northward migration for spawning after they leave estuaries as juveniles (Ruello 1975). This was also demonstrated by the results of the tagging experiment (discussed above).

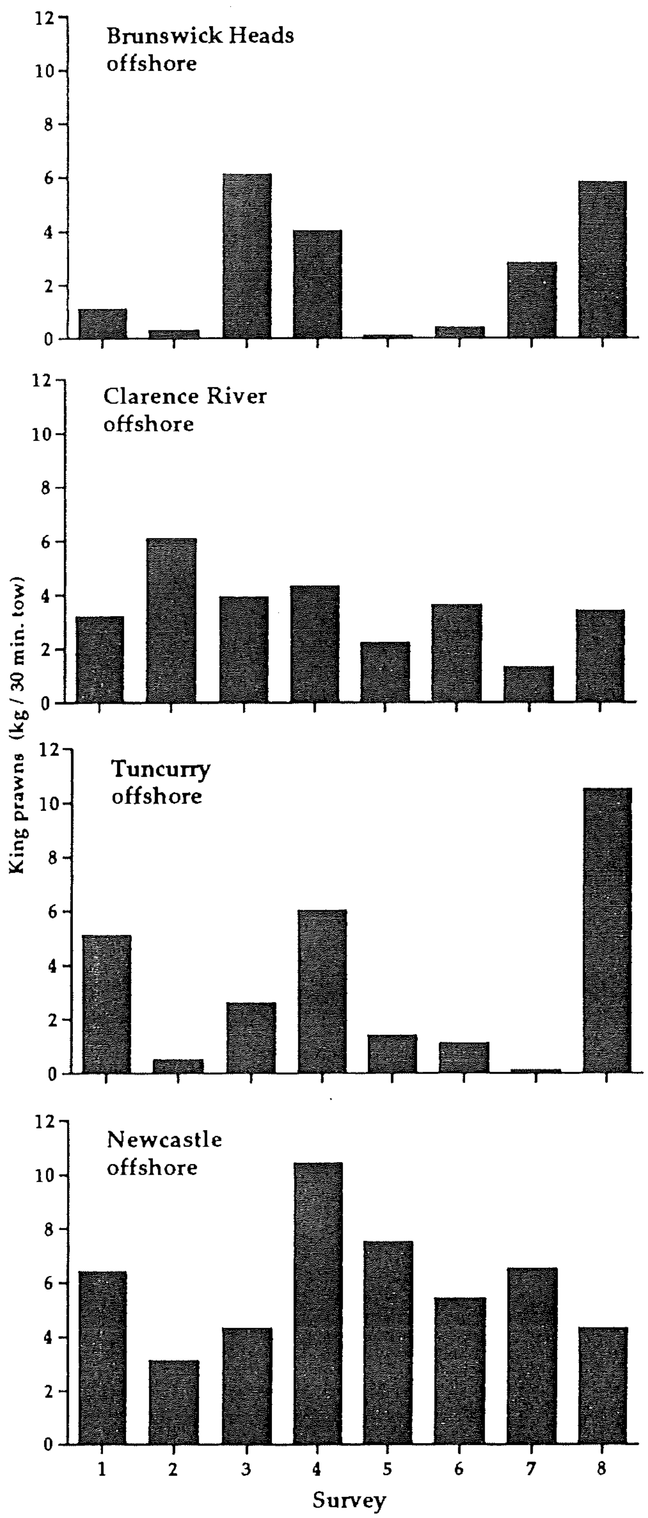


Figure 25: Mean catch rates (kg/30 minute tow) of king prawns on the offshore grounds during Surveys I–VIII.

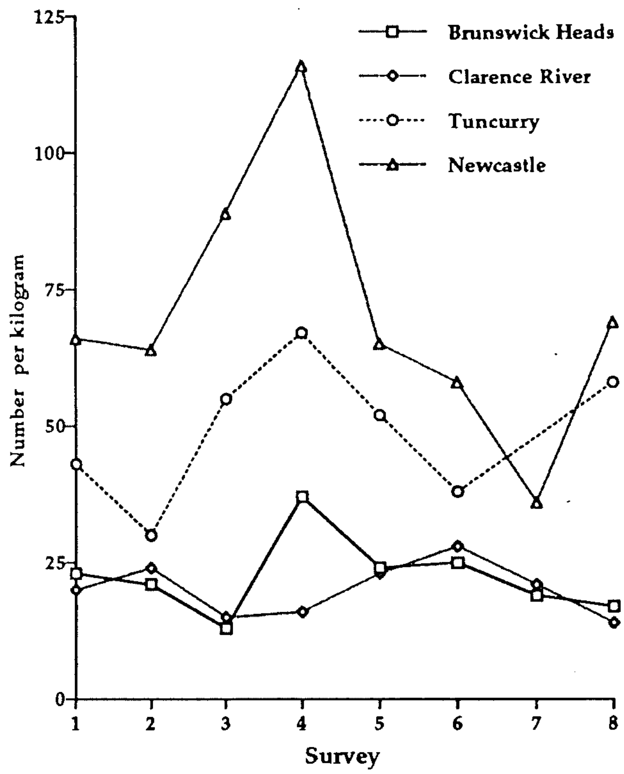


Figure 26: Mean number per kg of king prawns caught on the offshore grounds during Surveys I-VIII. (No data were available for Survey VII off Tuncurry.)

Commercial trawlers fished the offshore grounds during the periods of relatively high prawn catch rates and during most of these times, relatively small quantities of by-catch (commercial and trash species) were caught. Figure 27 shows that mean total by-catch weights were relatively small throughout almost all survey periods on the Clarence River and Newcastle grounds which are are continually subjected to greater fishing pressure than the other sampling sites. By-catch was also low on the Tuncurry ground during those surveys with high catch rates of prawns (Surveys IV and VIII). One interpretation of these results is that the reduction of by-catch weight (mainly fish species) on these grounds may have been caused by trawler activity rather than seasonal fluctuations in abundance.

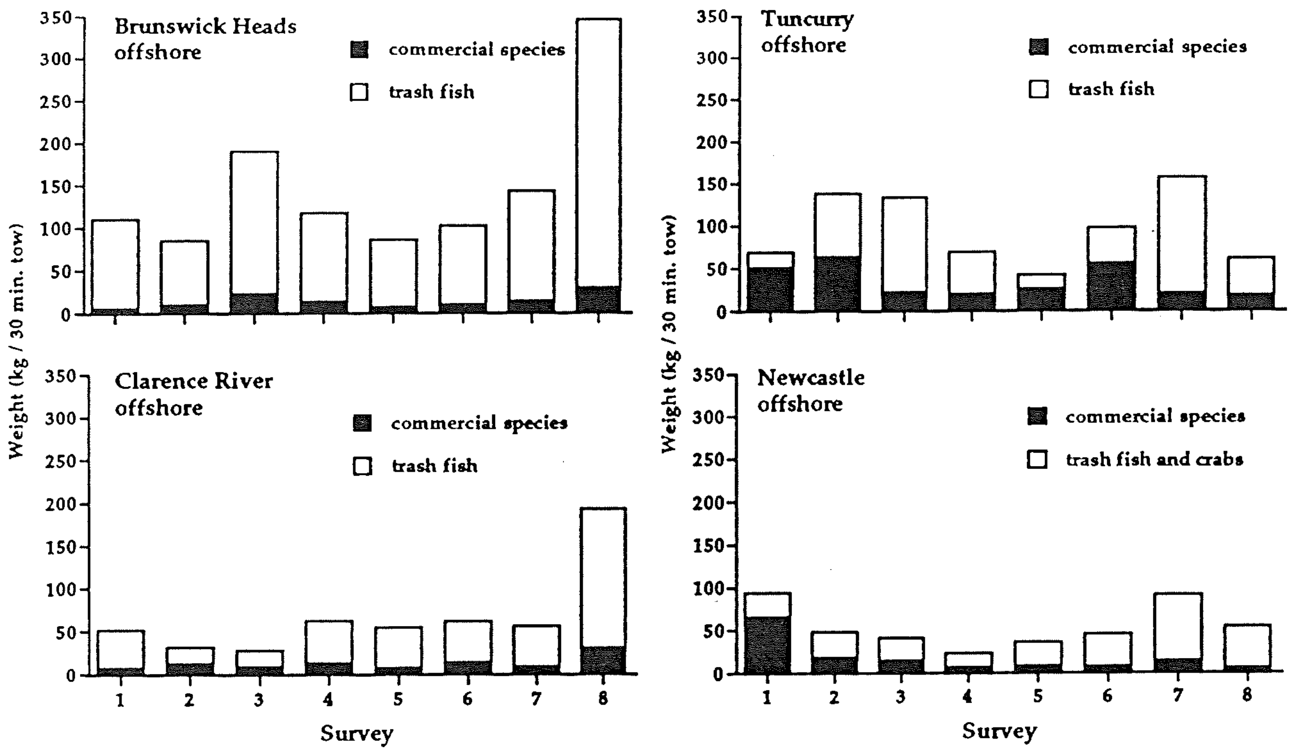


Figure 26: Mean catch rates (kg/30 min. tow) of total commercial by-catch (fish, crustacea and cephalopods) and trash species for Surveys I-VIII.

Catches of commercial by-catch species on the northern grounds were usually low. Smooth bugs were common on both grounds but the mean catch rates only exceeded 2.0 kg/tow during the two November surveys (III & VII) off Brunswick Heads. The capture of relatively large numbers of small bugs during Survey IV in February 1991 (see Cruise Report No.110) was not repeated in Survey VIII (March 1992). During the two years' sampling, only a single female smooth bug bearing eggs was captured; this was a 71 mm CL bug caught off Brunswick Heads during Survey VII (November).

The catch rates of octopus on the northern offshore grounds were very much higher during Survey VIII (Tables 6 & 7) than for any other period of the study. Large catches were also taken on the Brunswick Heads inshore ground during Survey VIII (Table 1) indicating a comparatively high level of abundance of octopus off much of northern NSW at this time. The absence of octopus on the Clarence River inshore ground during Survey VIII may have been caused by the more riverine conditions which produced relatively high school prawn catches.

Of the commercial fish species, smooth-backed flounder were generally more abundant off Brunswick Heads than the Clarence River with the highest catch rates in the summer. Redspot whiting showed no seasonal occurrence off Brunswick Heads but on the Clarence River ground, significant catches were only taken during the two August surveys (II and VI).

Data for the Tuncurry ground showed that the mean catch weights of tiger flathead were relatively large during most surveys when prawn catches were small; the highest catches were during August and September (Surveys II and VI). This same pattern was evident for the mean catch weights of the commercial fish species (combined) and for trash fish.

Catch weights of all by-catch on the Newcastle ground were generally small for all surveys but relatively large numbers of juvenile tiger flathead and redfish were caught on this ground, especially during Surveys V, VI and VII (Table 8). The Newcastle offshore ground differed from the other grounds in that during most surveys two species of non-commercial crabs (*Charybdis miles* and *C. bimaculata*) formed about half the total trash component with mean catches ranging from 6 to 31 kg/tow; catch weights of non-commercial crustaceans were very low on other grounds.

Overall, catch numbers and weights of commercial by-catch species were usually low on the Brunswick Heads, Clarence River and Tuncurry offshore grounds, especially during periods when commercial quantities of prawns were available and trawlers were operating. Only on the Newcastle ground were relatively large numbers of juvenile commercial fish caught.

Fish Fauna

During the eight surveys, 212 species were caught on the inshore grounds and 248 species on offshore grounds; the total number of species for the eight grounds and eight surveys was 353, of which 52 were single records. Of the inshore fauna, 49% were caught only on inshore grounds and for offshore species, 56% were taken only offshore. A total of 21 species was caught on all grounds.

The results of Surveys V-VIII show a number of similarities to the results obtained during the first year of the program (see Cruise Report No.110). The total number of species recorded from all grounds was 312 compared to 298 for Surveys I-IV; the total from inshore sites was 171 (cf. 176 for Surveys I-IV) and from offshore sites, 223 (cf. 204). During Surveys V-VIII, the total numbers of fish species recorded on each of the eight grounds did not vary greatly (95-113) and were almost identical to Surveys I-IV (97-109). In addition, the pattern of depth and latitudinal distribution of the fish fauna (Table 13) was also similar to that found during Surveys I-IV (see Table 14, Cruise Report No.110).

More species were recorded on the inshore grounds during surveys in the summer and autumn months. Figure 28 shows that species diversity on all grounds was relatively high for Surveys I, IV and VIII and the variation in the total numbers of fish species caught on each ground corresponded closely with seasonal fluctuations in sea surface temperature. Species with more tropical distributions would be expected on the grounds during times of higher water temperature. The results supported this as juveniles of several species of the family Carangidae (trevallies and scads) were present on the inshore grounds only during Surveys I and IV (see Cruise Report No.110) and especially during Survey VIII (see Appendices 4a and 4c). Adults of most of these species normally live in tropical waters to the north of NSW (Gunn 1990).

The diversity of the fish faunas on the offshore grounds did not vary greatly between surveys and showed no obvious seasonal fluctuations.

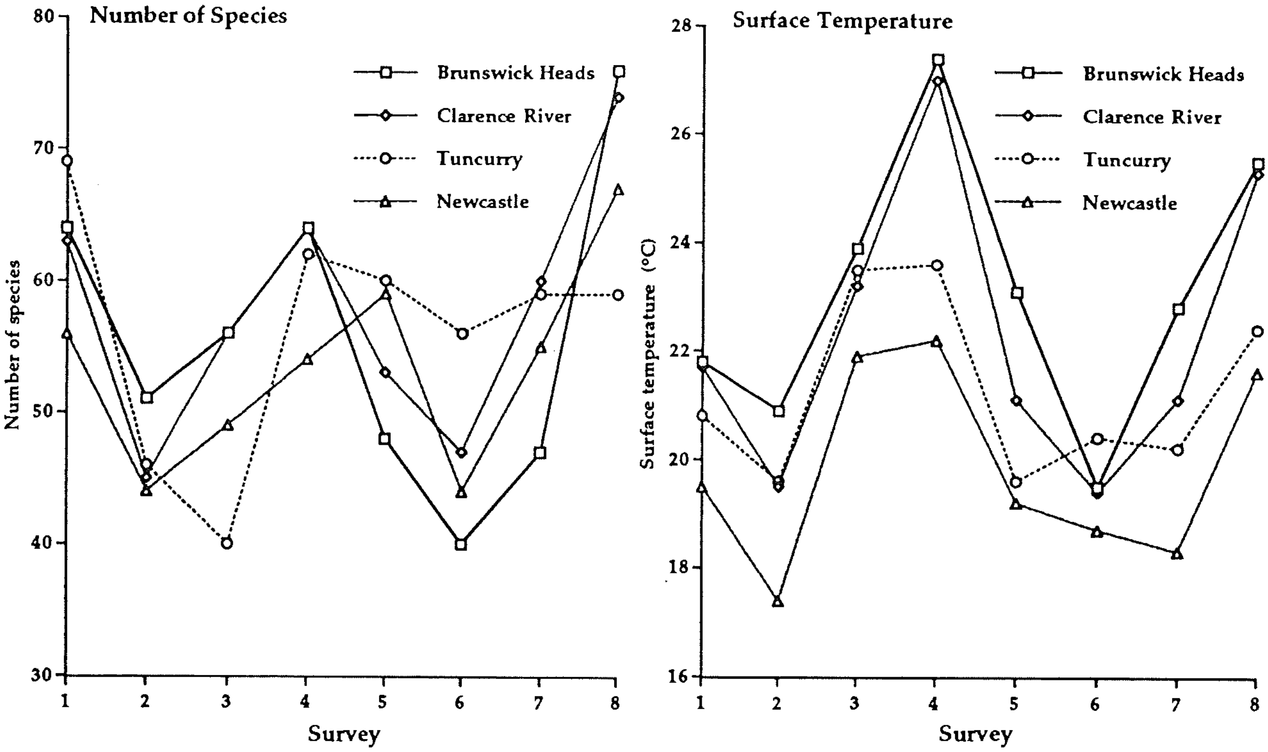


Figure 28: Total number of species recorded from each inshore ground during Surveys I-VIII, and sea surface temperatures at each inshore ground during Surveys I-VIII.

SUMMARY

1. Between May 1991 and May 1992, four surveys of inshore and offshore prawn grounds off Brunswick Heads, the Clarence River, Tuncurry and Newcastle completed the second half of the two year sampling program.

2. Abundance indices (mean catch rates) on a seasonal basis were calculated for school and king prawns and the associated by-catch (commercial species and trash).

3. Size-frequency data were collected for the prawn and commercial by-catch species taken during the surveys.

4. A total of 401 species of fishes, crustaceans and cephalopods was recorded on the survey grounds; geographical and depth distributional data were collected for these species.

5. Exploratory trawling was conducted in outer shelf waters off Brunswick Heads, the Clarence River and Coffs Harbour. Catches of king prawns were small.

6. About 9000 king prawns were tagged off Newcastle and South West Rocks and 614 prawns have been recaptured, all to the north of the tagging sites.

7. The results of the two year study showed that on inshore grounds, relatively high catch rates of school prawns, juvenile mulloway and juvenile teraglin were recorded following high rainfall; other commercial species (stout whiting, sand flathead, snapper and red gurnard) were sometimes abundant, but usually when few school prawns were available.

8. On offshore grounds, by-catch of commercially important species was generally small, although large numbers of juvenile tiger flathead and redfish were caught off Newcastle during some surveys.

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Appendix 1: List of common names and taxonomic names of species referred to in the tables and text.

Barred cod		*Epinephalus ergastularius*
Boarfish	- giant	*Paristiopterus labiosus*
Boxfish	- smooth	*Anoplocapros inermis*
Bream	- yellowfin (silver)	*Acanthopagrus australis*
Cobia		*Rachycentron canadus*
Flathead	- dusky	*Platycephalus fuscus*
	- marble	*Platycephalus marmoratus*
	- northern sand	*Platycephalus arenarius*
	- sand (blue-spotted)	*Platycephalus caeruleopunctatus*
	- tiger	*Platycephalus richardsoni*
	- spiky	*Ratabulus diversidens*
Flounder	- big-toothed	*Pseudorhombus arsius*
	- small-toothed	*Pseudorhombus jenynsii*
	- smooth-backed	*Pseudorhombus tenuirastrum*
Goatfish	- bartailed	*Upeneus tragula*
Gurnard	- butterfly	*Lepidotrigla* spp.
	- red	*Chelidonichthys kumu*
Hairtail		*Trichiurus lepturus*
John dory		*Zeus faber*
Kingfish	- banded	*Seriolina nigrofasciata*
Leatherjacket	- Chinaman	*Nelusetta ayraudi*
	- mosaic	*Eubalichthys mosaicus*
	- velvet	*Meuschenia scaber*
	- yellowfinned	*Meuschenia trachylepis*
Mackerel	- common	*Scomber australasicus*
Morwong	- rubberlip	*Nemadactylus douglasii*
Mulloway (jewfish)		*Argyrosomus hololepidotus*
Ocean perch		*Helicolenus percoides*
Pearl perch		*Glaucosoma scapulare*
Pilchard		*Sardinops sagax neopilchardus*
Pink tilefish (moonfish)		*Branchiostegus wardi*
Ray	- banjo	*Trygonorrina* sp.
	- shovelnose	*Aptychotrema rostrata*
	- white spotted	*Rhynchobatus djiddensis*
Redfish		*Centroberyx affinis*
Red mullet		*Upeneichthys lineatus*
Samson fish		*Seriola hippos*
Seapike		*Sphyraena africana*
Shark	- greeneye dog	*Squalus mitsukurii*
	- gummy	*Mustelus antarcticus*
	- hammerhead	*Sphyrna zygaena*
	- inshore angel	*Squatina australis*
	- offshore angel	*Squatina* sp.
	- Port Jackson	*Heterodontus portusjacksoni*
	- saw	*Pristiophorus* sp.
	- spiky dog	*Squalus megalops*
	- whaler	*Carcharhinus* spp.
	- wobbegong	*Orectolobus maculatus*
Snapper		*Pagrus auratus*
Stingaree		fam. Urolophidae
Stinkfish		fam. Callionymidae
Tailor		*Pomatomus saltatrix*
Tarwhine		*Rhabdosargus sarba*
Teraglin		*Atractoscion aequidens*
Toadfish		fam. Tetraodontidae

Appendix 1: (continued)

Trevally	- silver	*Pseudocaranx dentex*
Warehou	- blue	*Seriolella brama*
	- spotted	*Seriolella punctata*
Whiting	- redspot	*Sillago bassensis*
	- stout	*Sillago robusta*
	- trumpeter	*Sillago maculata*
Yellowtail		*Trachurus novaezelandiae*
Prawn	- banana	*Penaeus merguiensis*
	- greasyback	*Metapenaeus bennettae*
	- king	*Penaeus plebejus*
	- leader	*Penaeus monodon*
	- Racek	*Parapenaeus australiensis*
	- school	*Metapenaeus macleayi*
	- tiger	*Penaeus esculentus*
	- striped carid	*Plesionika spinipes*
Bug	- Balmain	*Ibacus peronii*
	- Bruce's	*Ibacus brucei*
	- smooth	*Ibacus* sp.nov.
Crab	- blue swimmer	*Portunus pelagicus*
	- coral	*Charybdis cruciata*
	- mud	*Scylla serrata*
	- spanner	*Ranina ranina*
	- three-spotted	*Portunus sanguinolentus*
	- two-spotted	*Ovalipes australiensis*
Lobster	- barking	*Linuparus trigonus*
	- eastern rock	*Jasus verrauxii*
Cuttlefish		fam. Sepiidae
Octopus	- misc.	*Octopus* spp.
	- southern	*Octopus australis*
Squid	- bottle	*Loliolus noctiluca*
	- broad	*Loligo chinensis*
	- slender	*Loligo* sp.
	- Gould's	*Nototodarus gouldi*
	- southern calamary	*Sepioteuthis australis*
Scallop	- saucer	*Amusium balloti*
	- southern	*Pectin fumatus*

Appendix 2(a): Operational data, prawn catches and by-catch totals for trawling conducted on the northern NSW grounds during Survey V (* night-time tow on inshore ground).

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Total Bycatch (kg)
Brunswick Heads Inshore									
910824	23-5-91	1340	28°36';153°34'	28°35';153°34'	5-7	9-13	0.2	5.0	201.2
910825	23-5-91	1505	28°35';153°34'	28°34';153°34'	9-10	16-19	0.1	0.4	61.2
910826	23-5-91	1605	28°33';153°34'	28°35';153°34'	9-10	16-19	-	0.3	58.1
910827	23-5-91	1655	28°35';153°34'	28°36';153°35'	7-9	12-17	0.2	0.1	67.5
910832	24-5-91	1150	28°36';153°34'	28°35';153°34'	5-6	9-11	-	15.0	145.6
910833	24-5-91	1245	28°34';153°34'	28°33';153°34'	6-8	11-15	-	5.8	63.5
910834	24-5-91	1435	28°33';153°34'	28°35';153°34'	7-8	12-15	0.1	7.0	92.2
910835	24-5-91	1530	28°35';153°34'	28°36';153°34'	5-6	9-11	-	4.0	64.4
910836*	24-5-91	1810	28°36';153°34'	28°34';153°34'	6-8	11-15	-	16.0	119.7
910837*	24-5-91	1855	28°34';153°34'	28°36';153°34'	5-6	9-11	-	4.7	119.8
910842	25-5-91	1235	28°36';153°34'	28°34';153°34'	4-7	7-13	-	14.0	106.9
910843	25-5-91	1330	28°34';153°34'	28°33';153°33'	5-6	9-11	0.1	3.4	133.9
910844	25-5-91	1420	28°33';153°33'	28°34';153°34'	6-7	11-12	-	7.3	37.5
910845	25-5-91	1520	28°34';153°34'	28°35';153°34'	6-7	11-12	-	13.5	43.8
Brunswick Heads Offshore									
910828	22-5-91	1915	28°27';153°39'	28°26';153°40'	26-29	47-53	0.1	-	54.5
910829	22-5-91	2015	28°25';153°39'	28°23';153°39'	27-28	49-52	0.1	-	72.1
910830	22-5-91	2110	28°23';153°40'	28°21';153°40'	29-30	53-55	-	-	48.6
910831	22-5-91	2215	28°23';153°38'	28°24';153°38'	24-26	43-48	0.1	-	116.9
910838	23-5-91	2115	28°27';153°39'	28°25';153°40'	26-28	47-52	0.1	-	92.5
910839	23-5-91	2210	28°25';153°40'	28°24';153°41'	29-30	53-55	-	-	86.4
910840	23-5-91	2305	28°24';153°40'	28°23';153°40'	29-30	53-55	-	-	98.2
910841	24-5-91	0000	28°24';153°41'	28°25';153°41'	29-30	53-55	0.4	-	133.2
910846	25-5-91	1805	28°27';153°39'	28°25';153°40'	26-29	47-53	-	-	95.4
910847	25-5-91	1905	28°24';153°40'	28°23';153°40'	29-31	53-57	-	-	63.0
910848	25-5-91	2000	28°23';153°41'	28°22';153°41'	31-32	56-59	0.2	-	67.6
910849	25-5-91	2100	28°23';153°40'	28°24';153°40'	30-31	54-57	-	-	130.3
Clarence River Inshore									
910805	21-5-91	1240	29°25';153°22'	29°23';153°23'	9-12	16-22	-	-	10.7
910806	21-5-91	1330	29°23';153°23'	29°22';153°24'	14-15	25-28	-	-	36.6
910807	21-5-91	1425	29°22';153°24'	29°23';153°23'	13-16	23-30	-	-	10.4
910808	21-5-91	1515	29°23';153°23'	29°23';153°23'	10-13	18-24	-	-	6.9
910814	22-5-91	1325	29°25';153°22'	29°23';153°22'	9-10	16-19	-	0.1	19.3
910815	22-5-91	1415	29°23';153°23'	29°22';153°23'	12-15	22-28	-	-	6.5
910816	22-5-91	1525	29°22';153°24'	29°23';153°23'	13-16	23-30	-	-	7.2
910917	22-5-91	1615	29°23';153°22'	29°25';153°22'	9-10	16-19	-	-	9.7
910818*	22-5-91	1750	29°25';153°22'	29°23';153°23'	9-11	16-21	-	0.9	28.7
910819*	22-5-91	1840	29°23';153°23'	29°24';153°23'	11-12	20-22	0.1	0.1	21.2
910851	26-5-91	0725	29°23';153°23'	29°25';153°23'	9-13	16-24	-	-	10.6
910852	26-5-91	0820	29°25';153°22'	29°23';153°23'	9-10	16-19	-	-	14.5
910853	26-5-91	0910	29°23';153°23'	29°22';153°23'	13-15	23-28	-	-	17.7
910854	26-5-91	1000	29°22';153°23'	29°24';153°23'	12-14	22-26	-	-	9.9
Clarence River Offshore									
910801	20-5-91	2335	29°28';153°34'	29°27';153°35'	38-39	69-72	3.7	-	42.0
910802	20-5-91	0035	29°26';153°35'	29°25';153°35'	39-40	71-74	1.4	-	17.3
910803	20-5-91	0135	29°24';153°35'	29°23';153°35'	37-39	67-72	1.7	-	15.1
910804	20-5-91	0235	29°23';153°35'	29°24';153°34'	36-37	65-68	3.2	-	70.2
910809	21-5-91	1815	29°25';153°34'	29°24';153°35'	36-39	65-72	2.2	-	61.2
910810	21-5-91	1915	29°23';153°36'	29°22';153°36'	37-39	67-72	0.6	-	109.8
910811	21-5-91	2015	29°22';153°36'	29°23';153°35'	37-38	67-70	1.5	-	58.9
910812	21-5-91	2115	29°25';153°34'	29°26';153°34'	36-38	65-70	2.3	-	55.3
910820	22-5-91	2045	29°25';153°33'	29°24';153°34'	33-35	60-64	2.1	-	49.8
910821	22-5-91	2135	29°25';153°34'	29°26';153°33'	35-36	64-66	2.8	-	65.4
910822	22-5-91	2235	29°27';153°33'	29°28';153°33'	35-37	64-68	1.8	-	66.1
910823	22-5-91	2335	29°29';153°33'	29°28';153°34'	36-39	65-72	2.8	-	28.4
Exploratory Tows off the Clarence River and Cape Byron									
910813	22-5-91	0005	29°24';153°46'	29°21';153°47'	85-95	155-175	0.1	-	200.0
910850	25-5-91	2350	28°34';153°38'	28°36';153°39'	22-26	40-48	0.8	-	155.0

Appendix 2(b): Operational data, prawn catches and by-catch totals for trawling conducted on the central NSW grounds during Survey V (* night-time tow; + daytime tow).

