STUDY OF THE BIOLOGY AND FISHERY OF BALMAIN AND SMOOTH BUGS (*IBACUS* SPP.) IN NSW

FINAL REPORT TO THE FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project No.: 92/006

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ISBN 0 7310 4934 9

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FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project title:	Study of the biology and fishery of balmain and smooth bugs (*Ibacus* spp) in NSW
Project reference no.:	92/006
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Funding organisation:	Fisheries Research & Development Corporation

NON-TECHNICAL SUMMARY

Balmain Bugs (*Ibacus peronii*) and Smooth Bugs (*Ibacus* sp.) are commercially important scyllarid lobsters occurring off the east coast of Australia. *I. peronii* and *Ibacus* sp. are morphologically alike and have only recently been identified as different species. They overlap in their distributions, with *I. peronii* found predominantly in relatively shallow inshore waters (less than 80m deep) from northern New South Wales around the south of the continent to Western Australia, whereas *Ibacus* sp. are found predominantly in mid-shelf waters (from 50m to 150m deep) in northern New South Wales and southern Queensland. Also referred to as "bugs", "shovelnosed lobsters", "flapjacks" and "sand lobsters", these two species are landed by prawn and fish trawlers along the east coast of Australia and are marketed as Balmain Bugs. Historically *Ibacus* spp. have been considered as an incidental by-catch when fishing for more lucrative species such as prawns. However, over the past few years, a combination of an expanding market, increased consumer awareness and higher prices has led to fishers in New South Wales and Victoria specifically targeting these animals. This increase in fishing effort, along with claims by fishers that the average size of landed *Ibacus* spp. has decreased, has led to concerns that stocks are being over-exploited. At present, there is virtually no management restrictions on the fishery in New South Wales or Victoria and given the morphological similarity of these two species and their overlapping distributions, any new regulations which are designed to manage the fishery better will need to consider both species.

One management option for these species involves the introduction of a minimum legal size limit. *Ibacus* spp. are particularly hardy and survive trawling quite well so undersized animals that are released would be likely to survive, grow, mature and increase the size of the spawning population and eventually the exploitable stock. Ideally, a legal minimum size should allow all individuals in the population the opportunity to spawn at least once before being recruited into the

fishery. Unfortunately, the economics of fisheries rarely allows for such an ideal minimum size limit and a compromise used in many lobster fisheries is to set the minimum size as the size at which at least 50% of the population has reached sexual maturity. Such management decisions are usually based on the size at which females reach sexual maturity because of (i) the importance of female fecundity and reproductive success to the next generation, and (ii) difficulties in staging the reproductive maturity of male decapods.

The aims of the reproductive components of this study were to make the first documented observations on the general reproductive biology of *Ibacus peronii* and *Ibacus* sp., and to estimate the size at sexual maturity for males and females of both species in New South Wales and Victoria. Two techniques were used to estimate size at sexual maturity (i) a histological examination of the gonads, and (ii) assessing changes in the relative growth rates of various body parts associated with maturity. The results of the present study were then used to recommend legal minimum size limits for *I. peronii* and *Ibacus* sp. in New South Wales and Victoria.

Another life-history parameter that is important when setting a minimum size limit is the rate of growth of the species . This is so that some estimate can be made about the consequences that the minimum size may have on future landings of the species and the time required for undersize individuals to recruit into the fishery. The most direct way that this can be done is to tag individuals in the wild, recapture them some time later and measure growth increments. We executed such a tagging project in this study and data from animals that are being recaptured by commercial fishers are providing us with excellent estimates of growth.

The results from this project have shown that one of these species (*Ibacus* sp.) mature and spawn somewhere outside of the areas studied. Future work should clearly concentrate on more northern locations to determine where and when *Ibacus* sp. matures. The different patterns of movement exhibited by *Ibacus peronii*

and *Ibacus* sp. also suggest that despite being morphologically alike, these species have evolved very different life-histories.

Recommending a minimum legal size for these species is made complex by the fact that one of the species appears to gain sexual maturity outside of the areas sampled. In the present study 95% of female *Ibacus peronii* became reproductively mature between 49.7mm and 51.1mm C.L. Male *I. peronii* were sexually mature as small as 38.5mm C.L. Using these results, and the proposition that lobster fisheries should be managed using size-limits that are set at the length at which 50% of females are mature, the legal minimum size-limit for *I. peronii* in N.S.W. should be set at 50.2mm C.L. and *Ibacus* sp. should not be landed at all. Given the morphological similarity of these two species, and the commercial importance of *Ibacus* sp. as a by-catch to the prawn trawl fleets in northern N.S.W., however, the minimum legal size-limit for *Ibacus* sp. in N.S.W. may have to be set at the same size as that implemented for *I. peronii*.