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Racek Prawn (kg)	Total Bycatch (kg)
Tuncurry Inshore										
910901	5-6-91	1030	32°09';152°31'	32°08';152°31'	5-9	9-17	-	-	-	133.1
910902	5-6-91	1120	32°08';152°31'	32°09';152°31'	6-8	11-15	-	-	-	186.0
910903	5-6-91	1310	32°09';152°31'	32°08';152°31'	8-9	14-17	-	-	-	136.5
910904	5-6-91	1400	32°08';152°31'	32°09';152°31'	9-10	16-19	-	-	-	212.7
911005	19-6-91	1245	32°07';152°30'	32°08';152°30'	7-8	12-15	-	-	-	198.4
911006	19-6-91	1335	32°08';152°30'	32°07';152°31'	8-9	14-17	-	-	-	184.2
911007	19-6-91	1430	32°07';152°31'	32°08';152°30'	6-8	11-15	-	-	-	109.3
911008	19-6-91	1520	32°09';152°31'	32°08';152°30'	9-11	16-20	-	0.1	-	116.1
911009*	19-6-91	1730	32°07';152°31'	32°08';152°30'	9-10	16-19	0.1	0.1	-	93.1
911010*	19-6-91	1820	32°09';152°30'	32°07';152°30'	6-9	11-17	-	-	-	398.7
911015	20-6-91	0820	32°09';152°30'	32°08';152°31'	7-10	12-19	-	-	-	78.5
911016	20-6-91	0910	32°08';152°31'	32°07';152°31'	10-11	18-20	-	0.1	-	97.4
911017	20-6-91	1000	32°07';152°31'	32°08';152°30'	7-10	12-19	-	-	-	97.7
911018	20-6-91	1055	32°08';152°31';	32°09';152°30'	7-10	12-19	-	-	-	75.1
Tuncurry Offshore										
910905	5-6-91	1800	31°59';152°48'	31°58';152°49'	47-49	86-90	2.0	-	-	73.1
910906	5-6-91	1905	31°57';152°49'	31°55';152°50'	47-49	86-90	2.7	-	-	66.2
910907	5-6-91	2010	31°55';152°50'	31°57';152°49'	49-50	89-92	2.7	-	-	68.4
910908	5-6-91	2115	31°57';152°50'	31°59';152°49'	50-51	91-94	1.5	-	-	86.1
911001	18-6-91	2230	32°00';152°49'	31°59';152°50'	50-52	91-95	0.2	-	-	62.0
911002	18-6-91	2340	31°57';152°50'	31°56';152°51'	49-51	89-94	0.6	-	-	66.4
911003	19-6-91	0040	31°56';152°50'	31°57';152°49'	47-49	86-90	0.7	-	-	105.8
911004	19-6-91	0140	31°58';152°49'	31°59';152°48'	47-49	86-90	0.9	-	-	126.3
911011	19-6-91	2115	31°58';152°49'	31°58';152°50'	47-50	86-92	0.7	-	-	77.5
911012	19-6-91	2215	31°57';152°52'	31°56';152°53'	52-55	95-101	1.5	-	-	66.4
911013	19-6-91	2320	31°55';152°53'	31°54';152°53'	50-54	91-99	1.5	-	-	51.0
911014	20-6-91	0020	31°53';152°53'	31°55';152°52'	50-51	91-94	1.8	-	-	57.6
Newcastle Inshore										
910909	6-6-91	0920	32°52';151°50'	32°53';151°48'	6-8	11-15	-	0.1	-	7.8
910910	6-6-91	1010	32°53';151°48'	32°52';151°50'	7-9	12-17	-	0.1	-	14.3
910911	6-6-91	1105	32°51';151°51'	32°50';151°52'	9-10	16-19	-	0.1	-	11.6
911101	25-6-91	0725	32°53';151°48'	32°52';151°50'	5-7	9-13	-	0.1	-	23.3
911102	25-6-91	0820	32°51';151°51'	32°50';151°53'	8-10	14-19	-	0.1	-	25.7
911103	25-6-91	0910	32°50';151°53'	32°51';151°52'	10-11	18-20	-	0.1	-	28.5
911104	25-6-91	1010	32°52';151°50'	32°53';151°49'	8-9	14-17	-	0.1	-	12.5
911105*	25-6-91	1805	32°53';151°48'	32°52';151°50'	9-10	16-19	0.1	3.8	-	45.7
911106*	25-6-91	1900	32°52';151°51'	32°51';151°53'	8-10	14-19	-	4.5	-	36.2
911111	26-6-91	0830	32°53';151°48'	32°52';151°50'	7-8	12-15	-	0.1	-	11.4
911112	26-6-91	0930	32°52';151°51'	32°51';151°52'	8-10	14-19	-	0.1	-	17.5
911113	26-6-91	1010	32°50';151°53'	32°51';151°52'	10-11	18-20	-	0.1	-	36.0
911114	26-6-91	1100	32°52';151°50'	32°53';151°48'	8-9	14-17	-	0.1	-	15.6
Newcastle Offshore										
910912	6-6-91	2015	32°55';151°57'	32°54';151°58'	35-37	64-68	7.6	-	-	21.5
910913	6-6-91	2110	32°53';151°59'	32°52';152°00'	35-38	64-70	5.5	-	-	23.0
910914	6-6-91	2210	32°53';152°00'	32°55';151°59'	40-45	73-83	11.0	-	0.1	20.5
910915	6-6-91	2310	32°55';151°58'	32°56';151°56'	41-44	75-81	24.0	-	-	35.5
911019	20-6-91	1805	32°53';152°01'	32°54';151°59'	37-44	67-81	3.1	-	0.1	36.2
911020	20-6-91	1905	32°53';151°59'	32°52';152°00'	38-42	69-77	3.3	-	0.1	51.8
911021	20-6-91	2000	32°53';152°01'	32°54';152°00'	39-40	71-73	2.7	-	0.1	44.2
911022	20-6-91	2055	32°55';151°58'	32°56';151°57'	40-43	73-79	2.6	-	0.2	56.0
911107	25-6-91	2055	32°52';152°02'	32°53';152°01'	36-39	65-72	8.5	-	-	47.9
911108	25-6-91	2200	32°53';152°02'	32°52';152°03'	40-42	73-77	7.8	-	0.5	32.4
911109	25-6-91	2340	32°52';152°02'	32°53';152°01'	40-41	73-75	9.5	-	0.3	40.8
911110	26-6-91	0035	32°53';152°00'	32°54';151°58'	36-40	65-73	3.8	-	0.4	23.5
911115+	26-6-91	1320	32°53';151°59'	32°53';152°00'	35-37	64-68	0.1	-	-	15.4
911116+	26-6-91	1420	32°53';152°00'	32°53';152°02'	39-41	71-75	0.3	-	0.2	22.6

Appendix 2(c): Operational data, prawn catches and by-catch totals for trawling conducted on the northern NSW grounds during Survey VI (* night-time tow; + daytime shot on offshore ground).

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Total Bycatch (kg)
Brunswick Heads Inshore									
911201	9-8-91	0900	28°37';153°35'	28°35';153°34'	6-8	11-15	0.1	0.1	91.3
911202	9-8-91	0950	28°35';153°34'	28°34';153°34'	6-8	11-15	-	0.1	54.5
911203	9-8-91	1115	28°34';153°34'	28°35';153°34'	8-10	14-19	-	-	69.0
911204	9-8-91	1205	28°36';153°34'	28°34';153°34'	8-10	14-19	-	-	70.7
911210	10-8-91	1035	28°36';153°35'	28°35';153°34'	7-8	12-15	-	-	73.5
911211	10-8-91	1125	28°35';153°34'	28°33';153°33'	8-9	14-17	-	-	63.1
911212	10-8-91	1215	28°33';153°34'	28°35';153°34'	5-8	9-15	-	0.1	36.4
911217	11-8-91	1250	28°37';153°35'	28°35';153°34'	5-7	9-13	-	0.1	72.0
911218	11-8-91	1350	28°35';153°34'	28°33';153°34'	5-7	9-13	-	0.1	34.2
911219	11-8-91	1440	28°33';153°34'	28°35';153°34'	8-9	14-17	-	-	67.6
911220	11-8-91	1530	28°35';153°34'	28°36';153°35'	7-8	12-15	0.1	-	122.9
Brunswick Heads Offshore									
911205	9-8-91	1915	28°25';153°39'	28°23';153°39'	28-29	51-53	0.1	-	118.3
911206	9-8-91	2010	28°22';153°39'	28°21';153°40'	29-30	53-55	-	-	93.7
911207	9-8-91	2110	28°21';153°40'	28°23';153°40'	29-31	53-57	0.2	-	101.8
911208	9-8-91	2210	28°24';153°40'	28°25';153°40'	28-31	51-57	0.5	-	140.5
911213	10-8-91	2055	28°25';153°39'	28°23';153°40'	28-30	51-55	0.3	-	117.5
911214	10-8-91	2130	28°22';153°39'	28°20';153°39'	29-31	53-57	0.3	-	71.5
911215	10-8-91	2255	28°21';153°40'	28°22';153°40'	29-30	53-55	1.6	-	94.1
911216	10-8-91	2355	28°22';153°40'	28°23';153°38'	26-28	47-51	0.4	-	97.4
911221	11-8-91	1845	28°26';153°39'	28°25';153°39'	26-28	47-51	0.4	-	97.1
911222	11-8-91	1945	28°24';153°38'	28°22';153°39'	26-28	47-51	0.2	-	102.3
911223	11-8-91	2040	28°22';153°39'	28°23';153°39'	27-29	49-53	0.4	-	101.7
911224	11-8-91	2135	28°24';153°39'	28°25';153°40'	28-30	51-55	0.2	-	91.3
Clarence River Inshore									
911225	12-8-91	1215	29°22';153°23'	29°23';153°23'	12-15	22-28	-	-	55.9
911226	12-8-91	1315	29°23';153°23'	29°24';153°22'	9-12	16-22	-	-	35.0
911227	12-8-91	1400	29°24';153°23'	29°23';153°23'	11-13	20-24	-	-	30.4
911228	12-8-91	1450	29°23';153°23'	29°25';153°22'	8-14	14-26	-	-	18.1
911233*	12-8-91	2335	29°22';153°23'	29°24';153°23'	9-14	16-26	0.1	0.3	28.1
911234*	13-8-91	0035	29°24';153°23'	29°25';153°22'	6-9	11-17	-	1.2	52.3
911235	13-8-91	0955	29°24';153°23'	29°23';153°23'	12-13	22-24	-	-	19.5
911236	13-8-91	1045	29°23';153°23'	29°22';153°24'	12-15	22-28	0.1	-	26.2
911237	13-8-91	1135	29°22';153°24'	29°23';153°23'	12-13	22-24	-	-	60.1
911238	13-8-91	1230	29°23';153°23'	29°24';153°22'	8-11	14-20	-	-	32.8
911245	14-8-91	1410	29°25';153°23'	29°24';153°23'	11-12	20-22	-	-	55.8
911246	14-8-91	1455	29°23';153°23'	29°21';153°24'	11-15	20-28	-	0.1	53.4
911247	14-8-91	1540	29°22';153°24'	29°23';153°23'	14-15	25-28	-	-	77.4
911248	14-8-91	1630	29°23';153°23'	29°24';153°22'	6-9	11-17	-	-	59.6
Clarence River Offshore									
911229	12-8-91	1835	29°30';153°33'	29°30';153°34'	37-38	67-70	4.5	-	30.3
911230	12-8-91	1930	29°28';153°34'	29°26';153°35'	38-41	69-75	3.6	-	61.9
911231	12-8-91	2025	29°26';153°35'	29°24';153°35'	37-39	67-72	3.8	-	48.1
911232	12-8-91	2130	29°24';153°35'	29°23';153°35'	37-38	67-70	2.7	-	56.2
911239+	13-8-91	1430	29°30';153°31'	29°28';153°33'	35-37	64-68	-	-	15.1
911240+	13-8-91	1525	29°27';153°34'	29°26';153°34'	38-40	69-73	0.1	-	31.9
911241	13-8-91	1820	29°24';153°36'	29°23';153°36'	39-40	71-73	3.5	-	72.1
911242	13-8-91	1920	29°23';153°36'	29°22';153°36'	38-40	69-73	2.6	-	68.0
911243	13-8-91	2030	29°21';153°36'	29°20';153°36'	37-38	67-70	2.5	-	75.1
911244	13-8-91	2115	29°21';153°35'	29°23';153°35'	36-38	65-70	5.7	-	93.0
911249	14-8-91	1840	29°25';153°34'	29°23';153°35'	36-38	65-70	4.8	-	47.4
911250	14-8-91	1940	29°22';153°35'	29°21';153°36'	38-39	69-72	3.8	-	76.8
911251	14-8-91	2040	29°22';153°36'	29°23';153°35'	38-39	69-72	3.3	-	73.9
911252	14-8-91	2140	29°24';153°34'	29°26';153°33'	35-37	64-68	2.9	-	38.0
Exploratory Tow off Brunswick Heads									
911209	10-8-91	0025	28°23';153°50'	29°21';153°51'	76-84	138-154	2.5	-	81.0

Appendix 2(d): Operational data, prawn catches and by-catch totals for trawling conducted on the central NSW grounds during Survey VI (* night-time tow; + daytime tow).

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Racek Prawn (kg)	Total Bycatch (kg)
Tuncurry Inshore										
911401	27-8-91	1040	32°09';152°31'	32°08';152°30'	7-8	12-15	-	-	-	142.6
911402	27-8-91	1130	32°08';152°31'	32°07';152°31'	9-11	16-20	-	-	-	196.0
911403	27-8-91	1225	32°07';152°31'	32°08';152°31'	9-12	16-22	-	-	-	215.5
911404	27-8-91	1330	32°09';152°30'	32°08';152°30'	4-6	7-11	-	-	-	120.9
911409	28-8-91	1140	32°10';152°30'	32°08';152°30'	4-7	7-13	-	-	-	220.9
911410	28-8-91	1230	32°08';152°31'	32°06';152°31'	7-9	12-17	-	-	-	486.5
911411	28-8-91	1335	32°06';152°31'	32°07';152°31'	10-12	18-22	-	-	-	223.9
911412	28-8-91	1420	32°08';152°31'	32°09';152°31'	8-10	14-19	-	-	-	290.0
911505	3-9-91	1210	32°10';152°31'	32°08';152°31'	6-7	11-13	-	-	-	409.7
911506	3-9-91	1255	32°08';152°31'	32°09';152°30'	8-10	14-18	-	-	-	322.9
911507	3-9-91	1345	32°09';152°31'	32°08';152°31'	10-12	18-22	-	-	-	236.5
911508	3-9-91	1440	32°07';152°30'	32°09';152°30'	3-6	5-11	-	-	-	176.8
Tuncurry Offshore										
911405	27-8-91	1925	32°00';152°50'	31°59';152°51'	53-56	96-103	0.2	-	-	206.0
911406	27-8-91	2040	31°59';152°50'	31°58';152°50'	49-51	89-94	0.5	-	-	157.1
911407	27-8-91	2145	31°57';152°49'	31°55';152°49'	46-48	84-88	1.4	-	-	146.4
911408	27-8-91	2250	31°56';152°49'	31°58';152°49'	48-50	87-91	2.0	-	-	262.9
911413	28-8-91	1825	31°59';152°47'	31°58';152°48'	45-47	82-86	1.5	-	-	158.8
911414	28-8-91	1925	31°57';152°50'	31°56';152°49'	46-48	84-88	0.8	-	-	176.0
911415	28-8-91	2035	31°55';152°51'	31°54';152°52'	48-50	87-92	1.1	-	-	86.1
911416	28-8-91	2140	31°56';152°51'	31°58';152°51'	49-53	89-97	1.0	-	-	172.1
911509	3-9-91	1850	31°55';152°51'	31°53';152°55'	49-50	89-92	0.3	-	-	120.3
911510	3-9-91	1950	31°54';152°52'	31°53';152°52'	47-49	86-90	1.9	-	-	117.4
911511	3-9-91	2105	31°53';152°51'	31°54';152°50'	46-48	84-88	2.0	-	-	118.7
911512	3-9-91	2210	31°56';152°50'	31°58';152°50'	47-49	86-90	0.9	-	-	275.0
Newcastle Inshore										
911417	29-8-91	1350	32°52';151°49'	32°53';151°48'	7-9	12-17	-	-	-	52.6
911418	29-8-91	1440	32°53';151°48'	32°52';151°50'	6-7	11-13	-	-	-	26.5
911419	29-8-91	1530	32°51';151°51'	32°51';151°52'	6-8	11-15	-	-	-	30.5
911420	29-8-91	1620	32°51';151°52'	32°51';151°51'	9-10	16-19	-	-	-	24.6
911421*	29-8-91	1830	32°51';151°52'	32°52';151°51'	6-8	11-15	0.1	0.3	-	36.4
911422*	29-8-91	1920	32°52';151°50'	32°53';151°49'	7-8	12-15	0.1	0.8	-	52.9
911515	4-9-91	1005	32°52';151°50'	32°53';151°49'	7-8	12-15	-	0.1	-	17.5
911516	4-9-91	1055	32°53';151°49'	32°52';151°50'	5-6	9-11	-	0.1	-	12.6
911517	4-9-91	1145	32°51';151°51'	32°50';151°52'	5-7	9-13	-	-	-	13.9
911518	4-9-91	1235	32°51';151°53'	32°51';151°52'	8-9	14-17	-	-	-	22.9
911523	5-9-91	0800	32°53';151°49'	32°52';151°50'	7-8	12-15	-	0.1	-	50.1
911524	5-9-91	0855	32°51';151°51'	32°51';151°53'	5-6	9-11	-	0.1	-	30.8
911525	5-9-91	0945	32°50';151°53'	32°51';151°52'	7-8	12-15	-	-	-	16.6
911526	5-9-91	1036	32°52';151°50'	32°53';151°49'	7-9	12-17	-	0.1	-	17.2
Newcastle Offshore										
911423	29-8-91	2110	32°56';151°56'	32°55';151°58'	42-43	76-79	11.0	-	0.1	42.9
911424	29-8-91	2210	32°54';151°58'	32°53';152°00'	37-41	67-75	2.1	-	0.1	33.4
911425	29-8-91	2305	32°53';152°01'	32°52';152°03'	37-43	67-79	10.5	-	0.1	60.6
911426	29-8-91	0005	32°53';152°02'	32°53';152°00'	40-41	73-75	6.2	-	-	61.8
911501	2-9-91	2120	32°55';151°57'	32°54';151°58'	37-42	67-77	1.2	-	0.6	48.1
911502	2-9-91	2215	32°54';151°59'	32°53';152°00'	39-40	71-73	2.5	-	1.0	49.4
911503	2-9-91	2315	32°53';152°00'	32°54';152°00'	39-42	71-77	1.8	-	0.7	44.5
911504	2-9-91	0025	32°53';152°01'	32°52';152°02'	41-43	75-79	10.6	-	1.0	40.6
911513+	4-9-91	0720	32°52';152°02'	32°53';152°01'	39-41	71-75	3.2	-	0.3	108.1
911514+	4-9-91	0820	32°53';152°00'	32°54';152°00'	35-39	64-72	0.1	-	0.1	49.6
911519	4-9-91	2120	32°54';151°58'	32°53';151°59'	38-40	69-74	1.6	-	0.4	27.2
911520	4-9-91	2225	32°53';152°01'	32°52';152°02'	39-41	71-75	8.7	-	0.4	49.3
911521	4-9-91	2330	32°53';152°02'	32°53';152°00'	39-40	71-73	7.2	-	0.5	51.2
911522	5-9-91	0035	32°54';151°59'	32°55';151°58'	38-40	69-73	1.3	-	0.4	51.9

Appendix 2(e): Operational data, prawn catches and by-catch totals for trawling conducted on the northern NSW grounds during Survey VII (* night-time tow; + daytime tow).

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Total Bycatch (kg)
Brunswick Heads Inshore									
911609	10-11-91	1430	28°37';153°35'	28°35';153°34'	5-7	9-13	0.1	0.1	271.7
911610	10-11-91	1530	28°35';153°34'	28°34';153°34'	7-8	12-15	0.1	0.1	79.6
911611	10-11-91	1630	28°34';153°34'	28°35';153°34'	7-9	12-17	0.1	-	81.5
911612	10-11-91	1715	28°35';153°34'	28°36';153°35'	5-6	9-11	-	0.1	304.2
911617	11-11-91	1430	28°36';153°35'	28°35';153°34'	6-7	11-13	0.1	0.1	167.5
911618	11-11-91	1530	28°35';153°34'	28°34';153°34'	7-8	12-15	0.1	-	111.2
911619	11-11-91	1630	28°34';153°34'	28°35';153°34'	7-8	12-15	0.1	-	107.5
911620	11-11-91	1730	28°35';153°34'	28°36';153°34'	5-6	9-11	-	0.1	161.6
911625	12-11-91	1530	28°36';153°35'	28°35';153°35'	7-8	12-15	-	0.1	211.9
911626	12-11-91	1605	28°35';153°34'	28°34';153°34'	7-9	12-17	-	-	117.3
911627	12-11-91	1700	28°34';153°34'	28°35';153°34'	7-9	12-17	0.1	-	99.8
911628	12-11-91	1750	28°35';153°35'	28°37';153°35'	6-8	11-15	-	-	226.7
Brunswick Heads Offshore									
911613	10-11-91	2025	28°27';153°40'	28°26';153°40'	26-29	47-53	0.3	-	140.9
911614	10-11-91	2120	28°25';153°40'	28°24';153°41'	29-31	53-57	0.6	-	195.5
911615	10-11-91	2225	28°23';153°40'	28°22';153°40'	30-31	54-57	2.0	-	171.7
911616	10-11-91	2330	28°21';153°40'	28°23';153°40'	29-30	53-55	0.2	-	195.5
911621	11-11-91	2015	28°23';153°41'	28°22';153°41'	30-32	54-59	5.3	-	138.6
911622	11-11-91	2110	28°21';153°41'	28°20';153°41'	31-33	56-61	4.4	-	114.5
911623	11-11-91	2210	28°20';153°40'	28°21';153°41'	30-32	54-59	4.0	-	98.8
911624	11-11-91	2310	28°22';153°41'	28°23';153°41'	31-32	56-59	4.5	-	134.0
911629	12-11-91	2115	28°24';153°40'	28°22';153°40'	29-30	53-55	0.6	-	151.3
911630	12-11-91	2215	28°22';153°40'	28°20';153°41'	29-31	53-57	2.2	-	110.2
911631	12-11-91	2315	28°20';153°41'	28°22';153°41'	31-32	56-59	4.0	-	121.6
911632	13-11-91	0015	28°23';153°41'	28°24';153°41'	30-32	54-59	5.7	-	143.7
Clarence River Inshore									
911633	13-11-91	0805	29°23';153°23'	29°25';153°23'	9-11	16-20	0.2	-	102.5
911634	13-11-91	0855	29°25';153°23'	29°23';153°23'	9-12	16-22	0.1	0.1	79.3
911635	13-11-91	0950	29°23';153°24'	29°24';153°23'	12-14	22-26	0.3	0.1	167.8
911636	13-11-91	1130	29°24';153°23'	29°23';153°23'	9-13	16-24	0.2	-	160.3
911637	14-11-91	1500	29°25';153°23'	29°23';153°23'	13-15	23-28	0.4	-	57.2
911638	14-11-91	1540	29°23';153°23'	29°21';153°23'	13-16	23-30	0.1	-	54.4
911639	14-11-91	1630	29°21';153°24'	29°23';153°23'	12-16	22-30	0.1	-	95.6
911640	14-11-91	1720	29°23';153°23'	29°25';153°23'	11-13	20-24	0.3	0.1	68.2
911641*	14-11-91	1945	29°24';153°22'	29°23';153°23'	10-11	18-20	6.3	0.2	127.1
911642*	14-11-91	2045	29°22';153°23'	29°21';153°24'	14-15	25-28	4.0	-	121.8
911645	19-11-91	0920	29°25';153°23'	29°24';153°23'	11-14	20-26	0.4	0.1	94.5
911646	19-11-91	1010	29°23';153°23'	29°22';153°24'	11-16	20-30	0.1	-	89.2
911647	19-11-91	1055	29°22';153°24'	29°23';153°23'	13-16	23-30	0.1	-	113.3
911648	19-11-91	1145	29°24';153°23'	29°25';153°23'	8-10	14-18	0.1	0.1	54.9
Clarence River Offshore									
911605	9-11-91	2315	29°29';153°34'	29°29';153°34'	38-39	69-72	1.0	-	16.0
911606	10-11-91	0020	29°28';153°33'	29°27';153°33'	35-37	64-68	1.3	-	34.0
911607	10-11-91	0120	29°28';153°33'	29°27';153°33'	36-37	65-68	1.0	-	23.9
911608	10-11-91	0235	29°28';153°34'	29°27';153°34'	38-39	69-72	0.5	-	24.6
911643+	19-11-91	0610	29°25';153°35'	29°24';153°35'	37-38	67-70	0.1	-	29.9
911644+	19-11-91	0710	29°24';153°35'	29°26';153°34'	37-38	67-70	0.1	-	24.8
911649	19-11-91	2120	29°22';153°36'	29°23';153°35'	38-39	69-72	1.3	-	84.8
911650	19-11-91	2220	29°25';153°35'	29°26';153°35'	38-39	69-72	0.7	-	34.1
911651	19-11-91	2320	29°28';153°35'	29°29';153°35'	40-41	73-75	3.3	-	122.5
911652	20-11-91	0020	29°31';153°34'	29°33';153°33'	40-41	73-75	1.1	-	81.1
Prawn Tagging Operational Data									
911601	5-11-91	1930	30°48';153°02'	30°47';153°02'	12-16	22-30	400 prawns tagged		
911602	6/7-11-91	1930	30°48';153°02'	30°47';153°02'	12-16	22-30	765 prawns tagged		
911603	7/8-11-91	2000	30°48';153°02'	30°47';153°02'	12-16	22-30	1100-prawns tagged		
911604	8/9-11-91	2000	30°48';153°02'	30°47';153°02'	12-16	22-30	750 prawns tagged		

Appendix 2(f): Operational data, prawn catches and by-catch totals for trawling conducted on the central NSW grounds during Survey VII (* night-time tow; + daytime tow).

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Racek Prawn (kg)	Total Bycatch (kg)
Tuncurry Inshore										
911803	03-12-91	1015	32°09';152°31'	32°08';152°31'	9–10	16–19	–	–	–	288.0
911804	03-12-91	1105	32°08';152°31'	32°09';152°30'	5–9	9–17	–	–	–	399.5
911805	03-12-91	1215	32°10';152°31'	32°08';152°31'	11–12	20–22	–	–	–	218.3
911806	03-12-91	1310	32°08';152°31'	32°07';152°31'	10–11	18–20	–	–	–	253.1
911811	04-12-91	0640	32°09';152°30'	32°08';152°30'	10–11	18–20	0.1	–	–	260.6
911812	04-12-91	0740	32°08';152°31'	32°09';152°31'	5–9	9–17	–	–	–	294.9
911813	04-12-91	0835	32°09';152°31'	32°08';152°31'	7–9	12–17	–	–	–	223.0
911814	04-12-91	0925	32°08';152°31'	32°09';152°31'	7–8	12–15	–	–	–	217.3
911904	10-12-91	0845	32°07';152°31'	32°08';152°31'	7–9	12–17	–	–	–	186.4
911905	10-12-91	0940	32°09';152°31'	32°10';152°31'	7–8	12–15	–	–	–	277.5
911906	10-12-91	1030	32°10';152°31'	32°08';152°31'	7–8	12–15	–	–	–	187.7
911907	10-12-91	1125	32°08';152°31'	32°06';152°32'	7–11	12–20	–	–	–	220.2
Tuncurry Offshore										
911807	03-12-91	2155	31°52';152°54'	31°53';152°53'	49–51	89–94	–	–	–	61.7
911808	03-12-91	2305	31°53';152°52'	31°54';152°51'	47–49	86–90	0.1	–	–	83.1
911809	04-12-91	0015	31°54';152°51'	31°55';152°50'	46–48	84–88	0.1	–	–	68.6
911810	04-12-91	0120	31°57';152°49'	31°58';152°49'	47–49	86–90	0.1	–	–	81.7
911901	10-12-91	0340	32°03';152°46'	32°02';152°47'	48–50	87–92	0.1	–	–	122.4
911902	10-12-91	0435	32°01';152°48'	32°00';152°49'	49–51	89–94	0.1	–	–	126.9
911903	10-12-91	0535	32°00';152°49'	31°59';152°50'	51–53	93–97	–	–	–	128.4
911908	10-12-91	2100	31°52';152°54'	31°54';152°53'	48–50	87–92	0.1	–	–	85.9
911909	10-12-91	2200	31°55';152°52'	31°56';152°51'	50–51	91–94	0.1	–	–	36.7
911910	10-12-91	2255	31°58';152°50'	31°59';152°50'	51–52	93–95	0.1	–	–	97.6
911911	11-12-91	0000	32°01';152°49'	32°02';152°48'	53–54	96–99	0.1	–	–	131.6
Newcastle Inshore										
911701	26-11-91	1455	32°53';151°49'	32°52';151°48'	7–8	12–15	0.1	0.4	–	14.5
911702	26-11-91	1550	32°52';151°51'	32°51';151°53'	8–9	14–17	–	0.1	–	18.9
911703	26-11-91	1645	32°51';151°53'	32°51';151°52'	8–11	14–20	0.1	–	–	18.3
911704	26-11-91	1735	32°52';151°51'	32°53';151°49'	8–9	14–17	0.2	0.8	–	17.3
911709	27-11-91	1345	32°53';151°49'	32°52';151°50'	7–8	12–15	–	0.2	–	7.4
911710	27-11-91	1445	32°52';151°51'	32°51';151°53'	9–11	16–20	–	–	–	17.7
911711	27-11-91	1540	32°51';151°53'	32°52';151°52'	9–11	16–20	–	–	–	15.8
911712	27-11-91	1640	32°52';151°50'	32°53';151°49'	7–9	12–17	0.2	3.2	–	20.7
911717	28-11-91	1455	32°53';151°49'	32°52';151°50'	7–8	12–15	0.1	8.0	–	26.0
911718	28-11-91	1555	32°52';151°51'	32°51';151°53'	9–11	16–20	0.1	0.1	–	19.1
911719	28-11-91	1645	32°51';151°53'	32°52';151°51'	9–11	16–20	0.1	0.1	–	25.1
911720	28-11-91	1735	32°52';151°50'	32°53';151°49'	8–9	14–17	0.1	4.8	–	33.6
911801*	03-12-91	0000	32°53';151°49'	32°52';151°51'	6–9	11–17	0.9	2.3	–	23.1
911802*	03-12-91	0100	32°52';151°51'	32°51';151°53'	9–11	16–20	0.7	1.2	–	23.2
Newcastle Offshore										
911705	26-11-91	2035	32°53';152°01'	32°52';152°02'	40–42	73–77	9.8	–	2.1	110.5
911706	26-11-91	2130	32°53';152°01'	32°53';152°00'	41–42	75–77	11.1	–	6.3	128.6
911707	26-11-91	2240	32°54';151°59'	32°53';152°00'	37–42	67–77	0.7	–	6.0	136.4
911708	26-11-91	2355	32°53';152°00'	32°52';152°01'	39–41	71–75	19.1	–	3.9	123.3
911713	27-11-91	2135	32°54';151°58'	32°54';152°00'	40–42	73–77	0.3	–	6.5	69.8
911714	28-11-91	0045	32°54';152°00'	32°53';152°01'	41–42	75–77	2.8	–	9.0	105.9
911715	28-11-91	0145	32°53';152°01'	32°52';152°02'	40–42	73–77	2.8	–	5.0	101.9
911716	28-11-91	0250	32°52';152°02'	32°52';152°00'	40–41	73–75	4.0	–	6.0	43.0
911721	28-11-91	2025	32°54';152°00'	32°53';152°01'	40–41	73–75	1.8	–	14.0	63.2
911722	28-11-91	2125	32°53';152°02'	32°52';152°03'	40–41	73–75	13.9	–	4.0	83.5
911723	28-11-91	2230	32°53';152°02'	32°54';152°00'	40–43	73–79	9.9	–	6.0	70.0
911724	28-11-91	2330	32°54';151°58'	32°55';151°57'	39–40	71–73	1.5	–	6.5	54.9
911815+	04-12-91	1705	32°53';152°01'	32°52';152°02'	38–40	69–73	0.1	–	2.2	40.7
911816+	04-12-91	1800	32°53';152°01'	32°53';152°00'	40–41	73–75	0.9	–	3.2	65.5
Prawn Tagging Operational Data										
911817	5/6-12-91	2100	33°11';151°44'	33°15';151°42'	34-36	62-66	1400 prawns tagged			
912001	16/17-12-91	2030	33°11';151°44'	33°15';151°42'	34-36	62-66	1650 prawns tagged			

Appendix 2(g): Operational data, prawn catches and by-catch totals for trawling conducted on the northern NSW grounds during Survey VIII (* night-time tow; + daytime tow).

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Total Bycatch (kg)
Brunswick Heads Inshore									
920206	20-3-92	1320	28°36';153°35'	28°35';153°34'	6-8	11-15	-	3.5	185.7
920207	20-3-92	1410	28°35';153°35'	28°34';153°34'	8-10	14-19	-	0.5	127.2
920208	20-3-92	1505	28°34';153°34'	28°35';153°35'	8-9	14-17	-	0.6	124.3
920209	20-3-92	1610	28°35';153°34'	28°36';153°35'	6-8	11-15	-	4.0	175.8
920214	24-3-92	1415	28°36';153°35'	28°35';153°34'	8-9	14-17	-	12.0	151.7
920215	24-3-92	1500	28°35';153°34'	28°36';153°35'	6-7	11-13	-	5.0	119.3
920216	24-3-92	1555	28°36';153°35'	28°35';153°34'	7-9	12-17	-	9.5	160.1
920217	24-3-92	1650	28°34';153°35'	28°36';153°35'	6-7	11-13	-	3.6	139.6
920222	25-3-92	1140	28°36';153°35'	28°35';153°34'	7-9	12-17	-	3.0	96.3
920223	25-3-92	1230	28°34';153°34'	28°36';153°35'	6-8	11-15	-	1.2	78.5
920224	25-3-92	1450	28°36';153°35'	28°35';153°34'	7-9	12-17	-	0.7	77.4
920225	25-3-92	1545	28°35';153°34'	28°36';153°35'	6-8	11-15	-	0.6	45.3
Brunswick Heads Offshore									
920210	20-3-92	1915	28°26';153°40'	28°25';153°40'	27-30	49-55	0.3	-	315.0
920211	20-3-92	2030	28°24';153°39'	28°23';153°39'	28-29	51-53	0.8	-	347.0
920212	20-3-92	2140	28°23';153°39'	28°21';153°40'	29-30	53-55	0.3	-	424.4
920213	20-3-92	2245	28°22';153°39'	28°24';153°40'	28-29	51-53	1.3	-	445.7
920218	24-3-92	1945	28°25';153°38'	28°23';153°38'	26-28	47-51	3.0	-	381.4
920219	24-3-92	2110	28°22';153°39'	28°21';153°40'	28-30	51-55	5.2	-	430.9
920220	24-3-92	2215	28°21';153°40'	28°23';153°40'	29-30	53-55	4.0	-	413.7
920221	24-3-92	2330	28°24';153°41'	28°25';153°40'	28-30	51-55	0.4	-	306.2
920226	25-3-92	1920	28°22';153°39'	28°21';153°38'	27-28	49-51	15.0	-	270.4
920227	25-3-92	2020	28°20';153°39'	28°22';153°40'	27-28	49-51	16.8	-	238.2
920228	25-3-92	2130	28°22';153°40'	28°20';153°39'	27-28	49-51	13.1	-	237.1
920229	25-3-92	2235	28°21';153°39'	28°23';153°39'	27-28	49-51	9.0	-	358.1
Clarence River Inshore									
920230	26-3-92	0755	29°24';153°22'	29°23';153°23'	7-11	12-20	0.5	15.5	62.8
920231	26-3-92	0850	29°22';153°23'	29°24';153°23'	9-12	16-22	0.3	13.0	76.4
920232	26-3-92	1025	29°24';153°23'	29°23';153°23'	10-12	18-22	0.7	10.0	63.0
920233	26-3-92	1115	29°22';153°23'	29°24';153°23'	8-10	14-19	0.1	5.5	76.7
920240*	1-4-92	0325	29°24';153°23'	29°22';153°23'	10-11	18-20	0.5	3.0	68.9
920241*	1-4-92	0420	29°23';153°23'	29°24';153°23'	8-11	14-20	0.2	5.2	86.9
920242	1-4-92	0715	29°22';153°24'	29°23';153°23'	12-15	22-28	-	0.1	39.8
920243	1-4-92	0820	29°24';153°23'	29°23';153°23'	9-11	16-20	-	0.1	47.6
920244	1-4-92	0915	29°23';153°23'	29°24';153°23'	8-11	14-20	-	0.1	33.8
920245	1-4-92	1010	29°24';153°23'	29°23';153°23'	10-14	18-26	0.1	0.1	126.2
920250	2-4-92	0610	29°24';153°23'	29°23';153°23'	9-14	16-26	0.1	1.2	69.5
920251	2-4-92	0700	29°23';153°23'	29°24';153°23'	9-13	16-24	0.1	10.2	42.4
920252	2-4-92	0750	29°24';153°23'	29°23';153°23'	9-12	16-22	0.1	4.0	72.9
920253	2-4-92	0835	29°23';153°23'	29°24';153°23'	8-11	14-20	-	2.0	211.0
Clarence River Offshore									
920202	19-3-92	1920	29°29';153°33'	29°28';153°33'	36-38	66-70	0.4	-	190.3
920203	19-3-92	2030	29°28';153°33'	29°27';153°34'	36-37	66-68	0.3	-	219.4
920204	19-3-92	2130	29°26';153°34'	29°25';153°34'	37-39	68-72	2.3	-	200.1
920205	19-3-92	2235	29°24';153°34'	29°22';153°35'	36-38	66-70	3.5	-	177.7
920234+	26-3-92	1425	29°22';153°35'	29°24';153°34'	34-36	62-66	0.1	-	100.0
920235+	26-3-92	1530	29°25';153°34'	29°26';153°34'	35-37	64-68	-	-	118.4
920236	26-3-92	1900	29°25';153°35'	29°24';153°35'	37-39	67-72	1.5	-	152.1
920237	26-3-92	2005	29°24';153°35'	29°23';153°36'	36-37	65-68	4.8	-	187.2
920238	26-3-92	2110	29°23';153°35'	29°25';153°34'	35-36	64-66	5.5	-	189.0
920239	6-3-92	2215	29°26';153°34'	29°28';153°33'	34-36	62-66	2.2	-	215.5
920246	1-4-92	2235	29°25';153°34'	29°27';153°34'	37-38	67-70	6.0	-	210.2
920247	1-4-92	2335	29°28';153°34'	29°26';153°34'	36-38	65-70	5.1	-	199.9
920248	2-4-92	0035	29°26';153°34'	29°25';153°35'	35-37	64-68	4.2	-	184.0
920249	2-4-92	0135	29°24';153°35'	29°23';153°36'	37-38	67-70	5.4	-	183.7
Exploratory Tow off Coffs Harbour									
920201	11-3-92	2220	30°21';153°24'	30°20';153°24'	76-84	138-154	0	-	25.0

Appendix 2(h): Operational data, prawn catches and by-catch totals for trawling conducted on the central NSW grounds during Survey VIII (* night-time tow; + daytime tow).

Operation No.	Date	Start Time	Position Start	Position Finish	Depth (fm)	Depth (m)	King Prawn (kg)	School Prawn (kg)	Racek Prawn (kg)	Total Bycatch (kg)
Tuncurry Inshore										
920501	5-5-92	0950	32°09';152°30'	32°08';152°31'	10–11	18–20	-	-	-	80.9
920502	5-5-92	1040	32°08';152°31'	32°09';152°30'	7–9	12–17	0.1	2.0	-	67.0
920503	5-5-92	1340	32°06';152°32'	32°07';152°31'	9–10	16–19	-	0.3	-	74.5
920504	5-5-92	1445	32°08';152°31'	32°10';152°31'	9–11	16–20	-	0.1	-	92.1
920509	6-5-92	1115	32°10';152°32'	32°08';152°32'	10–12	18–22	-	-	-	68.9
920510	6-5-92	1205	32°08';152°32'	32°07';152°33'	10–12	18–22	-	-	-	43.6
920511	6-5-92	1335	32°08';152°31'	32°09';152°31'	10–12	18–22	-	-	-	60.1
920512	6-5-92	1425	32°09';152°32'	32°08';152°32'	10–12	18–22	-	-	-	58.3
920517	7-5-92	1110	32°09';152°32'	32°08';152°32'	11–13	20–24	-	-	-	44.8
920518	7-5-92	1155	32°07';152°32'	32°06';152°33'	10–11	18–20	-	0.3	-	55.9
920519	7-5-92	1335	32°07';152°33'	32°08';152°33'	9–11	16–20	-	-	-	112.2
920520	7-5-92	1430	32°09';152°31'	32°08';152°31'	10–11	18–20	-	-	-	69.8
Tuncurry Offshore										
920505	5-5-92	1835	31°55';152°51'	31°55';152°51'	48–49	87–90	7.2	-	-	74.4
920506	5-5-92	1940	31°54';152°53'	31°53';152°54'	49–52	89–95	8.7	-	-	15.2
920507	5-5-92	2045	31°53';152°54'	31°55';152°53'	51–52	93–95	9.4	-	-	15.3
920508	5-5-92	2155	31°56';152°52'	31°57';152°51'	51–52	93–95	7.4	-	-	24.5
920513	6-5-92	1820	31°57';152°52'	31°56';152°53'	52–54	95–99	23.0	-	-	59.6
920514	6-5-92	1930	31°55';152°54'	31°53';152°54'	53–55	96–101	11.2	-	-	14.7
920515	6-5-92	2035	31°54';152°53'	31°56';152°53'	52–55	95–101	12.0	-	-	14.2
920516	6-5-92	2135	31°57';152°52'	31°58';152°51'	52–54	95–99	6.1	-	-	96.7
920521	7-5-92	1830	31°57';152°51'	31°56';152°52'	51–52	93–95	15.8	-	-	66.6
920522	7-5-92	1910	31°55';152°53'	31°54';152°54'	53–54	96–99	5.2	-	-	15.8
920523	7-5-92	2010	31°54';152°54'	31°55';152°53'	50–52	91–95	8.6	-	-	7.8
920524	7-5-92	2110	31°56';152°52'	31°57';152°52'	51–53	93–97	11.5	-	-	22.5
Newcastle Inshore										
920305	14-4-92	1330	32°53';151°48'	32°53';151°50'	6–7	11–13	-	1.1	-	28.8
920306	14-4-92	1430	32°52';151°52'	32°51';151°52'	7–8	12–15	1.1	7.0	-	102.4
920307	14-4-92	1525	32°51';151°53'	32°52';151°51'	7–8	12–15	0.1	5.5	-	78.0
920308	14-4-92	1620	32°52';151°50'	32°53';151°50'	7–8	12–15	0.1	1.0	-	36.5
920313	15-4-92	0745	32°53';151°48'	32°52';151°50'	7–8	12–15	0.2	8.5	-	29.1
920314	15-4-92	0835	32°52';151°51'	32°51';151°52'	6–8	11–15	1.5	2.5	-	37.4
920315	15-4-92	0930	32°51';151°53'	32°52';151°51'	6–9	11–17	0.9	2.1	-	39.2
920316	15-4-92	1030	32°52';151°50'	32°53';151°50'	6–8	11–15	0.3	6.4	-	36.7
920405	30-4-92	1025	32°53';151°49'	32°52';151°50'	6–10	11–19	0.1	3.7	-	38.7
920406	30-4-92	1120	32°52';151°52'	32°51';151°53'	7–10	12–19	0.1	0.3	-	35.2
920407	30-4-92	1210	32°51';151°54'	32°52';151°52'	7–9	12–17	0.1	0.6	-	30.1
920408	30-4-92	1305	32°52';151°51'	32°53';151°49'	7–8	12–15	0.1	1.2	-	32.9
920411*	30-4-92	1800	32°51';151°53'	32°52';151°52'	8–9	14–17	0.3	1.8	-	46.3
920412*	30-4-92	1900	32°52';151°50'	32°53';151°49'	7–8	12–15	0.2	3.1	-	31.3
Newcastle Offshore										
920301	13-4-92	2210	32°55';151°57'	32°54';151°59'	38–39	69–72	1.2	-	5.7	54.0
920302	13-4-92	2310	32°53';152°00'	32°53';152°01'	37–41	67–75	5.4	-	1.2	50.7
920303	14-4-92	0020	32°53';152°00'	32°53';152°01'	41–42	75–77	0.1	-	6.5	45.8
920304	14-4-92	0120	32°54';151°58'	32°55';151°56'	34–38	62–70	4.0	-	1.6	65.6
920309	14-4-92	1855	32°56';151°57'	32°55';151°57'	37–39	67–72	4.7	-	0.1	78.3
920310	14-4-92	2000	32°54';151°58'	32°54';151°59'	35–38	64–70	3.6	-	1.0	52.4
920311	14-4-92	2100	32°53';152°00'	32°52';152°01'	35–38	64–70	10.2	-	0.2	42.5
920312	14-4-92	2155	32°52';152°01'	32°53';151°59'	38–40	69–73	4.6	-	1.3	51.5
920401	29-4-92	2350	32°55';151°58'	32°54';151°59'	39–40	71–73	0.7	-	11.0	48.6
920402	30-4-92	0045	32°53';152°00'	32°52';152°01'	35–37	64–68	5.2	-	-	40.0
920403	30-4-92	0150	32°53';152°02'	32°54';152°00'	40–43	73–79	10.5	-	0.8	55.4
920404	30-4-92	0305	32°54';151°58'	32°55';151°56'	38–41	69–75	1.0	-	8.4	59.9
920409+	30-4-92	1505	32°56';151°55'	32°55';151°57'	35–37	64–68	-	-	-	72.3
920410+	30-4-92	1610	32°54';151°59'	32°53';152°00'	37–40	67–73	0.3	-	0.2	43.9
Prawn Tagging Operational Data										
920101	2/3-3-92	2000	33°11';151°44'	33°15';151°42'	34–36	62–66		2000 prawns tagged		
920102	3/4-3-92	2100	33°11';151°44'	33°15';151°42'	34–36	62–66		1200 prawns tagged		

Appendix 3: Length frequency histograms of important commercial species.

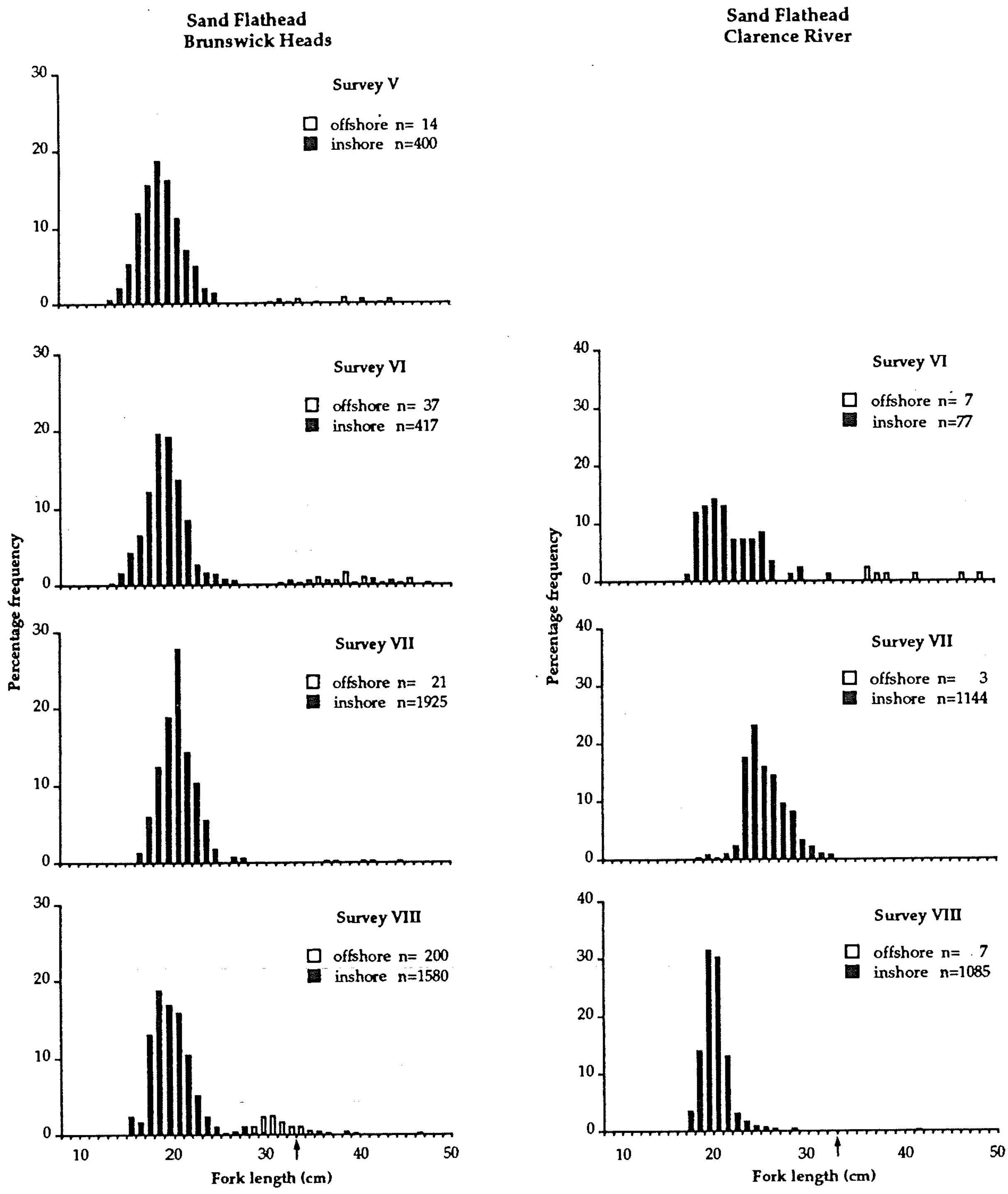


Figure 2: Length frequency of sand flathead on the Brunswick Heads and Clarence River inshore and offshore grounds during Surveys V–VIII (the arrow indicates the minimum legal length).

Appendix 3: (continued)

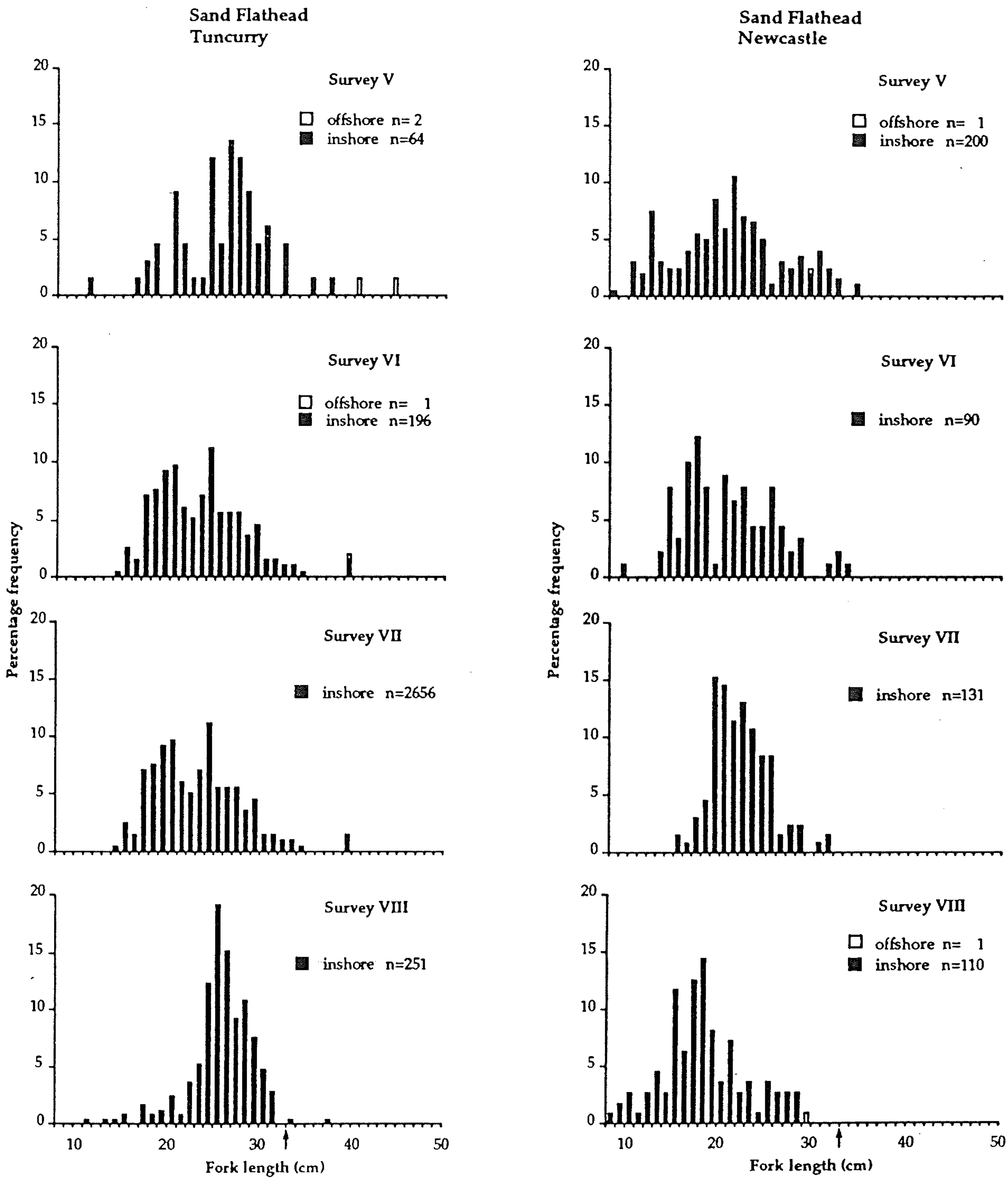


Figure 3: Length frequency of sand flathead on the Tuncurry and Newcastle inshore and offshore grounds during Surveys V–VIII (the arrow indicates minimum legal length).