The preliminary von Bertalanffy plots of the growth rates of these species based on the incomplete tagging dataset suggest that there is a marked similarity in growth rates between females of both species and male *Ibacus peronii* seem to grow much slower than females. This means that females may get to a size at 50% sexual maturity (the above recommended legal minimum size of approximately 50mm CL) at about 2 years old whilst males may reach this size after 5 years. A more thorough analysis of these growth rates can only be done once the tag return phase of this project is completed in 1 or 2 years time.

BACKGROUND AND INTRODUCTORY INFORMATION CONCERNING THE RESEARCH NEED

The background and introductory information for this project are described in detail in our various publications and reports (see Appendices A, B, C, D, E & F). We provide a summary below.

Balmain Bugs (*Ibacus peronii*) and Smooth Bugs (*Ibacus* sp.) are commercially important scyllarid lobsters occurring off the east coast of Australia. Also referred to as "bugs", "shovelnosed lobsters", "flapjacks" and "sand lobsters", these two species are landed as a by-catch by prawn and fish trawlers along the east coast of Australia and are marketed as Balmain Bugs. *I. peronii* and *Ibacus* sp. are morphologically alike and have only recently been identified as different species. They overlap in their distributions, with *I. peronii* found predominantly in relatively shallow inshore waters (less than 80m deep) from northern New South Wales around the south of the continent to Western Australia, whereas *Ibacus* sp. are found predominantly in mid-shelf waters (from 50m to 150m deep) in northern New South Wales and southern Queensland.

Unfortunately very little is known about the biology of scyllarid lobsters and despite the importance of *Ibacus* spp. as a fishery, there have been almost no published studies on any aspects of their biology. If good management of the *Ibacus* spp. fishery is to occur, key components of its biology must be documented. In addition, the general paucity of information on the biology of the Scyllaridae makes any study of species in this family invaluable.

Along the east coast of Australia, *Ibacus* spp. have historically been considered as an incidental by-catch when fishing for more lucrative species such as prawns. However, over the past few years, a combination of an expanding market, increased consumer awareness and higher prices has led to fishers in New South Wales and

Victoria specifically targeting these animals. This increase in fishing effort, along with claims by fishers that the average size of landed *Ibacus* spp. has decreased, has led to concerns that stocks are being over-exploited. At present, there is virtually no management restrictions on the fishery in New South Wales except that females which are carrying eggs may not be landed. In Victoria there is no management strategy for *Ibacus* spp. Given the morphological similarity of these two species and their overlapping distributions in New South Wales, any new regulations which are designed to manage the fishery better will need to consider both species.

One management option for these species involves the introduction of a minimum legal size limit. *Ibacus* spp. are particularly hardy and survive trawling quite well. Animals less than the minimum legal size that are released would therefore be likely to survive, grow, mature and increase the size of the spawning population and eventually the exploitable stock. Ideally, a legal minimum size should allow all individuals in the population the opportunity to spawn at least once before being recruited into the fishery. Unfortunately, the economics of fisheries rarely allows for such an ideal minimum size limit and a compromise used in many lobster fisheries is to set the minimum size as the size at which at least 50% of the population has reached sexual maturity (Aiken, 1984). Such management decisions are usually based on the size at which females reach sexual maturity because of (i) the importance of female fecundity and reproductive success to the next generation, and (ii) difficulties in staging the reproductive maturity of male decapods.

To assess the size at which large decapods become sexually mature, it is necessary to determine (i) the size at which physiological (or gonadal) maturity occurs and (ii) the size at which physical maturity occurs (ie. the size at which an animal is capable of mating, oviposition, brooding eggs, etc). Physiological and physical maturity in scyllarid lobsters may not occur at the same size (Jones, 1988), and both need to be known in order to ascertain the size at true sexual maturity.

Physiological maturity in female lobsters can be estimated by assessing the stage of development of ovaries. The size at which physical maturity occurs in lobsters has been historically studied by the morphometric examination of the relative growth of externally visible features.