Appendix 3: (continued)

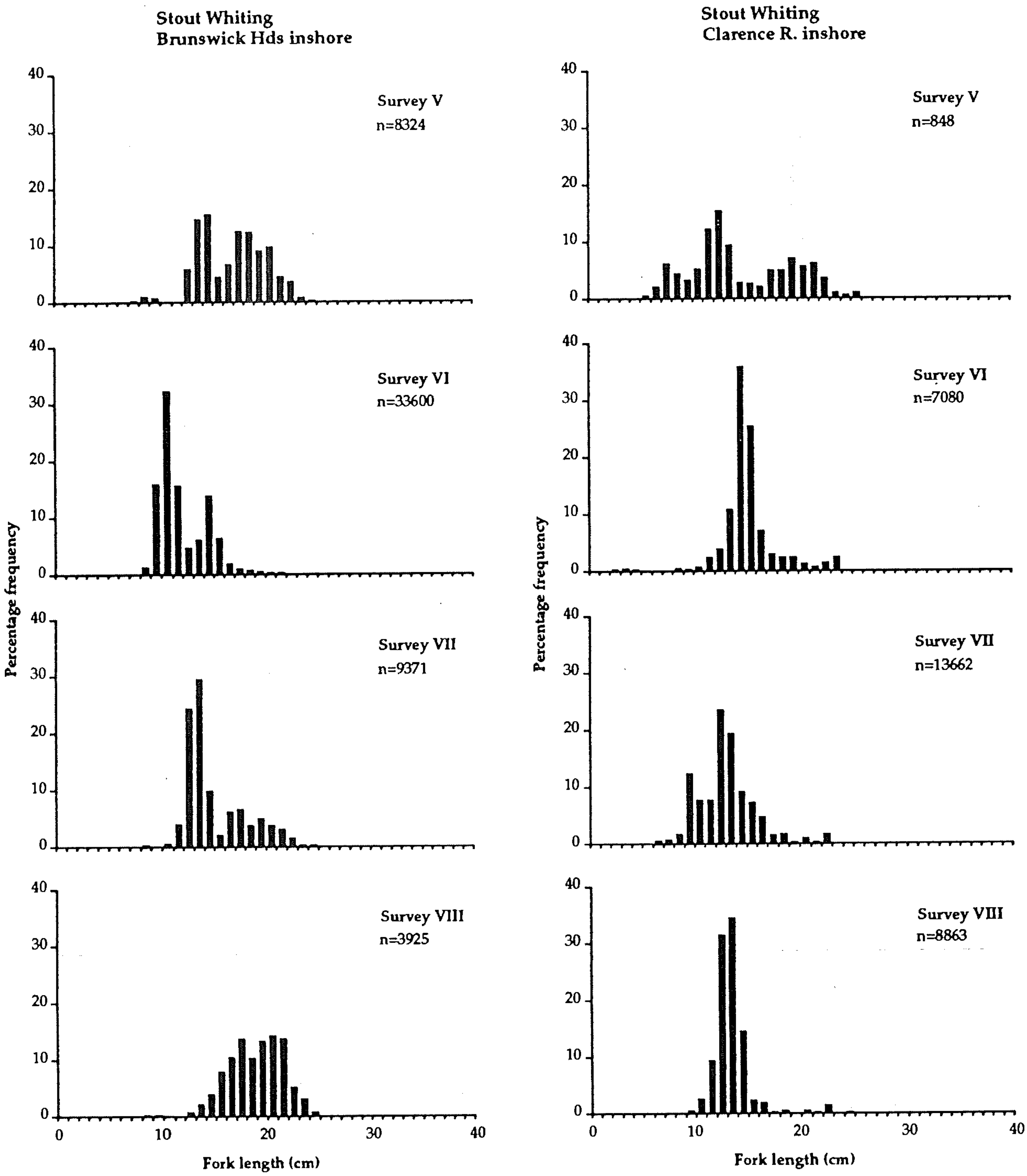


Figure 4: Length frequency of stout whiting on the Brunswick Heads and Clarence River inshore grounds during Surveys V–VIII.

Appendix 3: (continued)

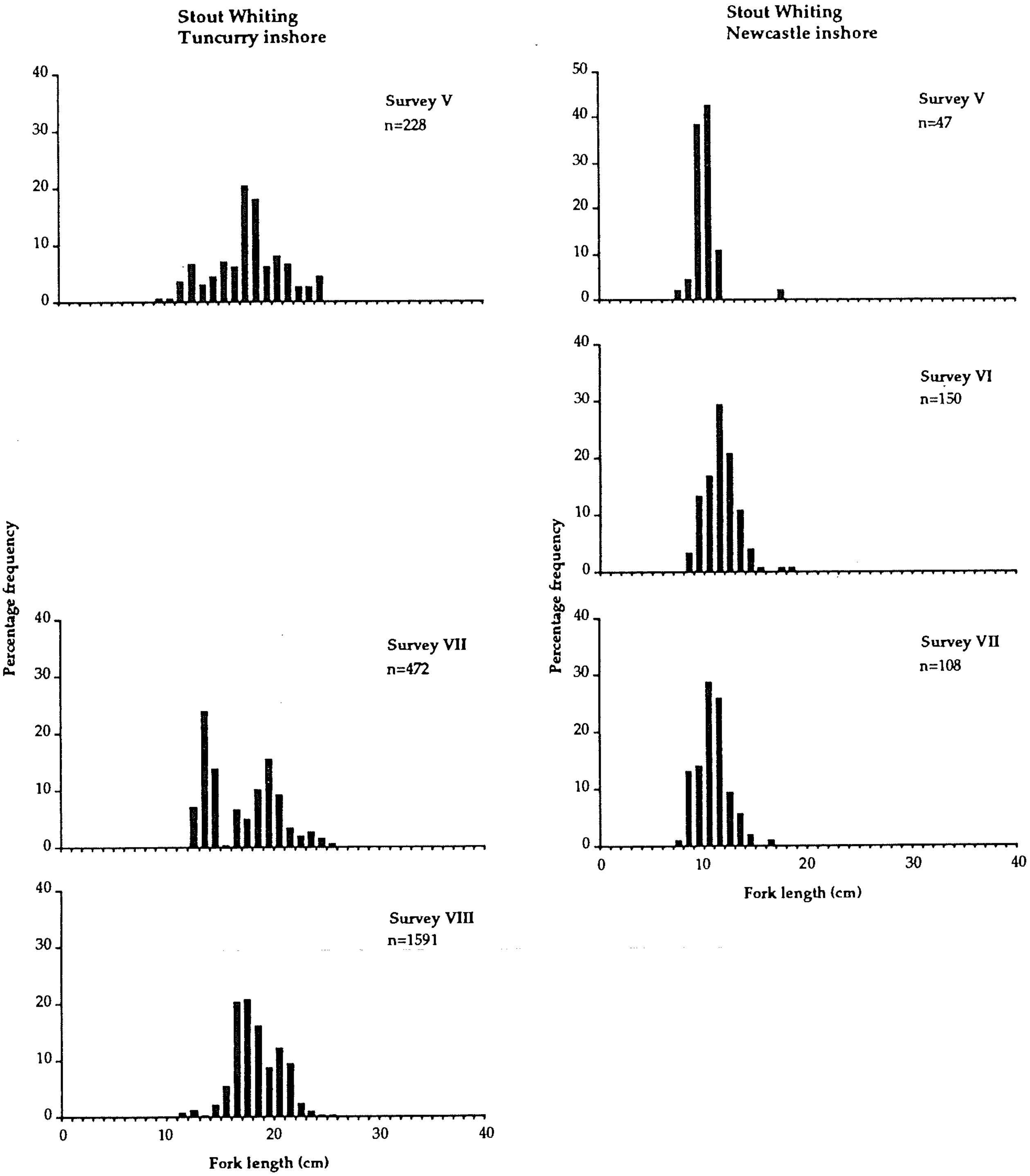


Figure 5: Length frequency of stout whiting on the Tuncurry and Newcastle inshore grounds during Surveys V-VIII.

Appendix 3: (continued)

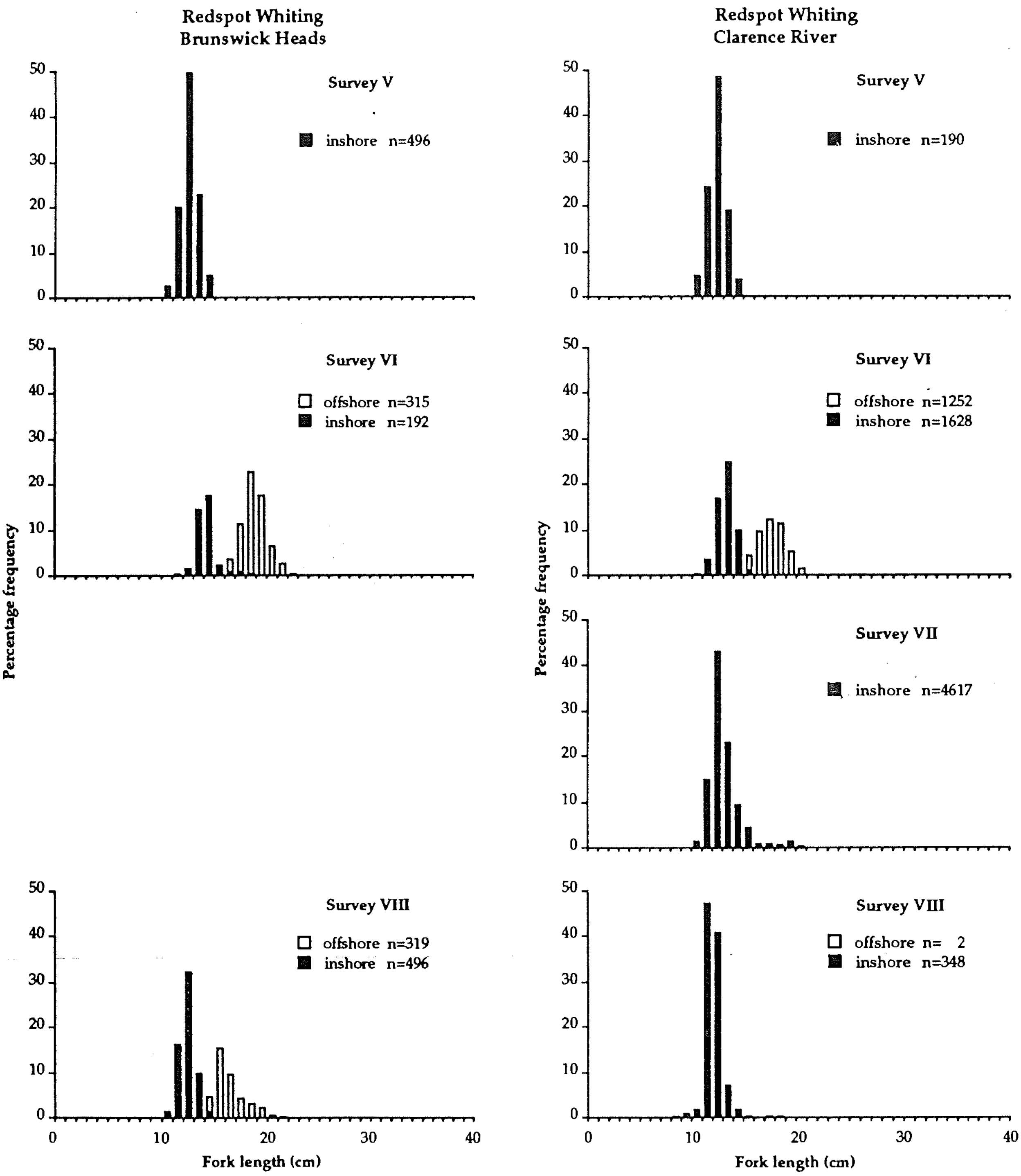


Figure 6: Length frequency of redspot whiting on the Brunswick Heads and Clarence River inshore and offshore grounds during Surveys V–VIII.

Appendix 3: (continued)

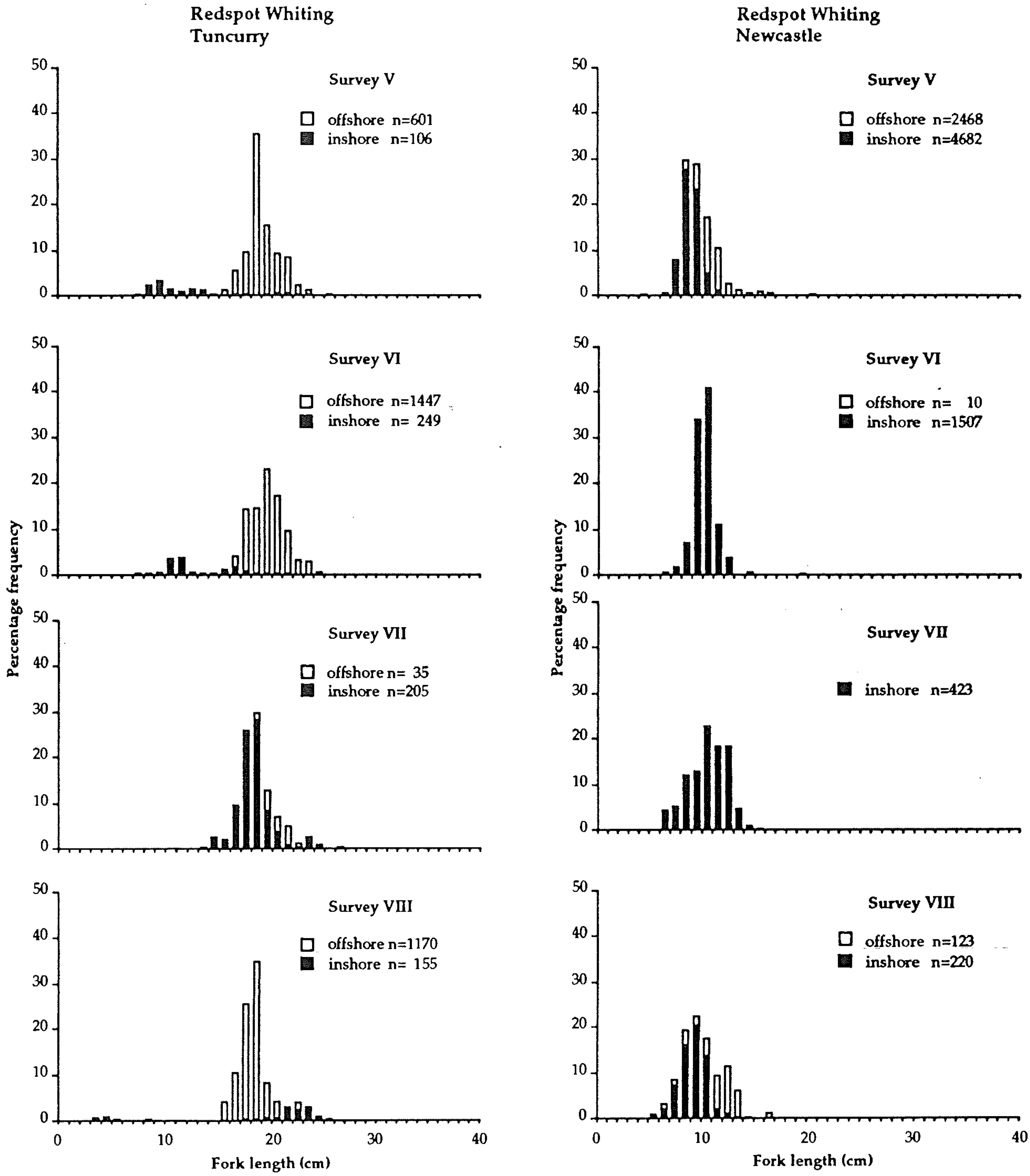


Figure 7: Length frequency of redspot whiting on the Tuncurry and Newcastle inshore and offshore grounds during Surveys V–VIII.

Appendix 3: (continued)

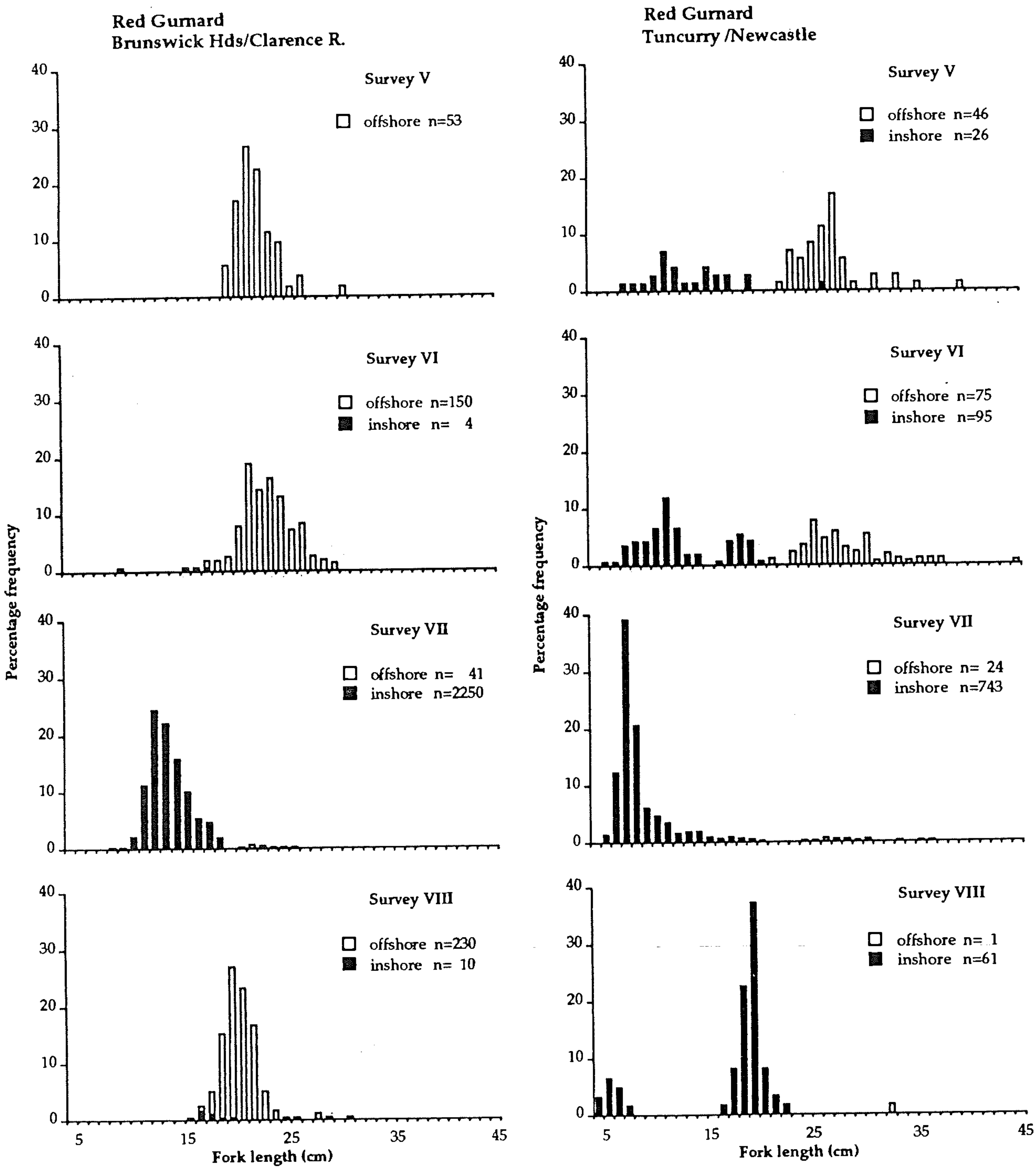


Figure 8: Length frequency of red gurnard on inshore and offshore grounds off Brunswick Heads and the Clarence River (combined), and Tuncurry and Newcastle (combined) during Surveys V–VIII.

Appendix 3: (continued)

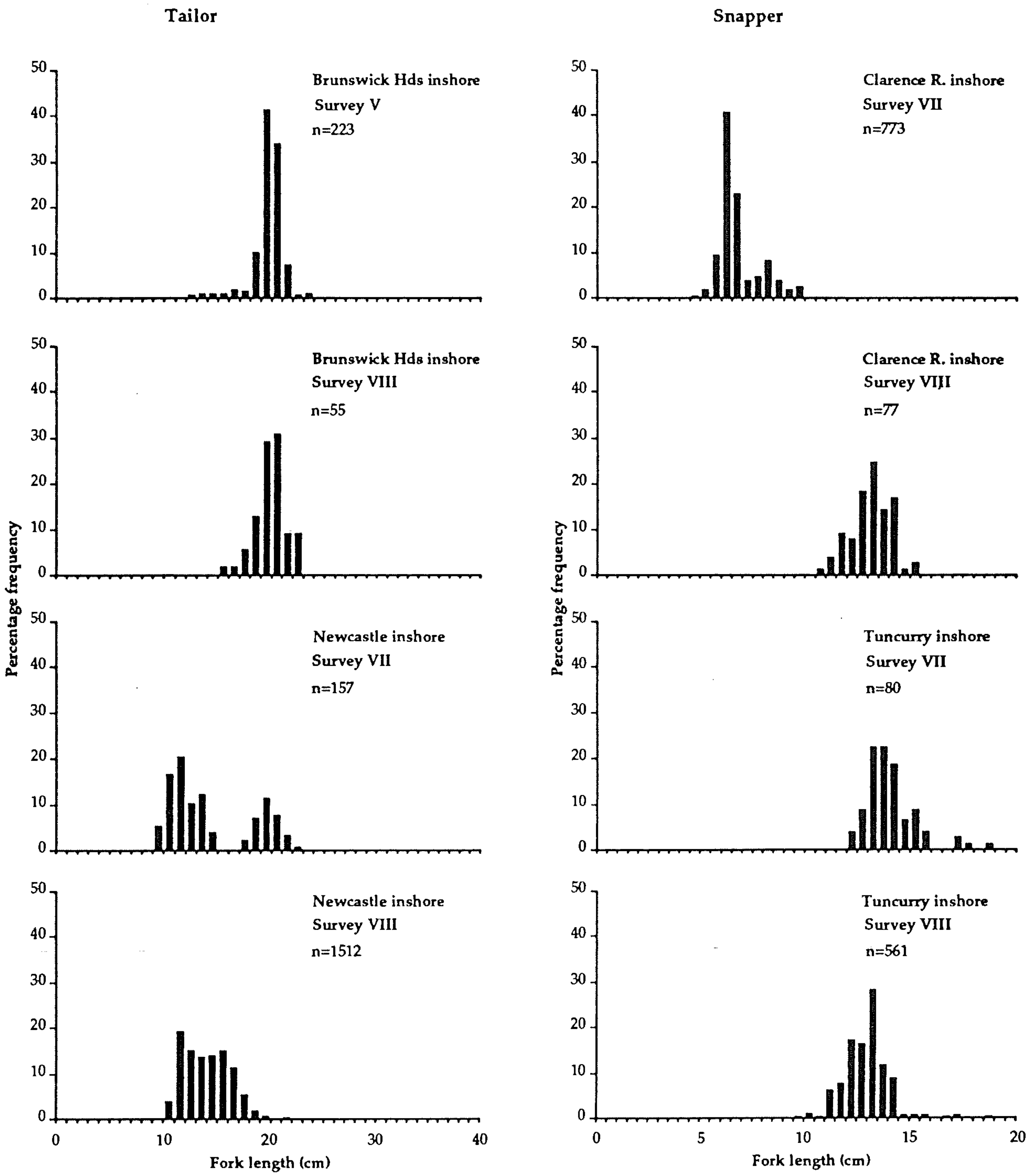


Figure 9: Length frequency of tailor on the Brunswick Heads (Surveys V and VIII) and Newcastle Surveys VII-VIII) inshore grounds, and of snapper on the Clarence River (Surveys VII-VIII) and Tuncurry (Surveys VII-VIII) inshore grounds.

Appendix 3: (continued)

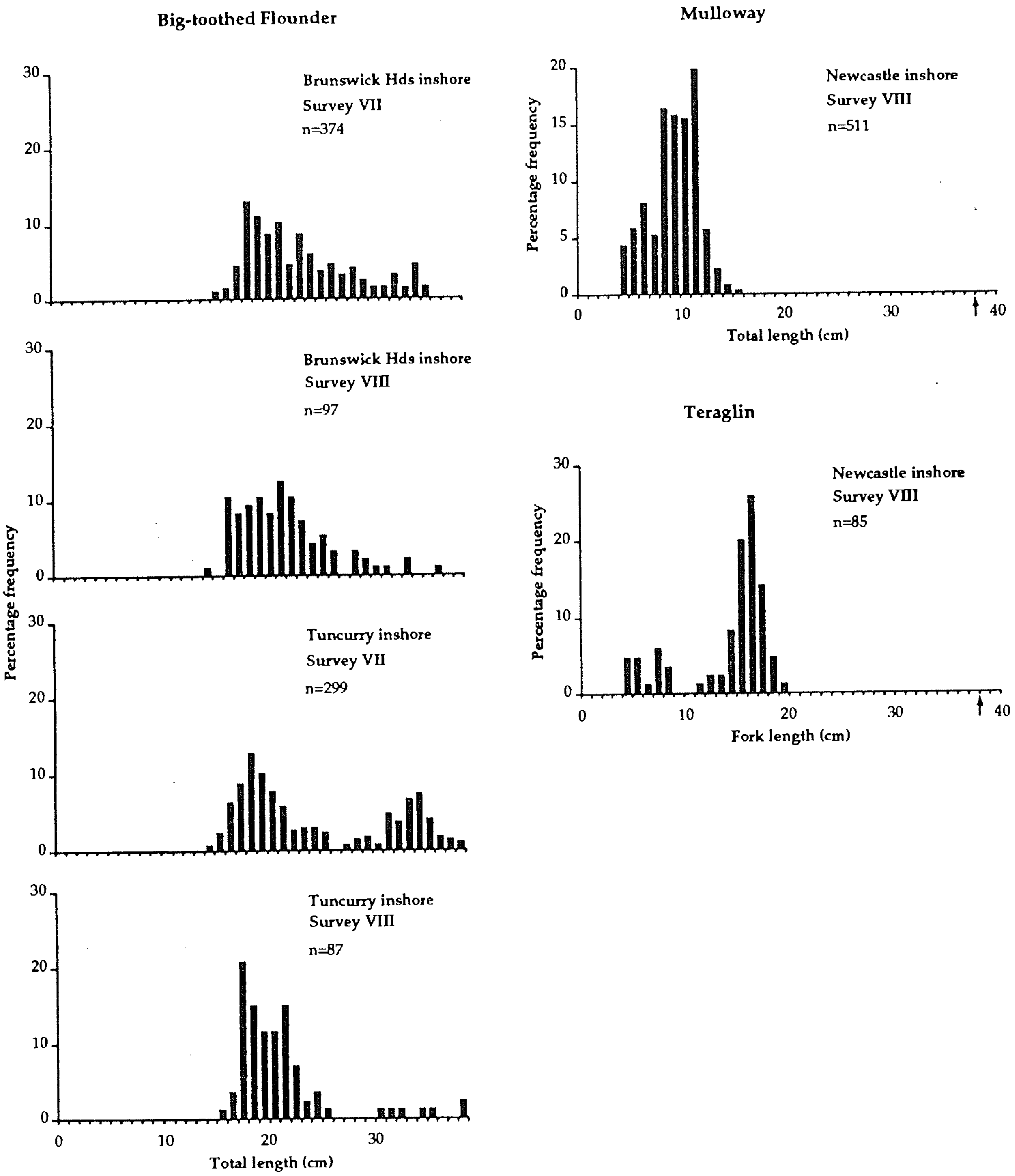


Figure 10: Length frequency of big-tooothed flounder on inshore grounds off Brunswick Heads and Tuncurry during Surveys VII and VIII, and of mulloway and teraglin on the Newcastle inshore ground during Survey VIII.

Appendix 3: (continued)

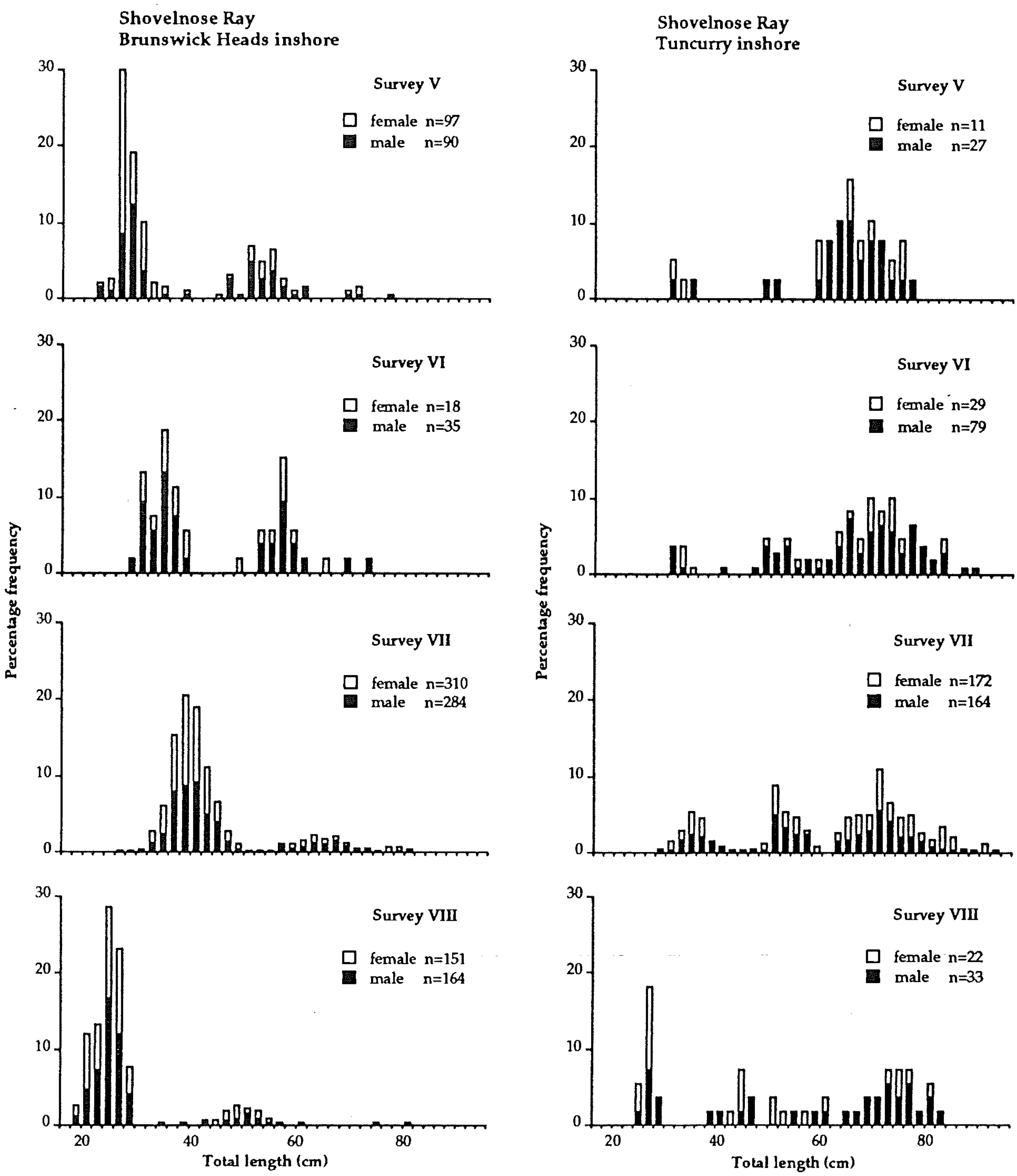


Figure 11: Length frequency of shovelnose rays on the Brunswick Heads and Tuncurry inshore grounds during Surveys V–VIII.

Appendix 3: (continued)

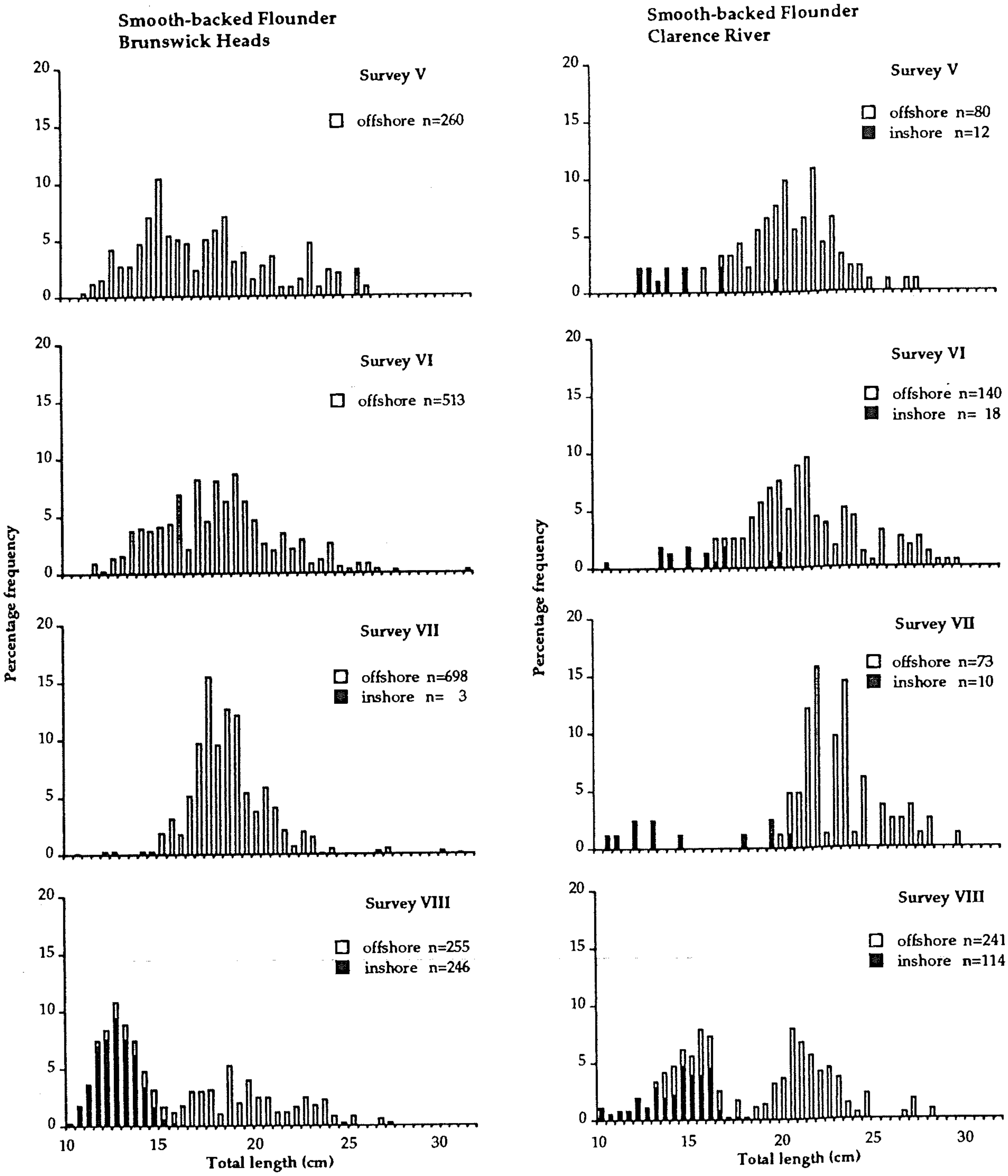


Figure 12: Length frequency of smooth-backed flounder on the Brunswick Heads and Clarence River inshore and offshore grounds during Surveys V–VIII.

Appendix 3: (continued)

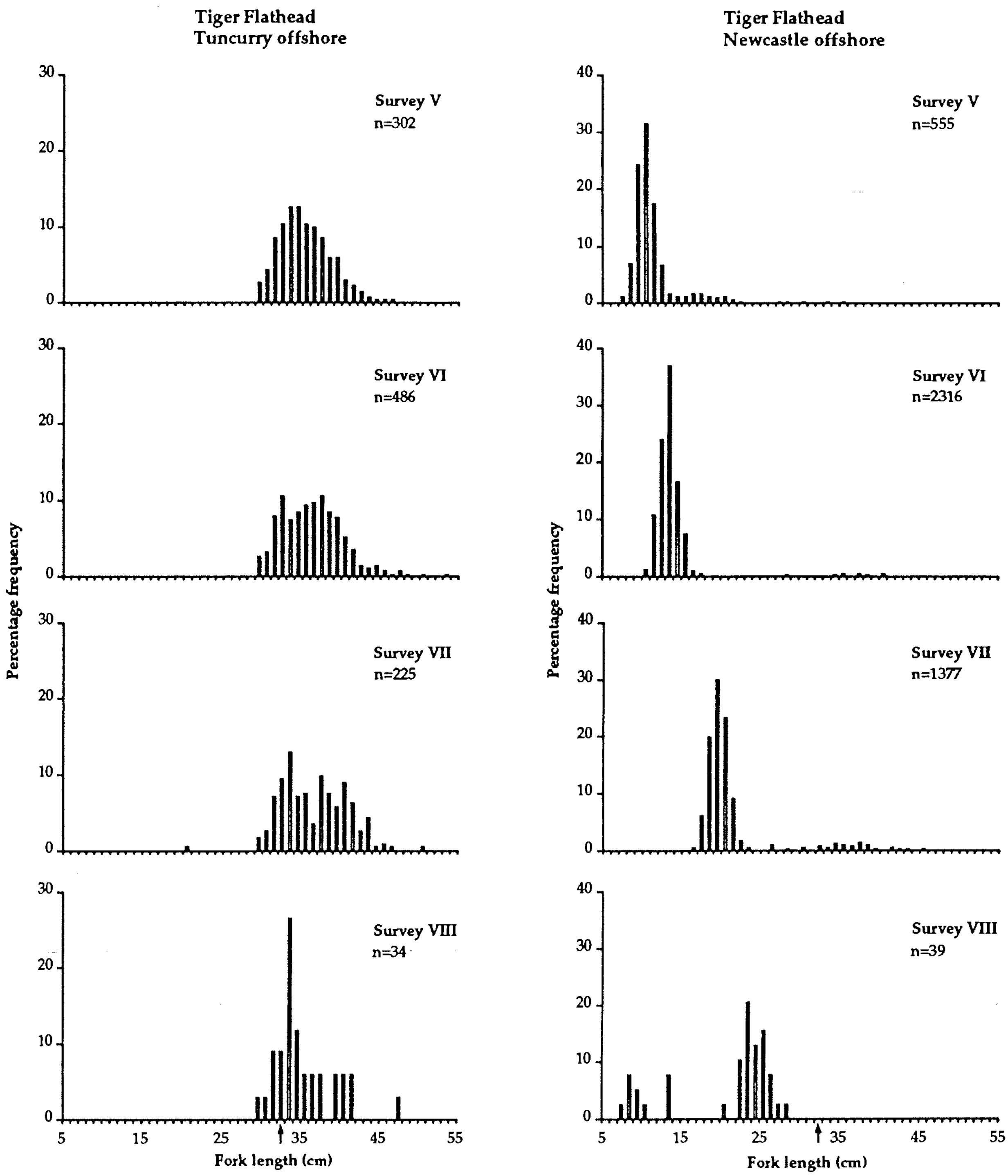


Figure 13: Length frequency of tiger flathead on the Tuncurry and Newcastle offshore grounds during Surveys V–VIII (the arrow indicates the minimum legal length).

Appendix 3: (continued)

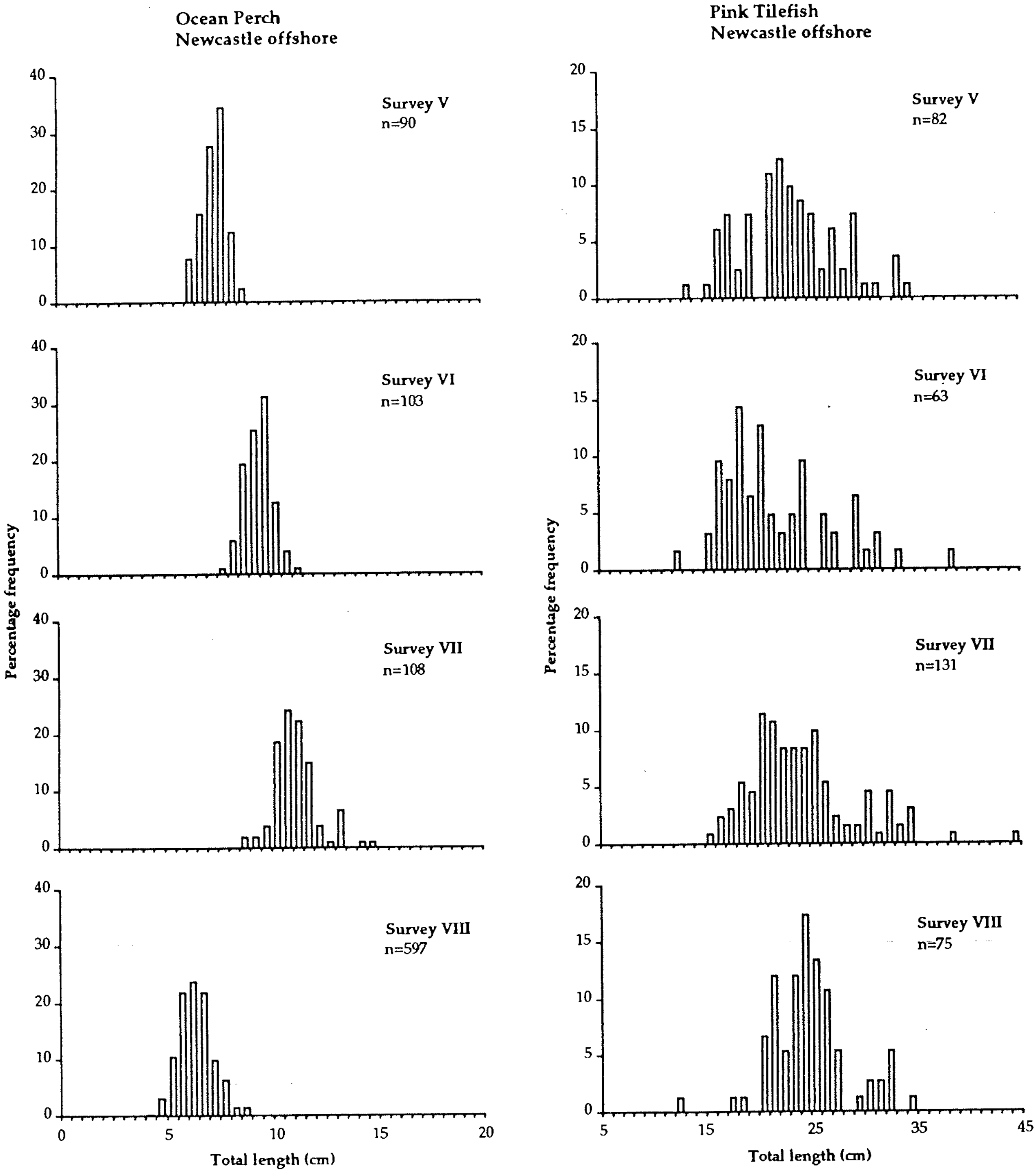


Figure 14: Length frequency of ocean perch and pink tilefish on the Newcastle offshore ground during Surveys V–VIII.

Appendix 3: (continued)

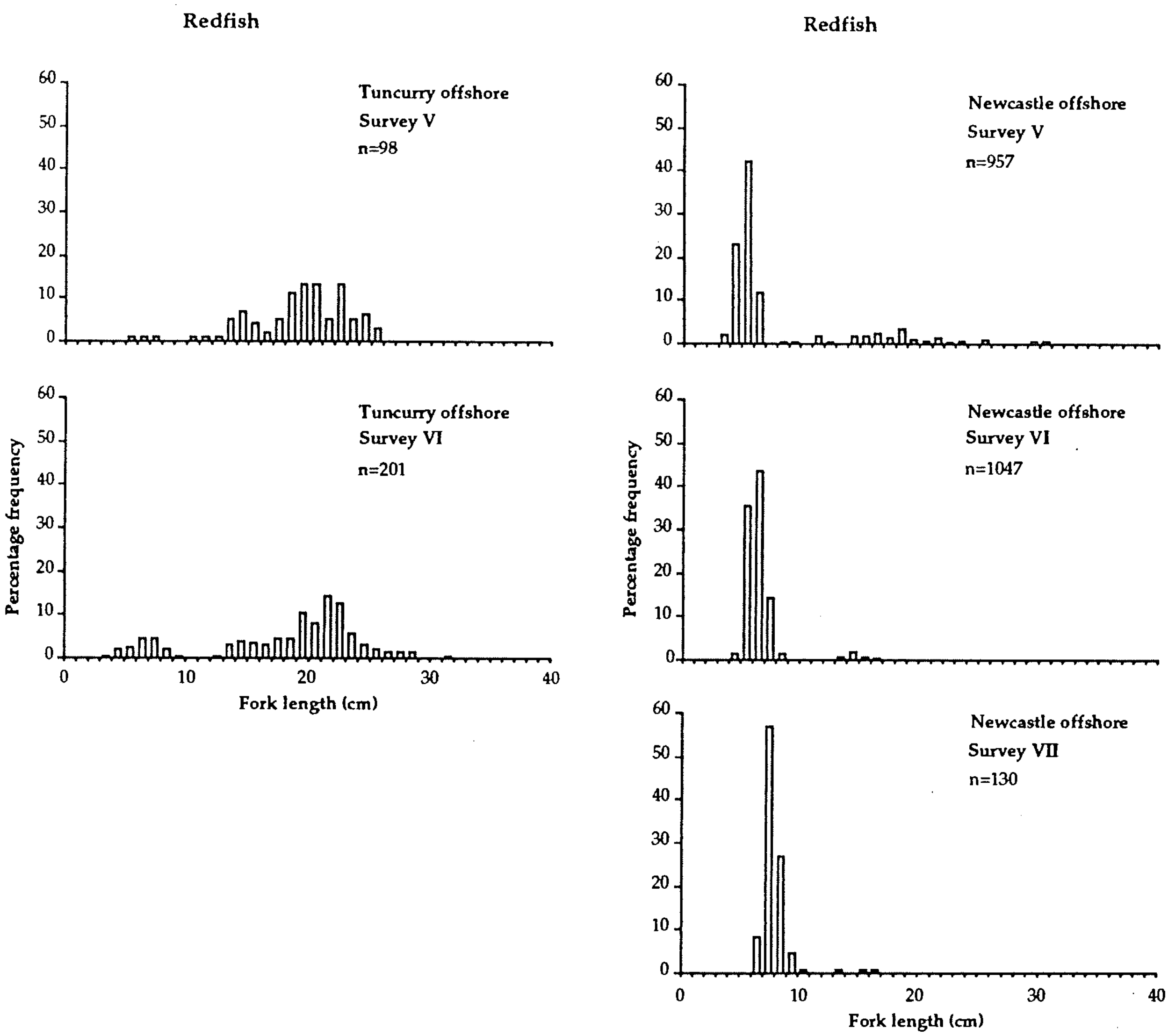


Figure 15: Length frequency of redfish on the Tuncurry and Newcastle offshore grounds during Surveys V–VII.

Appendix 3: (continued)

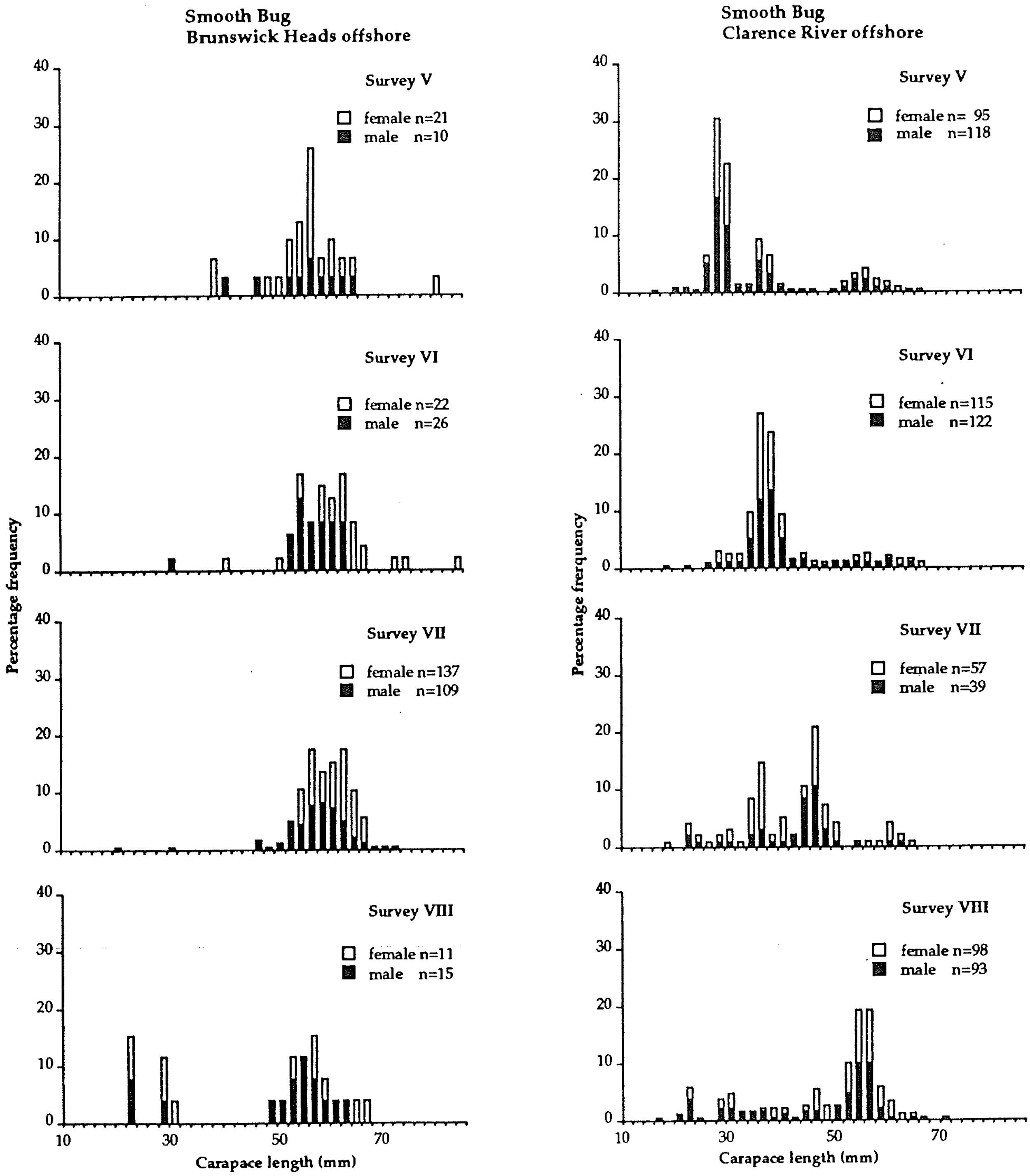
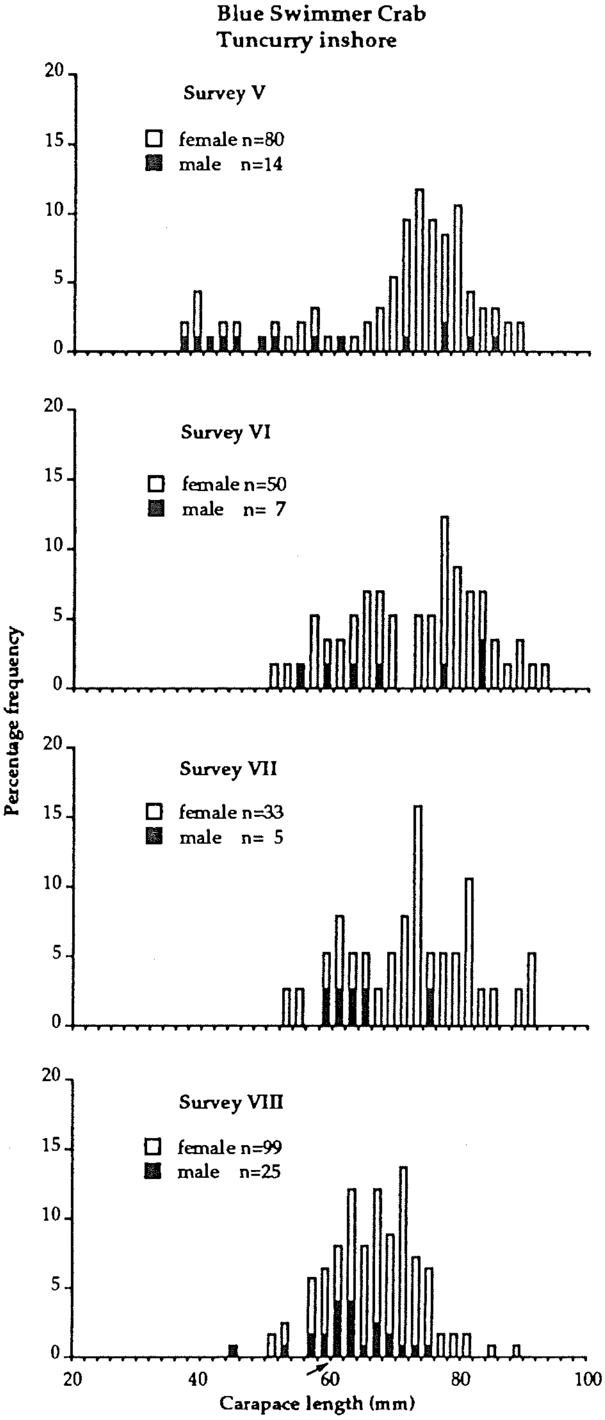


Figure 16: Length frequency of smooth bugs on the Brunswick Heads and Clarence River offshore grounds during Surveys V–VIII.