The aims of the reproductive components of this study were to make the first documented observations on the general reproductive biology of *Ibacus peronii* and *Ibacus* sp., and to estimate the size at sexual maturity for males and females of both species in New South Wales and Victoria. Two techniques were used to estimate size at sexual maturity (i) a histological examination of the gonads, and (ii) assessing changes in the relative growth rates of various body parts associated with maturity. The results of the present study were then used to recommend legal minimum size limits for *I. peronii* and *Ibacus* sp. in New South Wales and Victoria.

Another life-history parameter that is important to estimate when setting a minimum size limit is the rate of growth of the species . This is important so that some estimate can be made about the consequences that the minimum size may have on future landings of the species and the time required for undersize individuals to recruit into the fishery. The most direct way that this can be done is to tag individuals in the wild, recapture them some time later and measure growth increments. We executed such a tagging project in this study and data from animals that are being recaptured by commercial fishers are providing us with excellent estimates of growth.

ORIGINAL OBJECTIVES

A) To provide the first assessment of selected life-history parameters of *Ibacus* spp. in NSW.

B) To estimate the growth rates and sizes and ages at sexual maturity of *Ibacus* spp. with a view to recommending an appropriate minimum legal size for NSW waters.

RESEARCH METHODOLOGY

The methods used during this project are described in the various appendices and we provide a summary below.

Appendix A describes a pilot study which developed optimal methods for the sampling and measuring of oocytes. These methods were subsequently applied in the histological work done throughout the project. Size at physiological and physical maturity was determined for males and females of each species studied. Size at physiological maturity was determined via a histological examination of ovaries and testes and quantifying the smallest ovigerous females captured in the field. Size at physical maturity was estimated by analysing the relative growth rates of various body parts.

The reproductive cycles of both species were investigated at two locations, at Coffs Harbour and Lakes Entrance by sampling these populations every two months. The reproductive condition of females in each population was estimated by measuring the changes in the size of oocytes within ovaries, the gonosomatic index (GSI) and the proportion of ovigerous females in commercial catches. Male reproductive condition was estimated from GSI measurements and the presence of spermatophores within the vas deferentia.

Samples of egg-bearing female Balmain Bugs *Ibacus peronii* (Leach) were collected from Coffs Harbour, NSW and Lakes Entrance, Victoria to estimate their fecundity and egg-size.

The tag/recapture study was done out of four ports along the east coast of Australia: Ballina, Coffs Harbour and Newcastle in NSW, and Lakes Entrance in Victoria. Tagging was done approximately every two months throughout the period April 1993 to May 1994 onboard commercial fishing trawlers during their

normal fishing operations. *Ibacus* spp. were tagged with standard plastic T-bar tags which were inserted dorsally into the musculature at the interface between the carapace and abdomen, at a point midway between the midline and the left hand edge of the animal. A total of 3892 *Ibacus peronii* and 716 *Ibacus* sp. were tagged, sexed and measured during the study. *Ibacus* spp. smaller than approximately 30mm C.L. were not tagged because it was considered that they would not survive tagging. Tagged animals were kept alive onboard the fishing trawler in tanks of circulating seawater and were released at the end of the nights fishing. To minimise predation of tagged animals upon release, and to prevent predation as they sank to the bottom, all animals were released on the sea floor using a release cage that was opened once it reached the bottom.

The tagging programme was widely publicised by way of a tag return poster distributed at the start of the study. All offshore trawler fishermen were also sent letters informing them of the study. A reward of $5 was offered for the return of each recaptured tagged *Ibacus* spp. with the tag in place and information on where and when it was caught. Extensive liaison with fishermen at each port ensured a high rate of return of recaptured tagged animals. Recaptured tagged *Ibacus peronii* and *Ibacus* sp. that were returned with the date and location of their recapture were used to calculate the time at liberty, distance and direction moved and the rate of movement of each animal.

Data from some recaptured tagged *Ibacus* spp. provided information on moult increment and moult frequency. At this time we can only do preliminary analyses of these data because the tag return phase of the project is continuing until the return rate declines to a low level. We describe growth using the von Bertalanffy growth function as modified by Francis (1988). This technique provides the parameters K and L infinity for von Bertalanffy curves and also provides some estimation of growth variability between animals. The technique is available on the Fortran program GROTAG available from Francis (1988).

RESULTS

Details on the results from this project are described in the various appendices and we provide a summary below.