Appendix 3: (continued)



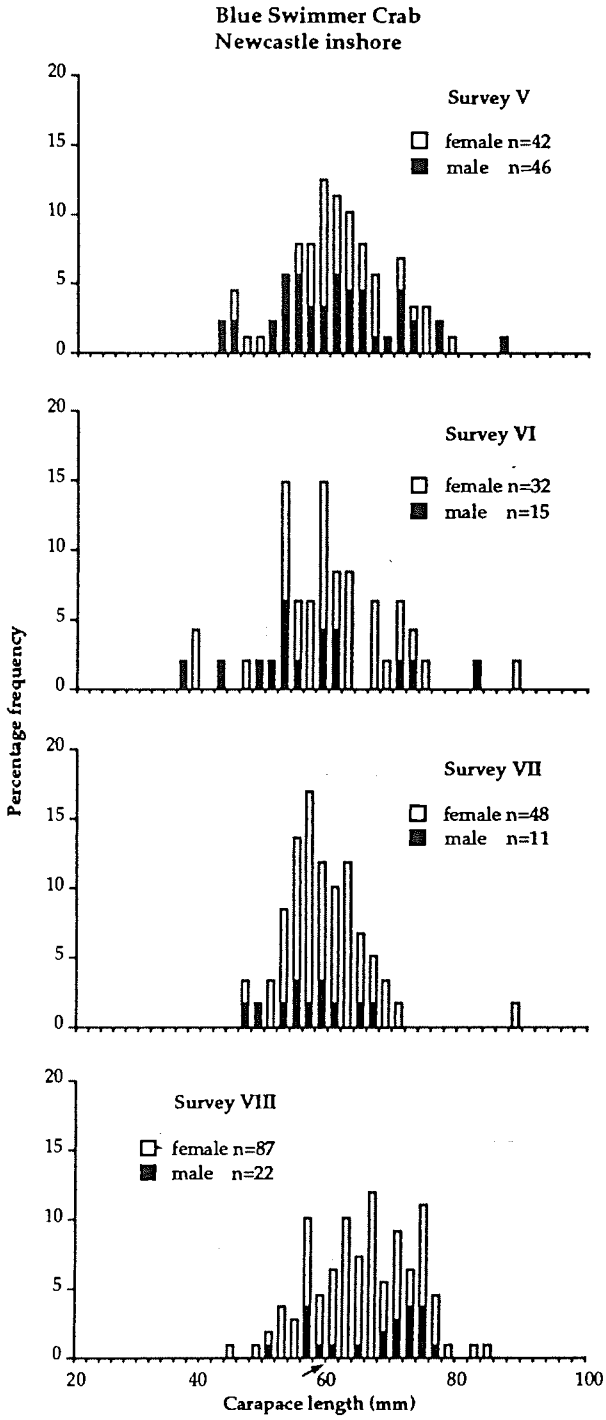


Figure 17: Length frequency of blue swimmer crabs on the Tuncurry and Newcastle inshore grounds during Surveys V–VIII (the arrow indicates the minimum legal length).

Appendix 3: (continued)

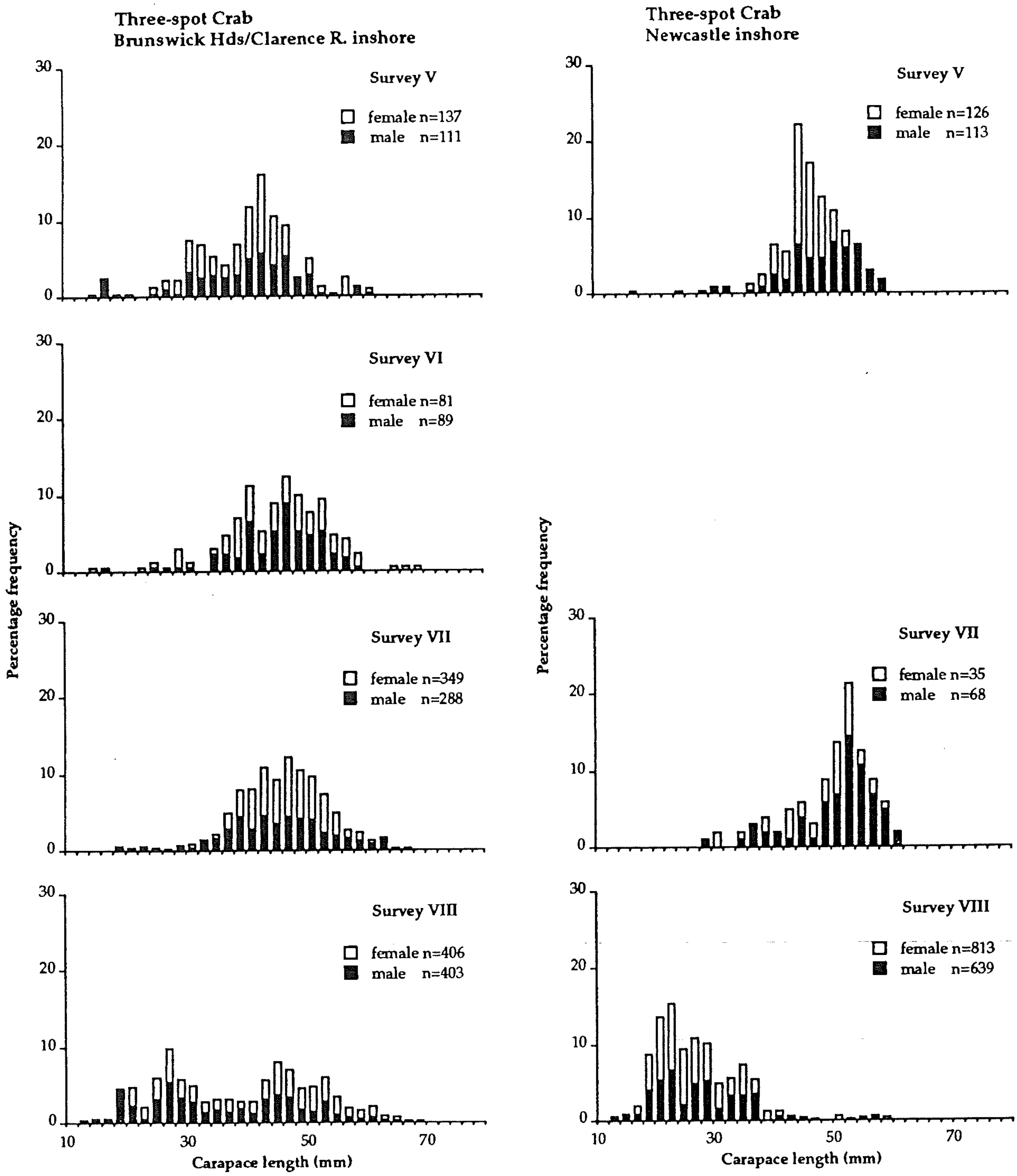


Figure 18: Length frequency of three-spotted crabs on the inshore grounds off Brunswick Heads and the Clarence River (combined), and off Newcastle during Surveys V–VIII.

Appendix 3: (continued)

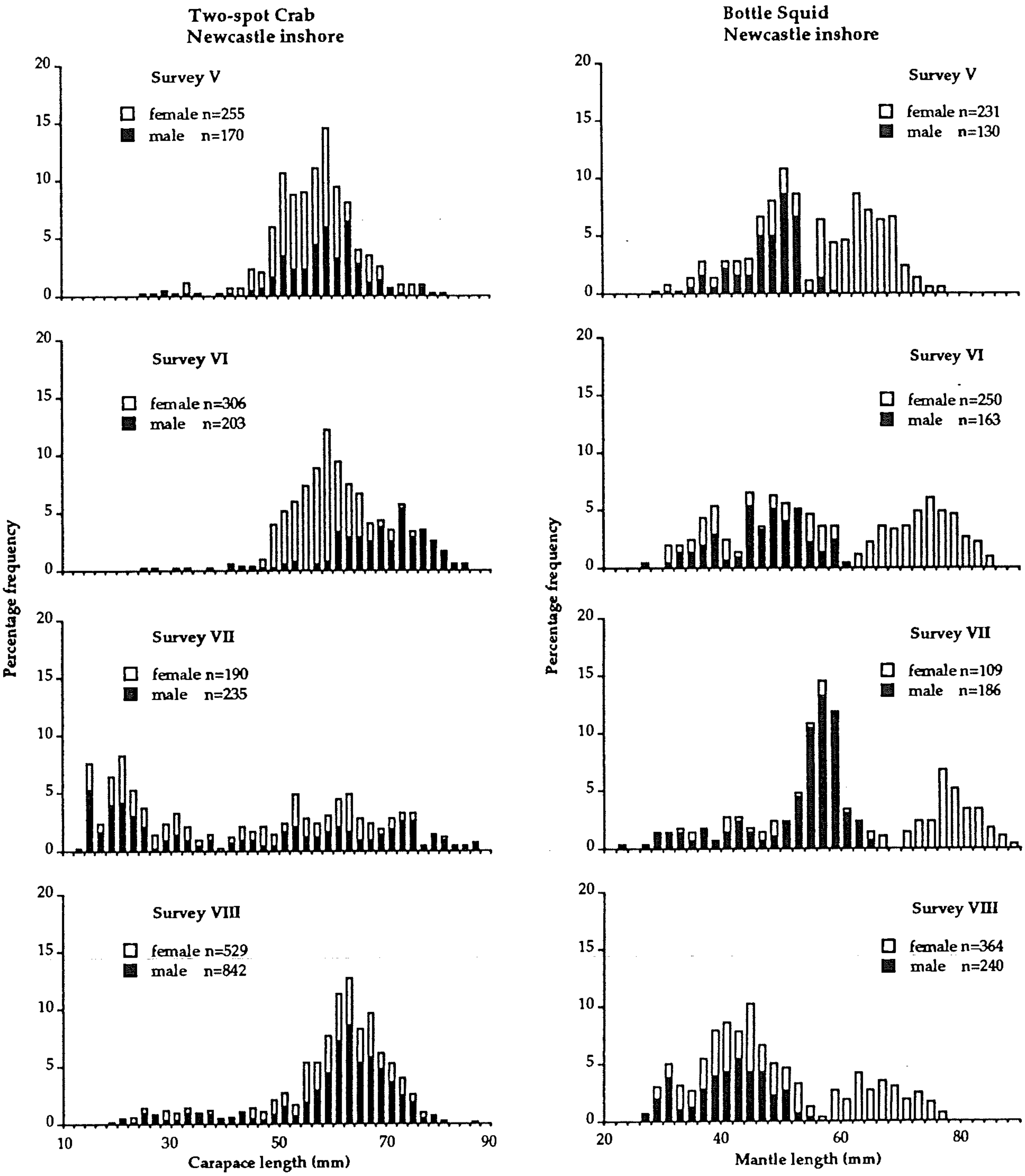


Figure 19: Length frequency of two-spotted crabs and bottle squid on the Newcastle inshore ground during Surveys V-VIII.

Appendix 3: (continued)

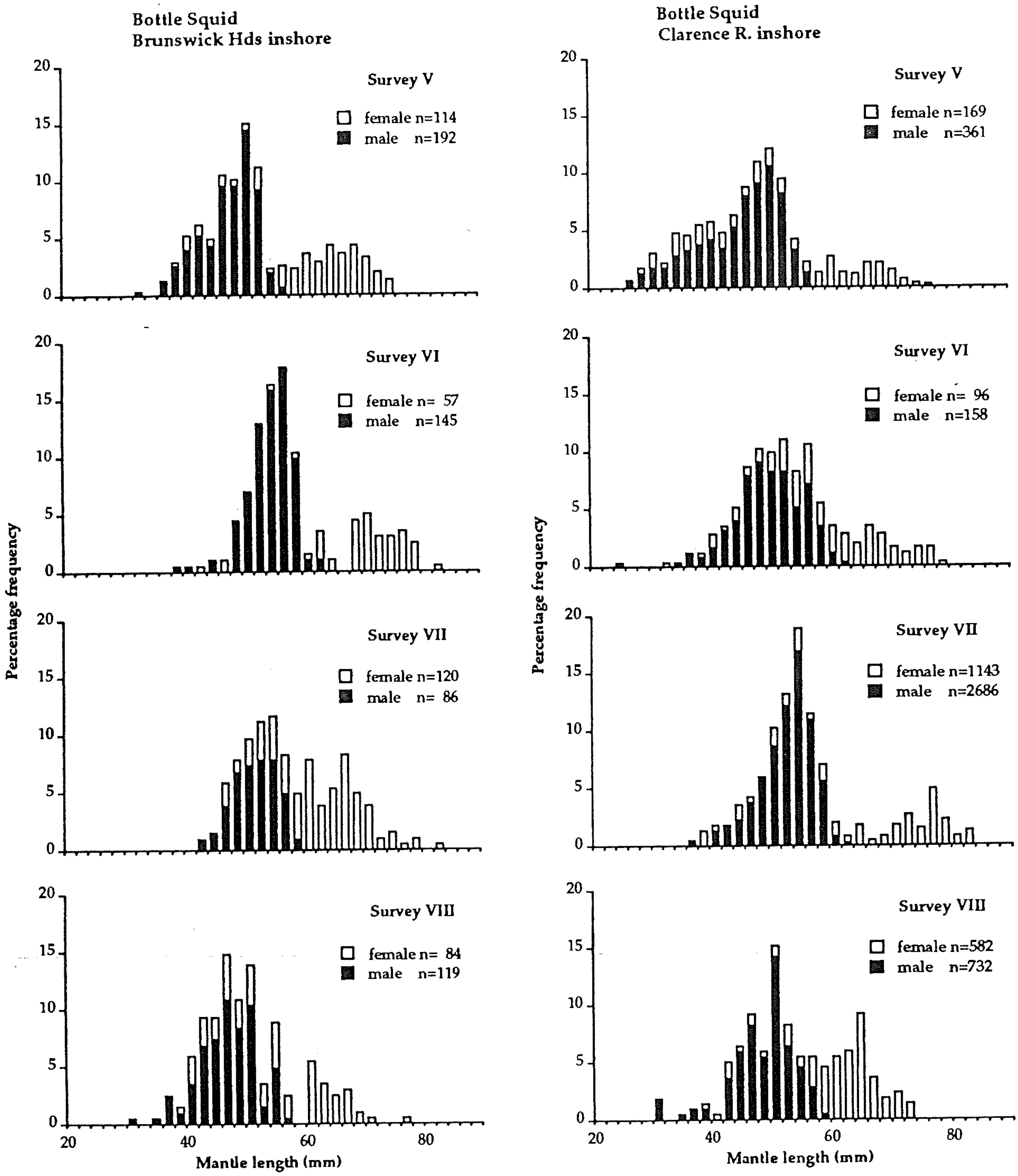


Figure 20: Length frequency of bottle squid on the Brunswick Heads and Clarence River grounds inshore during Surveys V–VIII.

Appendix 3: (continued)

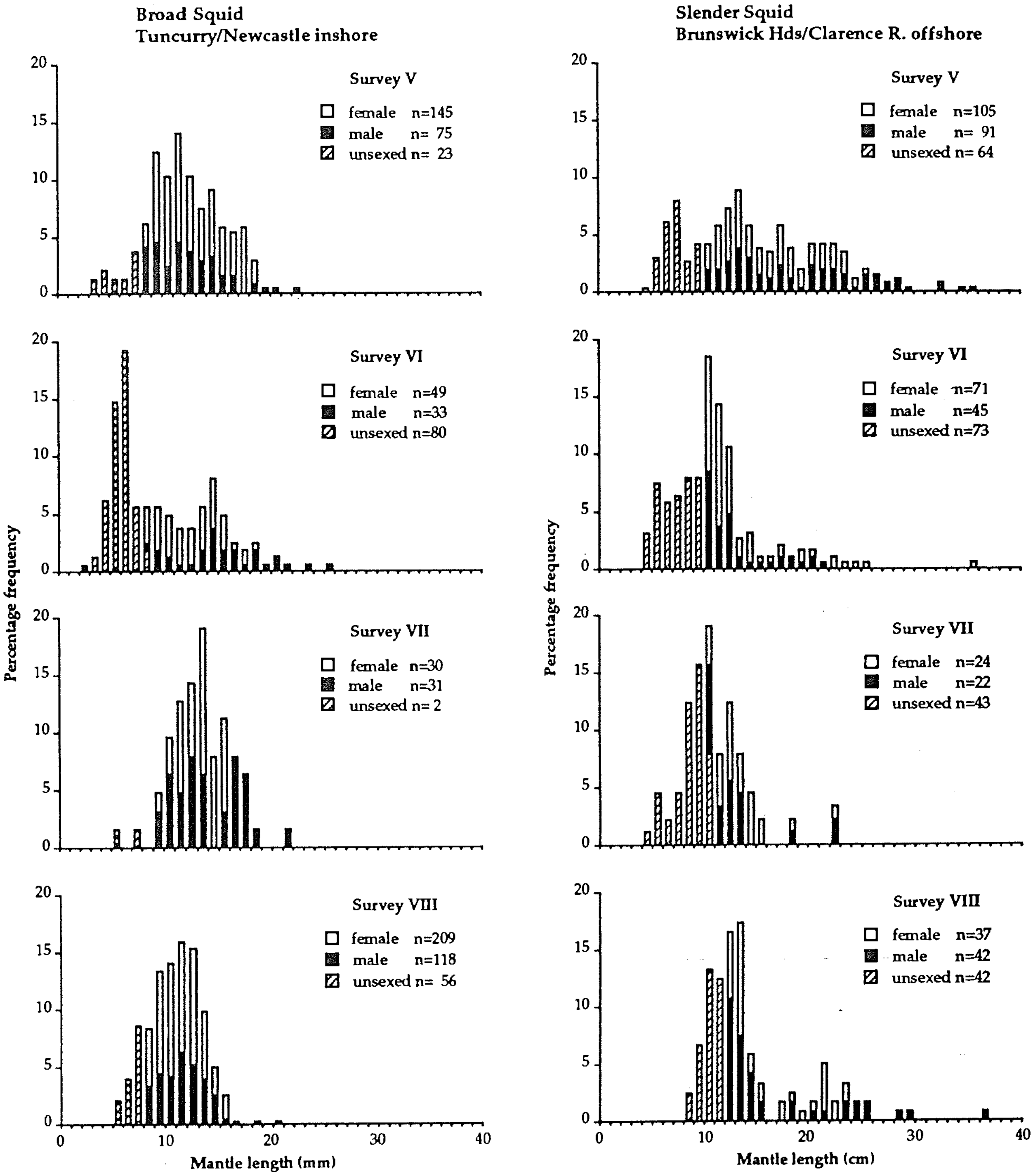


Figure 21: Length frequency of broad squid on the Tuncurry and Newcastle inshore grounds, and of slender squid on the Brunswick Heads and Clarence River offshore grounds, during Surveys V–VIII.

Appendix 3: (continued)

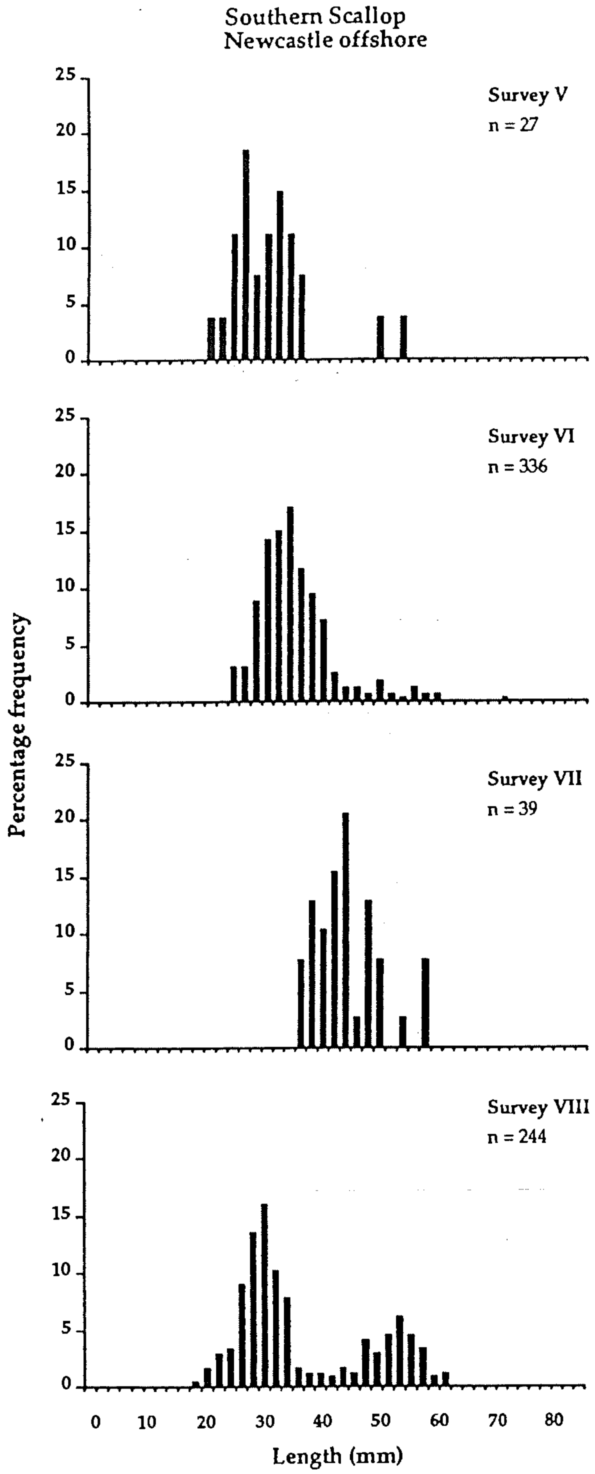


Figure 22: Length frequency of southern scallops on the Newcastle offshore ground during Surveys V–VIII.

Appendix 4(a): List of fish species and their frequency of occurrence (presence per 12 shots; * 11 tows for Brunswick Heads, Survey VI) for the daytime tows on the Clarence River and Brunswick Heads inshore grounds during Surveys V-VIII (# new distribution record for NSW; x caught only during night tows).

	Area:	Clarence R.				Brunswick Hds			
	Survey:	V	VI	VII	VIII	V	VI*	VII	VIII
ORECTOLOBIDAE	*Orectolobus maculatus*	–	1	–	–	1	–	–	–
TRIAKIDAE	*Mustelus antarcticus*	–	–	1	–	1	–	–	–
CARCHARHINIDAE	*Carcharhinus altimus*	–	–	–	–	–	–	–	1
	C. brevipinna	–	–	–	–	2	–	–	2
	C. obscurus	1	–	–	–	–	–	–	–
RHYNCHOBATIDAE	*Rhynchobatus djiddensis*	–	–	–	1	1	–	2	–
RHINOBATIDAE	*Aptychotrema rostrata*	5	3	1	12	12	11	12	12
	Trygonorrina sp.	–	–	x	–	–	–	–	–
TORPEDINIDAE	*Hypnos monopterygium*	9	8	8	4	12	8	10	9
DASYATIDIDAE	*Dasyatis fluviorum*	–	2	–	–	–	–	–	–
	D. kuhlii	–	3	2	–	5	6	10	3
UROLOPHIDAE	*Trygonoptera testaceus*	7	12	11	12	12	11	12	12
	Urolophus sp.	1	5	6	–	–	1	–	–
CLUPEIDAE	*Etrumeus teres*	1	–	–	2	6	–	1	3
	Herklotsichthys castelnaui	–	–	–	4	–	–	–	–
	Hyperlophus vittatus	x	–	3	6	–	–	–	1
	Sardinella gibbosa	1	–	–	–	–	–	1	–
	Sardinops sagax neopilchardus	1	5	6	x	–	–	–	5
ENGRAULIDIDAE	*Engraulis australis*	1	1	–	5	–	–	–	–
SYNODONTIDAE	*Trachinocephalus myops*	2	–	–	–	–	–	–	–
HARPADONTIDAE	*Saurida undosquamis*	1	1	12	1	–	2	12	3
PLOTOSIDAE	*Cnidoglanis macrocephalus*	4	–	2	7	–	–	1	2
	Euristhmus lepturus	–	–	3	–	4	4	–	9
	Plotosus lineatus	–	6	3	7	4	2	4	12
ANTENNARIIDAE	*Antennarius striatus*	–	–	8	–	–	1	10	7
HEMIRAMPHIDAE	*Hyporhamphus australis*	–	–	–	x	–	–	–	–
TRACHICHTHYIDAE	*Optivus* sp.	–	–	1	1	–	–	–	–
ZEIDAE	*Zeus faber*	1	–	2	–	–	–	–	–
FISTULARIIDAE	*Fistularia commersonii*	3	2	–	–	1	1	–	4
	F. petimba	6	–	–	–	–	–	–	–
SOLENOSTOMIDAE	*Solenostomus cyanoptera*	1	–	–	–	–	–	–	–
SCORPAENIDAE	*Centropogon australis*	8	10	12	1	2	5	6	1
	# *Minous versicolor*	1	–	–	–	–	–	–	–
	Notesthes robusta	12	2	–	11	5	–	–	–
TRIGLIDAE	*Chelidonichthys kumu*	–	x	12	1	–	3	12	6
	Lepidotrigla papilio	–	–	1	–	–	–	–	–
	L. umbrosa	–	1	12	5	–	11	12	2
PLATYCEPHALIDAE	*Platycephalus arenarius*	1	x	6	1	4	1	12	12
	P. caeruleopunctatus	8	11	12	12	12	10	12	12
	P. fuscus	–	–	7	5	1	–	11	8
	P. longispinis	9	12	12	12	11	11	12	12
	P. marmoratus	–	x	–	–	–	–	–	–
	Suggrundus jugosus	–	–	1	–	–	1	1	–
DACTYLOPTERIDAE	*Dactyloptena papilio*	–	–	–	4	–	2	2	–
SERRANIDAE	*Triso dermopterus*	–	–	3	–	–	–	–	–
TERAPONTIDAE	*Pelates quadrilineatus*	1	5	5	12	1	6	–	4
	Terapon jarbua	–	–	–	–	3	–	–	1
	T. theraps	–	–	–	–	–	–	–	6
PRIACANTHIDAE	*Priacanthus macracanthus*	7	9	1	12	9	8	1	11
APOGONIDAE	*Apogon fasciatus*	5	6	8	2	1	–	–	4
	A. nigripinnis	3	2	4	8	–	–	–	–
SILLAGINIDAE	*Sillago bassensis*	7	11	11	11	10	10	7	12
	S. maculata	–	1	1	2	–	–	–	2
	S. robusta	12	12	12	12	12	11	12	12
POMATOMIDAE	*Pomatomus saltatrix*	1	1	–	9	12	–	–	8
RACHYCENTRIDAE	*Rachycentron canadus*	–	1	–	2	–	–	–	–

Appendix 4(a): (continued)

		Area:	Clarence R.				Brunswick Hds			
		Survey:	V	VI	VII	VIII	V	VI*	VII	VIII
CARANGIDAE		*Alectis ciliaris*	–	–	–	5	–	–	–	–
		Alepes sp.	2	x	–	9	3	–	–	10
		Atule mate	–	–	–	8	–	–	–	10
		Carangoides chrysophrys	–	1	–	–	–	–	–	7
		C. coeruleopinnatus	–	–	–	6	–	–	–	9
		C. fulvoguttatus	–	–	–	2	–	–	–	3
		C. malabaricus	–	–	–	12	5	–	–	12
		Caranx sexfasciatus	–	–	–	11	–	–	–	12
	#	*"Caranx" kleini*	–	–	–	–	–	–	–	1
		Caranx sp.	–	–	–	3	–	–	–	1
		Decapterus macarellus	–	–	–	–	–	1	–	–
		D. macrosoma	–	–	–	2	2	2	2	–
		Megalaspis cordyla	–	–	–	1	–	–	–	1
	#	*Parastromateus niger*	–	–	–	–	–	–	–	3
		Pseudocaranx dentex	–	–	–	5	–	–	–	–
		Selar crumenophthalmus	–	–	–	5	–	–	–	1
		Selaroides leptolepis	–	1	–	1	–	–	1	–
		Seriolina nigrofasciata	–	–	–	3	–	–	–	5
		Seriola hippos	–	–	–	–	–	–	–	2
		Trachurus novaezelandiae	12	12	12	12	12	11	12	12
		Uraspis uraspis	–	–	–	2	–	–	–	1
LEIOGNATHIDAE		*Equulites mortoniensis*	2	3	1	1	4	8	6	12
LUTJANIDAE		*Lutjanus malabaricus*	–	–	–	6	–	–	–	1
GERREIDAE		*Gerres subfasciatus*	7	2	6	12	12	3	1	12
SPARIDAE		*Pagrus auratus*	7	–	12	10	4	–	–	4
		Rhabdosargus sarba	2	1	–	5	3	–	–	8
SCIAENIDAE		*Argyrosomus hololepidotus*	–	–	–	10	–	–	–	–
		Atractoscion aequidens	1	–	–	4	9	–	–	7
MULLIDAE		*Parupeneus signatus*	–	–	1	1	–	–	2	–
		Upeneichthys lineatus	1	1	12	1	–	2	2	1
		Upeneus tragula	–	x	1	–	–	1	–	–
MONODACTYLIDAE		*Schuettea scalaripinnis*	x	–	–	–	–	–	–	2
PEMPHERIDIDAE		*Pempheris analis*	–	–	–	3	1	–	–	7
SCORPIDIDAE		*Atypichthys strigatus*	–	–	x	–	–	–	–	–
		Microcanthus strigatus	–	–	–	1	2	1	–	5
		Scorpis lineolatus	–	–	–	–	–	–	–	1
CHAETODONTIDAE		*Chaetodon guntheri*	–	–	–	–	–	–	1	–
		Heniochus diphreutes	–	–	–	–	–	–	–	1
ENOPLOSIDAE		*Enoplosus armatus*	–	–	–	1	–	–	–	–
APLODACTYLIDAE		*Crinodus lophodon*	–	1	–	–	–	–	–	–
CHEILODACTYLIDAE		*Cheilodactylus fuscus*	–	–	1	–	–	–	–	–
		C. vestitus	–	–	1	–	–	–	1	–
SPHYRAENIDAE		*Sphyraena africana*	12	12	12	12	10	11	12	12
POLYNEMIDAE		*Polydactylus multiradiatus*	–	–	–	–	–	–	–	2
LABRIDAE		*Pseudolabrus gymnogenus*	–	–	1	–	–	–	–	–
PINGUIPEDIDAE		*Parapercis nebulosa*	–	–	1	–	–	–	–	–
URANOSCOPIDAE		*Ichthyscopus* sp.	–	–	x	–	–	–	–	–
BLENNIIDAE		*Petroscirtes lupus*	–	1	1	–	–	–	–	–
CLINIDAE		*Cristiceps aurantiacus*	–	1	–	x	–	–	–	–
CALLIONYMIDAE		*Callionymus calcaratus*	8	–	4	1	9	3	11	1
		C. macdonaldi	1	–	–	–	2	–	–	4
		Dactylopus dactylopus	–	–	–	–	–	–	–	1
TRICHIURIDAE		*Trichiurus lepturus*	–	–	–	2	–	–	–	–
SCOMBRIDAE		*Scomber australasicus*	2	12	11	1	5	–	2	5
NOMEIDAE		*Psenes whiteleggi* ?	–	–	–	2	–	–	–	–
BOTHIDAE		*Arnoglossus fisoni*	–	–	7	1	12	11	12	9
		Engyprosopon grandisquama	–	–	1	–	–	–	–	–
PARALICHTHYIDAE		*Pseudorhombus arsius*	3	4	11	9	6	7	12	12
		P. jenynsii	6	1	12	5	–	4	6	–
		P. tenuirastrum	8	6	2	9	–	–	2	12

Appendix 4(a): (continued)

		Area:	Clarence R.				Brunswick Hds			
		Survey:	V	VI	VII	VIII	V	VI*	VII	VIII
SOLEIDAE	*Synaptura nigra*		2	–	8	–	–	–	3	5
	Aseraggodes macleayanus		2	2	11	12	11	3	12	12
	Pardachirus hedleyi		–	–	–	–	–	–	–	2
CYNOGLOSSIDAE	*Paraplagusia unicolor*		3	7	10	10	11	7	12	12
TRIACANTHIDAE	*Tripodichthys angustrifrons*		–	–	–	1	1	–	–	–
MONACANTHIDAE	*Acanthaluteres vittiger*		1	–	1	1	–	–	–	–
	Arotrolepis filicauda		–	–	–	2	–	–	–	2
	Brachaluteres jacksonianus		–	–	–	–	–	–	10	1
	Eubalichthys mosaicus		–	–	–	–	–	–	1	–
	Meuschenia trachylepis		–	1	–	–	–	–	–	–
	Nelusetta ayraudi		–	–	4	–	–	–	1	–
	Paramonacanthus otisensis		2	x	3	–	–	–	–	–
OSTRACIIDAE	*Anoplocapros robustus*		7	12	–	1	–	4	–	–
TETRAODONTIDAE	*Lagocephalus cheesemani*		7	–	–	11	7	–	1	–
	L. inermis		–	–	–	–	1	–	–	–
	L. sceleratus		–	–	1	–	–	–	–	–
	Reicheltia halsteadi		3	12	12	12	12	11	12	12
	Tetractenos hamiltoni		–	x	–	–	–	–	–	–
	Torquigener pleurogramma		–	1	1	–	4	4	–	7
DIODONTIDAE	*Dicotylichthys punctulatus*		–	1	–	–	–	–	–	–

Appendix 4(b): List of fish species and their frequency of occurrence (presence per 12 tows; * 8 tows for Clarence River, Survey VII) for the night tows on the Clarence River and Brunswick Heads offshore grounds during Surveys V-VIII (# new distribution record for NSW; x caught only during daytime tows).

	Area:	Clarence R.				Brunswick Hds			
	Survey:	V	VI	VII*	VIII	V	VI	VII	VIII
HETERODONTIDAE	*Heterodontus galeatus*	–	–	–	–	–	1	–	–
BRACHAELURIDAE	*Brachaelurus* cf *colcloughi*	–	–	–	–	–	–	1	–
ORECTOLOBIDAE	*Orectolobus maculatus*	–	1	–	–	–	–	–	3
	Parascyllium collare	–	–	–	1	–	–	–	–
TRIAKIDAE	*Mustelus antarcticus*	–	3	4	7	8	–	11	8
RHINOBATIDAE	*Aptychotrema rostrata*	–	4	–	3	1	4	7	11
	Trygonorrina sp.	–	–	–	–	–	–	3	7
TORPEDINIDAE	*Hypnos monopterygium*	1	–	1	5	–	1	–	4
UROLOPHIDAE	*Urolophus* sp.	–	–	–	–	–	–	7	1
CONGRIDAE	*Gnathophis* sp.	12	9	8	12	3	12	11	12
	Poeciloconger kapala	–	–	1	–	–	–	–	–
CLUPEIDAE	*Etrumeus teres*	–	–	–	–	–	–	–	2
	Sardinops sagax neopilchardus	–	–	–	1	–	–	–	–
ENGRAULIDIDAE	*Engraulis australis*	–	–	1	–	–	–	–	–
SYNODONTIDAE	*Synodus hoshinonus*	–	–	3	2	–	–	–	1
	S. indicus	–	–	–	–	–	–	–	1
	Trachinocephalus myops	2	5	5	1	12	6	12	10
HARPADONTIDAE	*Saurida filamentosa*	–	8	4	12	–	–	–	–
	S. undosquamis	11	2	2	–	10	12	9	12
GONORYNCHIDAE	*Gonorynchus greyi*	11	8	7	12	12	12	10	12
BATRACHOIDIDAE	*Batrachomoeus dubius*	4	1	1	5	9	5	7	12
LOPHIIDAE	*Lophiomus setigerus*	–	–	1	1	–	–	–	–
ANTENNARIIDAE	*Antennarius striatus*	8	10	7	8	5	4	11	12
OGCOCEPHALIDAE	*Halieutaea brevicauda*	–	2	1	–	–	–	–	–
MORIDAE	*Pseudophycis breviuscula*	1	2	–	–	–	–	–	–
OPHIDIIDAE	*Ophidion* sp.	–	–	1	–	–	–	–	–
BELONIDAE	*Ablennes hians*	–	–	–	–	–	1	–	–
SCOMBEROSOCIDAE	*Scomberosox saurus*	–	6	–	–	–	1	–	–
TRACHICHTHYIDAE	*Optivus* sp.	2	3	1	10	1	7	12	3
BERYCIDAE	*Centroberyx affinis*	1	5	3	–	–	–	–	–
MONOCENTRIDAE	*Cleidopus gloriamaris*	–	x	–	–	–	2	–	–
HOLOCENTRIDAE	*Ostichthys* sp.	–	–	–	1	–	–	–	–
ZEIDAE	*Zeus faber*	2	9	–	2	–	–	–	–
CAPROIDAE	*Antigonia rubicunda*	–	–	1	–	–	–	1	–
VELIFERIDAE	*Velifer multiradiatus*	–	–	1	–	–	–	1	–
FISTULARIIDAE	*Fistularia commersonii*	–	–	–	–	–	–	–	2
	F. petimba	12	x	–	–	12	–	–	–
MACRORAMPHOSIDAE	*Macroramphosus gracilis*	–	–	2	3	–	–	–	–
	M. scolopax	9	12	8	12	–	–	–	–
SYNGNATHIDAE	*Hippocampus whitei*	–	–	–	–	–	–	1	–
	Solegnathus dunckeri	–	–	–	–	–	–	1	–
	Trachyrhamphus bioarctatus	–	–	–	–	1	–	–	–
SCORPAENIDAE	*Apistus carinatus*	–	–	–	–	1	–	–	1
	Centropogon australis	–	–	–	–	1	–	–	1
	Dendrochirus brachypterus	4	8	–	–	–	–	8	5
	D. zebra	–	–	–	–	2	–	–	–
	Ebosia bleekeri	–	–	–	–	–	–	2	–
	Erosa erosa	2	–	–	4	1	4	6	5
	Inimicus caledonicus	–	–	–	–	–	–	–	1
	Maxillicosta whitleyi	12	10	8	12	12	12	12	12
	Neocentropogon sp.	–	–	–	1	–	–	–	–
	Neosebastes incisipinnis	11	11	6	8	2	1	9	1
	Pterois volitans	–	–	–	–	1	–	–	–
	Scorpaena cardinalis	–	–	–	–	–	–	–	4
TRIGLIDAE	*Chelidonichthys kumu*	6	11	5	10	6	10	7	11
	Lepidotrigla argus	12	12	8	12	12	12	12	12
	L. papilio	–	2	–	3	1	1	–	–

Appendix 4(b): (continued)

		Area:	Clarence R.				Brunswick Hds			
		Survey:	V	VI	VII*	VIII	V	VI	VII	VIII
APLOACTINIDAE		*Aploactis aspersa*	–	–	–	–	1	2	1	2
PLATYCEPHALIDAE		*Platycephalus longispinis*	12	12	8	12	12	12	12	12
		P. caeruleopunctatus	–	5	2	3	7	12	6	9
		P. marmoratus	2	3	2	8	1	2	2	8
		P. richardsoni	–	1	–	–	–	–	–	–
		Suggrundus jugosus	–	–	–	–	2	–	–	3
		Ratabulus diversidens	4	7	8	12	6	1	6	2
DACTYLOPTERIDAE		*Dactyloptena orientalis*	–	–	–	–	–	–	2	–
		D. papilio	9	12	3	4	9	11	10	8
SERRANIDAE		*Epinephelus ergastularius*	1	3	2	–	–	–	2	2
	#	*E. radiatus*	–	–	–	–	–	–	–	1
		Lepidoperca caesiopercula	–	–	1	–	–	2	1	–
GLAUCOSOMIDAE		*Glaucosoma scapulare*	4	6	4	3	2	–	4	1
TERAPONTIDAE		*Pelates quadrilineatus*	–	–	–	–	–	–	1	–
BANJOSIDAE		*Banjos banjos*	–	–	–	–	–	–	1	–
PRIACANTHIDAE		*Priacanthus macracanthus*	12	6	x	4	11	12	1	9
		P. hamrur	–	–	–	–	1	–	–	–
		Pristigenys niphonia	7	5	1	2	2	1	–	–
APOGONIDAE		*Apogon nigripinnis*	2	1	–	–	1	6	3	3
SILLAGINIDAE		*Sillago bassensis*	–	12	–	2	–	8	–	4
		S. robusta	–	–	–	–	–	5	–	3
CARANGIDAE		*Carangoides equula*	1	–	8	9	–	–	7	1
		Decapterus macrosoma	1	5	–	–	–	–	–	1
		D. russelli	–	1	–	–	–	–	–	–
		Seriolina nigrofasciata	–	–	–	–	4	1	–	–
		T. novaezelandiae	7	12	4	5	6	–	8	3
NEMIPTERIDAE		*Nemipterus aurifilum*	–	1	4	–	–	–	–	–
		N. theodorei	9	12	8	12	–	3	9	8
LETHRINIDAE		*Gymnocranius elongatus*	–	–	–	–	–	–	–	1
		Lethrinus nematacanthus	–	–	–	–	–	–	–	1
SPARIDAE		*Allotaius spariformes*	–	–	4	10	–	–	–	–
		Pagrus auratus	–	–	–	1	–	–	–	–
		Rhabdosargus sarba	1	–	–	–	x	–	–	–
SCIAENIDAE		*Argyrosomus hololepidotus*	–	–	–	–	1	–	–	–
MULLIDAE		*Parupeneus signatus*	1	–	–	–	–	–	–	1
		Upeneichthys lineatus	1	–	–	11	7	9	3	11
		Upeneus filifer	–	2	1	2	–	–	–	–
PEMPHERIDIDAE		*Pempheris analis*	–	x	–	–	–	–	–	–
SCORPIDIDAE		*Atypichthys strigatus*	1	–	–	–	–	7	–	2
		Microcanthus strigatus	–	–	–	–	–	–	–	2
CHAETODONTIDAE		*Chelmonops truncatus*	–	3	–	–	–	–	–	1
		Heniochus diphreutes	–	–	–	–	x	–	–	–
ENOPLOSIDAE		*Enoplosus armatus*	–	x	–	–	–	–	–	–
PENTACEROTIDAE		*Zanclistius elevatus*	–	–	1	–	–	–	–	–
APLODACTYLIDAE		*Crinodus lophodon*	–	–	–	–	–	1	–	–
CHEILODACTYLIDAE		*Cheilodactylus vestitus*	–	–	–	–	1	–	–	–
CEPOLIDAE		*Cepola australis*	–	–	1	–	–	–	–	–
SPHYRAENIDAE		*Sphyraena africana*	11	–	4	4	1	–	9	–
LABRIDAE		*Choerodon frenatus*	2	x	1	3	–	–	–	–
		Suezichthys gracilis	–	–	x	–	–	–	–	–
MUGILOIDIDAE		*Parapercis nebulosa*	–	–	–	–	8	4	5	12
		Parapercis sp.	–	–	–	2	–	–	–	–
URANOSCOPIDAE		*Ichthyscopus* sp.	–	–	–	–	–	–	–	3
CHAMPSODONTIDAE		*Champsodon* sp.	–	x	–	–	–	–	–	–
BLENNIIDAE		*Xiphasia setifer*	–	–	–	–	–	–	–	1
CALLIONYMIDAE		*Callionymus calcaratus*	–	–	–	8	12	10	8	12
		C. japonicus scaber	12	8	7	12	3	–	–	5
		C. limiceps	–	–	–	–	6	5	4	–
		C. moretonensis	7	3	8	1	–	–	–	–
		Synchiropus calauropomus	12	12	8	12	12	6	11	12
		S. rameus	–	–	–	1	2	3	2	9
SCOMBRIDAE		*Scomber australasicus*	2	6	4	1	–	–	–	–

Appendix 4(b): (continued)

	Area:	Clarence R.				Brunswick Hds			
	Survey:	V	VI*	VII	VIII	V	VI	VII	VIII
BOTHIDAE	*Crossorhombus azureus*	2	–	1	1	11	12	12	9
	Engyprosopon grandisquama	–	–	–	–	11	11	8	11
	E. maculipinnis	11	11	8	12	2	–	8	1
	Grammatobothus pennatus	2	2	2	2	6	7	1	6
	Lophonectes gallus	12	12	8	12	12	12	12	12
	Psettina gigantea	3	–	–	–	–	–	–	–
	P. iijimae	–	2	–	–	–	–	–	–
PARALICHTHYIDAE	*Psuedorhombus arsius*	–	–	–	–	–	–	–	2
	P. tenuirastrum	12	12	8	12	12	12	12	12
PLEURONECTIDAE	*Plagiopsetta glossa*	–	–	–	2	–	–	–	–
SOLEIDAE	*Aesopia cornuta*	–	–	–	–	–	–	–	1
	A. microcephala	–	–	–	–	1	–	–	1
	Aseraggodes macleayanus	–	–	–	–	–	8	–	3
	Zebrias fasciatus	8	4	5	11	12	12	12	12
CYNOGLOSSIDAE	*Cynoglossus maculipinnis*	6	6	7	10	2	4	–	4
MONACANTHIDAE	*Aluterus monoceros*	–	–	–	–	1	–	–	1
	Arotrolepis filicauda	–	–	–	5	–	–	–	–
	Brachaluteres taylori ?	–	–	–	–	1	–	–	–
	Cantheschenia longipinnis	1	1	–	x	–	–	–	–
	Laputa sp.	3	4	2	9	12	10	–	12
	Meuschenia trachylepis	–	1	–	–	–	–	–	–
	Nelusetta ayraudi	1	–	–	–	–	–	–	–
	Paramonacanthus otisensis	–	–	–	–	1	–	12	–
	Pseudomonacanthus peroni	–	–	–	–	–	–	–	1
	Thamnaconus harpargyreus	–	–	1	–	–	–	–	–
OSTRACIIDAE	*Anoplocapros robustus*	2	12	8	1	–	12	12	–
	Lactoria diaphana	–	–	–	–	–	–	5	–
	Trioris reipublicae	11	12	7	12	12	12	12	12
TETRAODONTIDAE	*Canthigaster callisterna*	–	–	x	1	–	–	3	–
	Lagocephalus cheesemani	12	10	3	12	12	7	3	8
	L. inermis	–	–	–	x	–	–	–	–
	L. sceleratus	–	–	–	–	3	–	–	1
	Torquigener altipinnis	12	9	6	7	12	12	12	12
	T. tuberculiferus	–	–	–	–	2	–	–	–
DIODONTIDAE	*Allomycterus pilatus*	–	–	1	–	–	–	–	–
	Dicotylichthys punctuatus	–	2	–	–	–	2	1	–
	Diodon holocanthus	–	–	–	2	–	1	–	–

Appendix 4(c): List of fish species and their frequency of occurrence (presence per 12 tows; * 11 tows for Newcastle, Survey V) for daytime tows on the Newcastle and Tuncurry inshore grounds during Surveys V-VIII (x caught only during night tows).

	Area:	Newcastle				Tuncurry			
	Survey:	V*	VI	VII	VIII	V	VI	VII	VIII
HETERODONTIDAE	*Heterodontus portusjacksoni*	5	10	2	–	8	11	11	6
ODONTASPIDIDAE	*Eugomphodus taurus*	–	1	–	–	–	–	–	–
ORECTOLOBIDAE	*Orectolobus maculatus*	–	–	–	–	–	1	–	–
BRACHAELURIDAE	*Brachaelurus waddi*	–	–	–	1	–	–	–	–
TRIAKIDAE	*Mustelus antarcticus*	–	–	1	–	–	–	–	–
CARCHARHINIDAE	*Carcharhinus brevipinna*	–	–	–	3	–	–	–	–
	C. obscurus	–	1	–	1	–	–	–	–
SPHYRNIDAE	*Sphyrna zygaena*	–	–	–	5	–	–	–	–
SQUATINIDAE	*Squatina australis*	–	1	–	–	–	–	3	–
RHYNCHOBATIDAE	*Rhinchobatus djiddensis*	–	–	–	–	1	–	–	–
RHINOBATIDAE	*Aptychotrema rostrata*	2	6	5	9	10	12	12	11
	Trygonorrina sp.	–	–	–	–	10	12	12	3
TORPEDINIDAE	*Hypnos monopterygium*	–	–	x	x	8	–	–	5
DASYATIDIDAE	*Dasyatis fluviorum*	–	–	–	–	–	4	–	1
	D. brevicaudata	–	–	–	–	–	–	1	–
	D. thetidus	–	–	–	–	–	1	–	–
UROLOPHIDAE	*Trygonoptera testaceus*	9	7	4	6	12	12	12	12
	Urolophus sp.	2	7	1	–	6	10	12	10
MYLIOBATIDIDAE	*Myliobatis australis*	1	–	1	6	9	8	10	2
CONGRIDAE	*Gnathophis* sp.	x	–	–	x	–	–	–	–
CLUPEIDAE	*Etrumeus teres*	1	–	–	3	–	–	–	1
	Hyperlophus vittatus	11	2	7	12	–	–	–	–
	Sardinops sagax neopilchardus	–	–	–	2	–	–	–	–
ENGRAULIDIDAE	*Engraulis australis*	1	–	–	–	–	–	–	–
SYNODONTIDAE	*Trachinocephalus myops*	3	4	2	1	–	–	–	–
HARPADONTIDAE	*Saurida undosquamis*	5	–	7	–	1	9	12	8
PLOTOSIDAE	*Cnidoglanis macrocephalus*	2	–	–	–	–	3	7	3
	Euristhmus lepturus	3	–	–	–	–	–	–	–
	Plotosus lineatus	–	–	–	–	10	8	11	6
ANTENNARIIDAE	*Antennarius striatus*	x	–	–	–	–	–	–	–
MORIDAE	*Pseudophycis breviuscula*	–	–	–	–	–	–	–	–
HEMIRAMPHIDAE	*Hyporhamphus australis*	x	–	–	–	–	–	–	–
TRACHICHTHYIDAE	*Optivus* sp.	–	–	–	3	–	–	–	–
BERYCIDAE	*Centroberyx affinis*	–	–	–	–	–	–	–	–
ZEIDAE	*Zeus faber*	1	1	1	–	6	–	1	–
FISTULARIIDAE	*Fistularia commersonii*	7	–	–	8	5	–	–	2
	F. petimba	2	–	–	–	1	–	–	6
SYNGNATHIDAE	*Hippocampus abdominalis*	–	–	1	–	–	–	–	–
SCORPAENIDAE	*Centropogon australis*	11	9	10	5	7	8	11	11
	Dendrochirus brachypterus	–	–	–	–	x	–	–	–
	Notesthes robusta	6	–	–	12	7	–	–	4
TRIGLIDAE	*Chelidonichthys kumu*	8	9	12	3	3	11	11	10
	Lepidotrigla mulhalli	–	–	–	–	–	–	1	–
	L. papilio	–	–	–	–	–	–	1	–
	L. umbrosa	x	1	7	–	–	1	4	–
PLATYCEPHALIDAE	*Platycephalus arenarius*	1	4	7	2	–	5	6	4
	P. caeruleopunctatus	11	12	12	12	11	12	12	12
	P. fuscus	x	2	2	8	–	–	7	3
	P. longispinis	10	12	12	7	12	12	12	12
DACTYLOPTERIDAE	*D. papilio*	–	–	–	2	–	–	6	–
SERRANIDAE	*Epinephelus ergastularius*	–	–	–	–	1	–	–	1
	E. undulostriatus	–	–	–	–	1	1	–	–
TERAPONTIDAE	*Pelates quadrilineatus*	4	1	–	6	1	8	–	2
PRIACANTHIDAE	*Priacanthus macracanthus*	1	–	–	7	2	5	2	5
APOGONIDAE	*Apogon nigripinnis*	–	–	–	–	5	4	5	4
	A. limenus	–	–	1	–	–	–	–	–

Appendix 4(c): (continued)