The size at physiological maturity (± 95% confidence intervals) was estimated to be 50.4mm ± 0.7mm carapace length (C.L.) for female *Ibacus peronii* from Coffs Harbour and 50.2mm ± 0.4mm C.L. for female *I. peronii* from Lakes Entrance. Male *I. peronii* were estimated to be physiologically mature at 45mm C.L. from Coffs Harbour and 38.5mm from Lakes Entrance. All female *Ibacus* sp. sampled in the study were found to be immature. The size at physical maturity for female *I. peronii* was 54.9mm ± 4.0mm C.L. from Coffs Harbour and 56.6mm ± 3.1mm C.L. from Lakes Entrance.

Female *Ibacus peronii* exhibited a peak spawning season during the cooler months (from June to October) at both locations, with small amounts of spawning occurring during the rest of the year. The presence of well developed ovaries in ovigerous females suggests that some female *I. peronii* are able to produce two broods of eggs in the same year. Male *I. peronii* showed no reproductive cycle and were capable of spawning at all times of the year. No sign of ovarian maturation was observed in any female *Ibacus* sp. throughout the study, indicating that female *Ibacus* sp. mature and spawn somewhere outside of the study area. Male *Ibacus* sp. contained spermatophores in their vas deferentia at all times of the year, but it could not be determined whether they were sexually active. The overall ratios of males to females was approximately 1:1 for both species.

Fecundity of *Ibacus peronii* ranged between 5,500 and 37,000 eggs per brood with a mean egg diameter of 1.18mm ± 0.013mm. Fecundity did not vary significantly between Coffs Harbour and Lakes Entrance and the data were combined to provide a general fecundity-size relationship for *I. peronii*. This relationship is

described by the positive linear regression $y = 943x - 45296$ ($r^2 = 0.676$, $p<0.01$). The fecundity of *Ibacus* sp. remains unknown as no ovigerous females were found during the present study.

Of the 3892 *Ibacus peronii* and 716 *Ibacus* sp. tagged and released between April 1993 and May 1994, 382 (9.8%) *I. peronii* and 77 (10.8%) *Ibacus* sp. were recaptured by the end of 1994. Of these, 374 *I. peronii* and 70 *Ibacus* sp. were returned with information on the date and location of recapture. Distances moved were calculated as the shortest distance between the release and recapture locations. This is likely to have underestimated the actual distances and rates of movements of recaptured tagged *Ibacus* spp. as it is unlikely that movement occurred in a direct line.

Recaptured tagged *Ibacus peronii* were at liberty for an average of 144 days (S.E. = 6.8 days) during which time they moved an average of 0.28km (S.E. = 0.07km). There were no trends in the directions of movement of recaptured tagged *I. peronii*. There were no apparent differences in movements of recaptured tagged male and female *I. peronii*.

Recaptured tagged *Ibacus* sp. were at liberty for an average of 171.2 days (S.E. = 16.9 days) during which time they moved an average of 27.6km (S.E. = 4.8km). Of the 70 *Ibacus* sp. returned with the date and location of recapture, 33 had moved greater than 10km, all of them northwards and generally into deeper water. The greatest distance moved by a recaptured tagged *Ibacus* sp. was approximately 260km having been tagged off Coffs Harbour in NSW and recaptured off Southport in Queensland 364 days later. There was a large variation in the rates of movement of recaptured tagged *Ibacus* sp., with some animals moving less than 5km in 125 days, and others moving at a mean rate of up to 0.71km per day. There were no apparent differences in movements of recaptured tagged male and female *Ibacus* sp.

There were insufficient data for even a preliminary analysis of the growth of male *Ibacus* sp. Preliminary von Bertalanffy growth curves for female and male *Ibacus peronii* and for female *Ibacus* sp. showed that females of both species had similar growth rates whilst male *I. peronii* grew much slower.

DISCUSSION OF RESULTS

Discussion of the various results from this project are provided in the attached appendices and we provide summaries below.

Studies on the reproductive biology of *Ibacus peronii* and *Ibacus* sp. in this project have allowed some insight into its mechanics. The general reproductive anatomy has been shown to be somewhat similar to that of other scyllarid lobsters and also the palinurid lobsters. However, the processes of mating, fertilization, oviposition, incubation and hatching suggest that these species of *Ibacus* differ in many aspects of their reproductive biology.