	Area:	Newcastle				Tuncurry			
	Survey:	V*	VI	VII	VIII	V	VI	VII	VIII
SILLAGINIDAE	*Sillago bassensis*	11	12	12	11	7	7	9	11
	S. maculata	–	–	4	x	2	–	1	8
	S. robusta	5	9	10	4	4	2	8	12
POMATOMIDAE	*Pomatomus saltatrix*	7	3	11	11	3	–	–	4
RACHYCENTRIDAE	*Rachycentron canadus*	–	–	–	–	–	–	1	1
CARANGIDAE	*Alectis ciliaris*	1	–	–	1	1	–	–	–
	Alepes sp.	–	–	–	3	3	–	–	–
	Atule mate	–	–	–	3	–	–	–	1
	Carangoides chrysophrys	–	–	–	–	11	5	–	–
	C. coeruleopinnatus	–	–	–	1	1	–	–	–
	C. ferdau	–	–	–	1	–	–	–	–
	C. fulvoguttatus	–	–	–	–	–	–	–	4
	C. malabaricus	–	–	–	12	–	–	–	8
	Caranx sexfasciatus	–	–	–	2	–	–	–	–
	Caranx sp.	1	–	–	7	–	–	–	–
	Decapterus macrosoma	1	–	–	–	–	1	–	–
	Megalaspis cordyla	–	–	–	2	–	–	–	–
	Pseudocaranx dentex	2	–	3	2	1	4	–	5
	# *Selaroides leptolepis*	–	–	–	–	–	1	–	–
	Seriola hippos	–	–	–	–	–	–	10	–
	S. rivoliana	–	1	–	–	–	–	1	–
	Trachurus declivis	–	–	1	–	–	–	–	–
	T. novaezelandiae	11	12	12	12	12	12	12	12
GERREIDAE	*Gerres subfasciatus*	8	–	7	12	2	–	11	9
LETHRINIDAE	*Lethrinus nematacanthus*	–	–	–	1	–	–	–	–
SPARIDAE	*Pagrus auratus*	x	–	1	–	4	1	7	12
	Rhabdosargus sarba	1	–	1	4	2	–	5	6
	Acanthopagrus australis	2	–	4	5	–	1	–	–
SCIAENIDAE	*Argyrosomus hololepidotus*	–	1	2	10	–	–	–	1
	Atractoscion aequidens	–	–	1	8	–	–	–	4
MULLIDAE	*Upeneichthys lineatus*	1	–	–	2	3	1	1	3
	Upeneus tragula	1	2	–	1	6	5	4	9
MONODACTYLIDAE	*Schuettea scalaripinnis*	3	–	–	–	–	–	–	–
PEMPHERIDIDAE	*Pempheris analis*	–	–	4	3	–	–	–	–
	P. compressus	10	–	–	x	–	–	–	–
SCORPIDIDAE	*Atypichthys strigatus*	1	–	–	1	x	2	–	–
	Microcanthus strigatus	3	–	–	3	2	–	–	–
CHAETODONTIDAE	*Chaetodon guntheri*	–	–	–	–	1	–	–	–
	Heniochus diphreutes	–	–	–	–	1	–	–	–
ENOPLOSIDAE	*Enoplosus armatus*	1	2	1	7	4	4	4	5
SPHYRAENIDAE	*Sphyraena africana*	8	12	10	12	8	3	8	12
	S. obtusata	1	–	–	1	–	–	–	
BLENNIDAE	*Petroscirtes lupus*	–	–	–	–	–	2	–	–
CLINIDAE	*Cristiceps aurantiacus*	1	4	–	–	3	4	5	2
	Cristiceps australis	–	2	–	–	–	–	–	–
CALLIONYMIDAE	*Callionymus calcaratus*	4	4	6	1	–	3	2	–
	C. macdonaldi	–	–	2	1	–	–	–	–
TRICHIURIDAE	*Trichiurus lepturus*	–	–	5	4	–	–	–	–
SCOMBRIDAE	*Scomber australasicus*	9	–	x	5	–	5	–	2
	Scomberomorus queenslandicus	–	–	–	–	1	–	–	–
CENTROLOPHIDAE	*Seriolella brama*	–	–	7	–	–	–	–	–
	S. punctata	–	–	1	–	–	–	–	–
NOMEIDAE	*Psenes whiteleggi* ?	–	–	–	5	–	–	–	–
BOTHIDAE	*Arnoglossus fisoni*	–	–	1	–	–	–	4	–
	Lophonectes gallus	–	–	–	–	–	–	2	–
PARALICHTHYIDAE	*Pseudorhombus arsius*	9	7	9	11	3	9	12	12
	P. jenynsii	5	5	1	4	1	3	9	6
	P. tenuirastrum	3	2	2	4	–	1	8	3
SOLEIDAE	*Aseraggodes macleayanus*	8	7	12	12	1	10	12	12
	Pardachirus hedleyi	–	–	–	x	–	–	2	9
	Synaptura nigra	*	–	4	5	6	10	10	12
CYNOGLOSSIDAE	*Paraplagusia unicolor*	10	10	12	7	3	12	12	10

Appendix 4(c): (continued)

	Area:	Newcastle				Tuncurry			
	Survey:	V*	VI	VII	VIII	V	VI	VII	VIII
MONACANTHIDAE	*Acanthaluteres vittiger*	–	1	1	–	–	–	–	–
	Arotolepis filicauda	–	–	–	12	–	–	–	1
	Brachaluteres jacksonianus	2	2	–	–	4	6	4	1
	Eubalychthys mosaicus	–	–	–	–	–	1	–	–
	Meuschenia scaber	–	1	–	–	–	–	–	–
	M. trachylepis	4	–	1	–	6	9	–	4
	Nelusetta ayraudi	–	–	4	–	–	–	5	–
	Paramonacanthus otisensis	–	–	–	–	5	6	3	–
OSTRACIIDAE	*Anoplocapros robustus*	8	7	9	–	12	12	12	12
	Lactoria cornuta	–	–	–	–	1	–	–	–
	Trioris reipublicae	–	–	x	–	11	8	6	–
TETRAODONTIDAE	*Arothron aerostaticus*	–	–	–	–	1	–	–	–
	A. manillensis	–	–	–	1	–	–	–	–
	Lagocephalus cheesemani	–	–	–	–	–	–	–	3
	L. inermis	–	1	1	1	–	–	4	–
	Reicheltia halsteadi	11	12	12	12	12	12	12	12
	Tetractenos glaber	–	x	–	–	–	–	–	–
	T. hamiltoni	1	1	–	–	3	5	–	–
	Torquigener altipinnis	–	–	–	–	–	1	–	–
	T. pleurogramma	1	2	–	–	–	–	–	–
	T. squamicauda	2	–	–	–	–	–	–	–
	Sphoeroides pachygaster	–	–	2	–	–	–	–	–
DIODONTIDAE	*Allomycterus pilatus*	–	–	–	–	–	1	2	–
	Dicotylichthys punctulatus	9	12	10	1	12	12	10	8
	Diodon holocanthus	x	–	–	–	1	–	3	–

Appendix 4(d): List of fish species and their frequency of occurrence (presence per 12 tows; * 11 tows for Tuncurry, Survey VII) for the night tows on the Newcastle and Tuncurry offshore grounds during Surveys V-VIII (# new distribution record for NSW; x caught only during daytime tows).

	Area:	Newcastle				Tuncurry			
	Survey:	V	VI	VII	VIII	V	VI	VII*	VIII
HETERODONTIDAE	*Heterodontus portusjacksoni*	4	6	1	1	–	–	–	–
ORECTOLOBIDAE	*Orectolobus maculatus*	–	–	1	–	–	3	–	–
	Parascyllium collare	–	–	–	–	3	10	7	–
SCYLIORHINIDAE	*Asymbolus* sp.	–	–	–	–	1	7	1	–
TRIAKIDAE	*Mustelus antarcticus*	–	–	1	–	–	3	–	–
SQUALIDAE	*Squalus megalops*	–	–	–	–	1	1	–	–
	S. mitsukurii	–	–	–	–	3	1	–	–
PRISTIOPHORIDAE	*Pristiophorus* sp.	–	–	4	–	–	9	2	2
SQUATINIDAE	*Squatina australis*	–	–	–	x	–	–	–	–
	Squatina sp.	–	–	–	1	–	4	5	–
RHINOBATIDAE	*Aptychotrema rostrata*	5	4	1	3	1	7	1	–
	Trygonorrina sp.	2	–	1	1	–	2	1	–
TORPEDINIDAE	*Hypnos monopterygium*	4	3	5	4	3	1	–	1
RAJIDAE	*Raja australis*	–	–	–	–	8	12	8	10
DASYATIDIDAE	*Dasyatis brevicaudata*	–	–	2	–	–	1	–	–
	D. thetidis	–	2	–	–	–	1	–	–
UROLOPHIDAE	*Urolophus bucculentus*	–	1	1	1	3	8	7	–
	U. paucimaculatus	–	–	–	–	–	–	1	–
	U. sufflavus	–	–	2	–	3	8	8	3
	U. viridis	–	1	–	–	7	11	11	–
MURAENOSOCIDAE	*Oxyconger leptognathus*	–	–	–	–	–	–	–	1
	Muraenesox cinereus	1	1	1	–	–	–	–	–
NETTASTOMATIDAE	*Nettastoma* sp.	–	–	1	2	–	–	–	–
CONGRIDAE	*Conger verreauxi*	1	–	–	3	–	–	–	–
	Gnathophis sp.	8	1	6	12	12	11	10	12
	Uroconger lepturus	3	7	7	7	–	–	–	–
CLUPEIDAE	*Etrumeus teres*	–	–	–	1	–	–	–	–
	Sardinops sagax neopilchardus	5	–	9	–	–	–	–	–
ENGRAULIDIDAE	*Engraulis australis*	1	–	–	–	–	–	–	1
ARGENTINIDAE	*Argentina australiae*	–	2	–	–	4	3	–	3
AULOPIDAE	*Aulopus curtirostris*	–	–	–	–	3	–	2	9
	A. purpurissatus	1	1	2	–	1	–	1	1
SYNODONTIDAE	# *Synodus macrops*	–	–	–	–	–	–	–	1
HARPADONTIDAE	*Saurida filamentosa*	–	6	11	12	8	9	10	12
CHLOROPHTHALMIDAE	*Chlorophthalmus nigripinnis*	–	–	–	–	–	–	1	10
GONORYNCHIDAE	*Gonorynchus greyi*	–	–	4	–	10	10	10	12
LOPHIIDAE	*Lophiomus setigerus*	3	–	–	1	6	5	1	–
ANTENNARIIDAE	*Antennarius striatus*	12	12	10	12	7	5	5	1
	Kuiterichthys furcipilis	–	–	–	–	1	–	6	5
OGCOCEPHALIDAE	*Halieutaea brevicauda*	–	2	12	2	11	6	5	7
MORIDAE	*Pseudophycis breviuscula*	12	12	12	12	11	6	5	10
BREGMACEROTIDAE	*Bregmaceros* sp.	–	1	1	–	–	–	–	–
OPHIDIIDAE	*Neobythites* sp.	1	–	1	1	1	–	–	–
	Ophidion sp.	2	–	–	–	–	–	–	–
HEMIRAMPHIDAE	*Hyporhamphus australis*	3	–	–	–	–	–	–	–
BELONIDAE	*Ablennes hians*	1	–	–	–	2	4	–	–
SCOMBEROSOCIDAE	*Scomberosox saurus*	–	–	–	–	–	–	–	4
TRACHICHTHYIDAE	*Aulotrachichthys novaezelandiae*	–	–	–	–	4	–	–	–
	Optivus sp.	11	7	–	10	12	9	7	10
BERYCIDAE	*Centroberyx affinis*	12	12	12	6	11	11	7	5
MONOCENTRIDIDAE	*Cleidopus gloriamaris*	–	1	1	–	–	–	–	–
HOLOCENTRIDAE	*Ostichthys* sp.	8	7	7	12	–	–	–	–
ZEIDAE	*Zenopsis nebulosus*	–	–	x	–	–	–	–	–
	Zeus faber	9	6	10	10	7	9	11	7
CAPROIDAE	*Antigonia rhomboidea*	9	3	4	7	–	–	–	5
	A. rubicunda	9	11	10	6	–	1	–	–

Appendix 4(d): (continued)

	Area:	Newcastle				Tuncurry			
	Survey:	V	VI	VII	VIII	V	VI	VII*	VIII
FISTULARIIDAE	*Fistularia petimba*	4	–	–	–	12	4	1	5
MACRORAMPHOSIDAE	*Macroramphosus scolopax*	7	3	12	10	12	12	11	11
SCORPAENIDAE	*Helicolenus percoides*	6	7	11	12	–	–	1	1
	Dendrochirus brachypterus	2	–	–	–	–	–	–	–
	Ebosia bleekeri	–	–	1	–	–	–	–	–
	Maxillicosta whitleyi	1	–	–	11	11	7	9	12
	Neosebastes incisipinnis	2	–	4	x	12	4	2	7
	Scorpaena cardinalis	1	–	–	–	–	–	–	–
TRIGLIDAE	*Chelidonichthys kumu*	4	8	1	–	10	9	5	1
	Lepidotrigla argus	12	12	1	12	12	11	11	12
	L. grandis	–	1	x	1	3	1	2	2
	L. mulhalli	3	2	2	1	12	12	10	9
	L. papilio	–	–	–	1	–	–	–	1
	Pterygotrigla polyommata	–	–	–	–	–	4	1	–
PLATYCEPHALIDAE	*Bembras japonicus*	–	–	–	–	–	–	–	1
	Platycephalus caeruleopunctatus	1	–	–	1	1	1	–	–
	P. longispinis	–	x	–	1	–	–	–	–
	P. marmoratus	–	–	–	1	8	7	6	12
	P. richardsoni	12	12	12	10	12	12	11	7
	Ratabulus diversidens	9	8	11	11	12	11	11	12
HOPLICHTHYIDAE	*Hoplichthys ogilbyi*	–	–	2	–	–	–	–	–
SERRANIDAE	*Ellerkeldia maccullochi*	–	x	–	–	–	–	–	–
	Epinephelus ergastularius	6	2	3	–	–	3	4	1
	Lepidoperca pulchella	–	–	1	2	–	–	–	–
	Anthiid sp.	–	–	–	1	–	–	–	–
PRIACANTHIDAE	*Cookeolus japonicus*	–	–	–	–	3	6	–	–
	Priacanthus macracanthus	6	x	–	1	3	–	–	1
	Priacanthus sp.3	–	–	–	–	–	–	–	4
	Pristigenys niphonia	–	–	1	–	–	–	–	–
ACROPOMATIDAE	*Apogonops anomalus*	11	12	12	4	4	1	10	3
SILLAGINIDAE	*Sillago bassensis*	10	6	–	7	5	6	6	7
BRANCHIOSTEGIDAE	*Branchiostegus serratus*	–	–	2	–	–	1	–	–
	Branchiostegus wardi	9	12	12	10	–	–	–	–
POMATOMIDAE	*Pomatomus saltatrix*	3	–	–	x	–	–	–	–
CARANGIDAE	*Carangoides equula*	–	–	–	–	5	–	1	–
	Decapterus macrosoma	–	–	–	2	–	–	–	6
	Trachurus declivis	–	–	–	–	4	4	1	1
	T. novaezelandiae	9	7	12	12	1	4	2	8
NEMIPTERIDAE	*Nemipterus theodorei*	2	–	–	–	–	–	–	–
SPARIDAE	*Allotaius spariformes*	–	–	1	–	7	2	4	4
	Pagrus auratus	2	–	–	–	–	–	1	–
MULLIDAE	*Upeneichthys lineatus*	9	2	1	1	1	2	2	–
	Upeneus moluccensis	1	–	–	1	–	–	–	–
SCORPIDIDAE	*Atypichthys strigatus*	3	–	–	–	–	–	–	–
ENOPLOSIDAE	*Enoplosus armatus*	2	–	–	–	–	–	–	–
PENTACEROTIDAE	*Paristiopterus labiosus*	–	–	–	–	–	3	–	–
	Zanclistius elevatus	1	–	–	–	–	–	–	–
CHEILODACTYLIDAE	*Cheilodactylus vestitus*	–	–	–	–	1	–	–	–
	Nemadactylus douglasii	–	2	4	–	1	4	8	–
CEPOLIDAE	*Cepola australis*	2	x	x	7	–	–	–	–
	Owstonia pectinifer	–	–	–	1	–	–	–	–
SPHYRAENIDAE	*Sphyraena africana*	1	–	–	–	3	–	2	–
PINGUIPEDIDAE	*Parapercis allporti*	6	6	8	2	–	–	–	–
	P. binivirgata	2	6	2	4	–	–	–	–
	P. macrophthalma	2	–	3	1	–	–	–	–
	Parapercis sp.	6	5	4	4	–	1	1	–
URANOSCOPIDAE	*Gnathagnus innotabilis*	–	–	9	10	–	1	–	–
	Uranoscopus cognatus ?	–	–	–	x	–	–	–	–
	Uranoscopus sp.1	5	10	4	11	2	–	1	–
CHAMPSODONTIDAE	*Champsodon* sp.	5	7	8	9	1	–	–	3
CALLIONYMIDAE	*Callionymus moretonensis*	2	6	1	1	9	2	2	10
	Synchiropus calauropomus	6	8	11	7	4	–	–	11

Appendix 4(d): (continued)

	Area:	Newcastle				Tuncurry			
	Survey:	V	VI	VII	VIII	V	VI*	VII	VIII
GOBIIDAE	*Oxyurichthys* sp.	–	2	–	–	–	–	–	–
TRICHIURIDAE	*Trichiurus lepturus*	1	–	–	–	–	–	–	–
SCOMBRIDAE	*Scomber australasicus*	4	7	12	2	3	–	5	1
CENTROLOPHIDAE	*Seriolella brama*	–	–	2	–	–	–	–	–
	S. punctata	–	–	2	–	–	–	–	–
NOMEIDAE	*Cubiceps whiteleggi* ?	–	–	1	–	–	–	–	–
BOTHIDAE	*Lophonectes gallus*	12	12	12	12	12	12	11	12
PARALICHTHYIDAE	*Pseudorhombus arsius*	1	–	–	–	–	–	–	–
	P. tenuirastrum	2	–	1	x	10	11	5	6
SOLEIDAE	*Zebrias fasciatus*	–	–	–	–	–	1	1	3
MONACANTHIDAE	*Arotrolepis filicauda*	–	–	–	4	–	–	–	–
	Cantheschenia longipinnis	–	–	–	1	–	–	–	–
	Eubalichthys mosaicus	–	x	1	–	–	–	1	–
	Meuschenia scaber	–	5	2	1	–	2	1	1
	Nelusetta ayraudi	–	1	x	0	1	2	–	–
	Thamnaconus harpargyreus	–	3	5	–	–	–	–	–
OSTRACIIDAE	*Anoplocapros robustus*	6	2	1	–	10	5	5	1
	Trioris reipublicae	–	–	–	1	–	–	–	1
TETRAODONTIDAE	*Canthigaster callisterna*	–	–	–	1	–	–	–	–
	Lagocephalus cheesemani	–	–	–	2	–	5	4	4
	Torquigener altipinnis	–	–	–	–	–	–	–	1
DIODONTIDAE	*Allomycterus pilatus*	–	–	–	–	–	3	3	–
	Dicotylichthys punctulatus	–	x	–	–	–	–	–	–
	Diodon holocanthus	–	–	–	–	–	–	–	1

Appendix 5: List of crustaceans and cephalopods identified from catches during Surveys V to VIII. The data indicate the percentage of total tows on each ground in which each species was recorded: 1= < 25%; 2 = 25-49%; 3 = 50-74%; 4 = 75-99%; 5 = 100%. (BH=Brunswick Heads; CR=Clarence River; T=Tuncurry; N=Newcastle; * NSW record; + daytime tows only)

		INSHORE				OFFSHORE			
		BH	CR	T	N	BH	CR	T	N
CRUSTACEA									
STOMATOPODA (mantis shrimps)									
HARPIOSQUILLIDAE									
Harpiosquilla annandalei		–	–	–	–	–	–	–	1
Harpiosquilla melanoura		–	–	–	–	–	–	–	1
HEMISQUILLIDAE									
Hemisquilla ensigera australiensis		–	–	–	–	–	–	–	+
ODONTODACTYLIDAE									
**Odontodactylus japonicus*		–	–	–	–	1	–	–	–
SQUILLIDAE									
Alima laevis		1	4	–	1	1	–	–	1
Anchisquilloides mcneilli		–	–	–	–	–	–	3	4
Kempina mikado		–	–	–	–	–	–	–	2
Oratosquilla imperialis		–	–	–	–	–	1	–	–
Oratosquilla woodmasoni		1	–	–	–	–	–	–	1
LYSIOSQUILLIDAE									
Lysiosquilla sp.nov.		–	–	–	–	–	–	1	–
DECAPODA: PENAEIDEA									
SOLENOCERIDAE									
Solenocera choprai	Ridgeback prawn	–	–	–	–	–	1	2	5
Solenocera sp.		–	–	–	–	–	3	3	3
PENAEIDAE									
Metapenaeopsis lamellata	Hunchback prawn	–	–	–	–	1	1	–	–
Metapenaeopsis mogiensis	Velvet prawn	–	–	–	–	1	–	–	–
Metapenaeopsis novaeguineae	Velvet prawn	–	–	–	–	–	–	–	1
Metapenaeopsis cf *wellsi*	Velvet prawn	–	–	–	–	–	–	1	–
Metapenaeus bennettae	Greasy back prawn	–	1	–	–	–	–	–	–
Metapenaeus macleayi	School prawn	4	2	1	4	–	–	–	–
Parapenaeus australiensis	Racek prawn	–	–	–	–	–	–	–	4
?*Parapenaeus* sp.		–	–	–	–	–	–	1	3
Penaeus esculentis	Tiger prawn	1	1	–	–	1	–	–	1
Penaeus longistylus	Redspot king prawn	–	–	–	–	1	–	–	–
Penaeus merguiensis	Banana prawn	2	1	–	1	–	–	–	–
Penaeus monodon	Leader prawn	2	1	–	–	–	–	–	–
Penaeus plebejus	King prawn	2	2	1	2	4	5	4	5
Trachypenaeus curvirostris	Hard-back prawn	2	2	1	1	2	4	1	1
SICYONIDAE									
Sicyonia cristata	Ridgeback rock prawn	–	–	–	–	1	1	–	–
DECAPODA: CARIDEA									
PANDALIDAE									
Plesionika spinipes	Red-striped carid prawn	–	–	–	–	–	1	1	1
Plesionika ortmani	Carid prawn	–	–	–	–	–	1	1	4
DECAPODA: PALINURA									
PALINURIDAE									
Jasus verreauxii	Eastern rock lobster	–	–	–	1	–	–	–	1
Linuparus trigonus	Barking lobster	–	–	–	–	–	–	1	1
SCYLLARIDAE									
Ibacus brucei	Red (Bruce's) bug	–	–	–	–	–	–	1	–
Ibacus peronii	Balmain bug	–	–	–	1	1	1	1	–
Ibacus sp.	Smooth bug	–	–	–	–	4	4	3	2
Scyllarides sp.	Slipper lobster	–	1	–	–	–	–	–	–
Scyllaris sordidus		–	–	–	–	–	–	1	1
Thenus orientalis	Moreton Bay bug	–	1	–	–	–	–	–	–
DECAPODA: BRACHYURA									
CALAPPIDAE									
Calappa lophus		–	1	–	–	–	1	1	–
Calappa philargius		1	1	–	–	–	–	–	–
Matuta planipes		3	2	–	3	–	–	–	–
Mursia curtispina		–	–	–	–	–	–	2	–
CORYSTIDAE									
Jonas luteanus		–	–	–	–	–	1	–	–

Appendix 5: (continued)

		INSHORE				OFFSHORE			
		BH	CR	T	N	BH	CR	T	N
DORIPPIDAE									
Dorippe quadridens		–	–	–	–	–	1	–	–
GONEPLACIDAE									
Carcinoplax meridionalis		–	–	–	–	–	–	–	2
?*Psopheticus* sp.		–	–	–	–	–	–	–	2
Ommatocarcinus macgillivrayi		–	–	–	–	–	–	–	1
HOMOLIDAE									
Homola orientalis		–	–	–	–	–	–	–	1
LATREILLIDAE									
Latreilla philargium		–	–	–	–	–	–	2	1
LEUCOSIIDAE									
Arcania undecimspinosa		–	–	–	–	1	1	1	–
Philyra undecimspinosa		1	1	1	1	–	–	–	–
MAJIDAE									
Ephippias endeavouri		–	–	–	–	–	1	–	–
Hyastenus elatus		1	–	–	–	1	–	–	–
Leptomithrax waitei		–	–	–	–	–	–	1	1
Leptomithrax tuberculatus		1	–	–	–	1	1	1	3
Naxioides robillardi		–	–	–	–	–	–	–	3
Phalangipus australiensis		1	1	–	–	1	–	–	–
PARTHENOPIDAE									
Eumedonus villosus		–	–	–	–	1	1	–	–
PORTUNIDAE (swimming crabs)									
Charybdis bimaculata		–	–	–	1	–	–	3	5
Charybdis cruciata	Coral crab	2	1	1	1	1	–	–	–
Charybdis jaubertensis		2	1	–	–	–	–	–	–
Charybdis miles		–	1	–	–	–	1	1	5
Charybdis natator		2	1	–	–	1	2	–	–
Charybdis orientalis		–	1	–	1	1	1	–	–
Charybdis truncata		–	–	–	–	–	–	–	–
Lupocyclas sp.		–	–	–	–	–	1	–	–
Macropipus corrugatus		–	–	–	–	–	–	–	1
Ovalipes australiensis	Two–spotted crab	1	2	1	5	–	–	–	1
Ovalipes molleri		–	–	–	–	–	–	1	–
Portunus argentatus		–	–	–	–	–	3	–	–
Portunus orbitosinus		–	1	–	–	–	–	–	–
Portunus pelagicus	Blue–swimmer crab	2	3	4	4	1	–	–	1
Portunus pubescens		–	–	1	–	–	–	–	–
Portunus rubromarginatus		4	1	–	–	4	1	–	–
Portunus sanguinolentus	Three–spotted crab	4	4	1	4	1	–	–	1
Scylla serrata	Mud crab	–	–	–	1	–	–	–	–
Thalamita sima		1	1	1	–	–	–	–	–
RANINIDAE (spanner crabs)									
Lyreidus tridentatus		–	–	–	–	–	–	1	4
Ranina ranina	Commercial spanner crab	1	1	–	1	–	1	–	–
MOLLUSCA									
CEPHALOPODA									
SEPIIDAE									
Sepia spp.	Cuttlefish	1	1	1	1	5	5	4	5
SEPIOLOIDIDAE									
Sepioloidea lineolata	Lined dumpling squid	1	1	–	–	2	2	1	–
LOLIGINIDAE									
Loligo chinensis	Broad squid	3	3	3	4	–	–	–	–
Loligo sp.	Slender squid	–	1	1	1	4	4	1	1
Loliolus noctiluca	Bottle squid	5	5	3	5	–	–	–	–
Sepioteuthis australis	Southern calamary	1	2	3	2	3	2	1	1
OMMASTREPHIDAE									
Nototodarus gouldi	Gould's (arrow) squid	–	–	1	1	1	3	4	2
OCTOPODIDAE									
Octopus australis	Southern octopus	2	1	3	1	4	4	2	4
Octopus sp.2	Octopus	1	–	1	1	1	2	1	1
Octopus sp.3	Long–armed octopus	–	1	–	–	–	–	1	1
Hapalochlaena fasciata	Blue–ringed octopus	–	–	1	–	–	–	–	–