The estimates, with 95% confidence intervals, of the size at physiological maturity for female *Ibacus peronii* of 50.4mm ± 0.7mm C.L. for Coffs Harbour and of 50.2mm ± 0.4mm C.L. for Lakes Entrance suggest that there is no variation in the size at which ovarian maturity occurs at these locations for this species. The smallest ovigerous females observed (50.9mm C.L. from Coffs Harbour and 49.7mm C.L. from Lakes Entrance) and the smallest females observed to have mated (50.9mm C.L. from Coffs Harbour and 50.3mm C.L. from Lakes Entrance) are very close to the estimates of physiological maturity based on the histological study. This suggests that female *I. peronii* are able to mate and carry eggs as soon as ovarian maturity occurs.

No sign of ovarian development was observed in any female *Ibacus* sp. and while samples were taken regularly only from Coffs Harbour, samples taken further north from Ballina also lacked any sign of ovarian development. We conclude that female *Ibacus* sp. become mature outside of the main fishing areas in NSW. This may relate to the fact that the areas sampled were at the southern end of this species distribution. There are several examples of crustacean species on the N.S.W. coast that are essentially non-reproductive populations being seeded by northern

populations and recruiting larvae from the southward flowing east Australian current (eg. the Eastern King Prawn *Penaeus plebejus* and the Eastern Rock Lobster *Jasus verreauxi.*)

Previous studies have emphasized the difficulty in defining stages of maturity in male scyllarid lobsters, but our identification of spermatophores in the vas deferens at least permits the recognition of males that are potentially mature. The size at first physiological maturity for male *Ibacus peronii* from Coffs Harbour is therefore estimated to be 45.0mm C.L and from Lakes Entrance 38.5mm C.L. For male *Ibacus* sp. from Coffs Harbour this size is estimated to be 47.4mm C.L.

Size at physical maturity for female *Ibacus peronii* was estimated from discontinuities in the plots of pleopod endopodal setal length and C.L. Spline linear regressions revealed clear intersect points with 95% confidence intervals in these relationships for female *I. peronii* from Coffs Harbour of 54.9mm ± 4.0mm and from Lakes Entrance of 56.6mm ± 3.1mm C.L. The similar sizes at which these discontinuities occurred and their overlapping confidence intervals, suggests that there is no difference between the estimated size at physical maturity between Coffs Harbour and Lakes Entrance.

The results showed that for female *Ibacus peronii*, physiological maturity occurred at a slightly smaller size than physical maturity. It should be noted, however, that the discontinuities in the relationships between pleopod endopodal setal length and C.L. in the present study cannot be directly related to the ability to reproduce. In addition, our definition of a "mature" ovary in the histological study included those ovaries which were either in a spent or redeveloping condition. Our estimates of size at physiological maturity are therefore the best estimates of the true size at sexual maturity.

Ibacus peronii from Coffs Harbour and Lakes Entrance spawn mainly during the cooler months of the year (winter to early spring) and some lower level spawning occurs throughout the rest of the year. Male *I. peronii* were potentially reproductively active all year at both locations. Although similar patterns of spawning were evident for *I. peronii* from Coffs Harbour and Lakes Entrance, there were some differences which suggest a slightly different spawning strategy between the two locations. During the peak spawning times, a mean maximum (± S.E.) of 63% ± 9.8% of mature female *I. peronii* were ovigerous at Coffs Harbour, but at Lakes Entrance this mean maximum was only 31% ± 0.6%. In addition, the peak spawning period at Coffs Harbour was from June to August/September, whereas at Lakes Entrance this period extended until at least October. The resultant pattern is a more protracted, but less intense, peak spawning period at Lakes Entrance than at Coffs Harbour. Lakes Entrance is much further south than Coffs Harbour and is therefore more likely to experience much colder water. Development time is strongly correlated with temperature in ectotherms suggesting that Lakes Entrance's colder water could be responsible for the more prolonged incubation period.

Successive spawnings by individual female *Ibacus peronii* in the one year were not found in the present study, but the presence of well-developed ovaries in some egg-bearing females suggests that it could be possible.

Unfortunately it was not possible to determine the reproductive cycle of *Ibacus* sp. in this study. No ovigerous females were observed and even large animals with well developed sexual characteristics (such as long ovigerous setae on their pleopods), showed little sign of ovarian development. The mean maximum sizes of oocytes remained very small all year, as did their mean GSI values. Male *Ibacus* sp. contained spermatophores within their vas deferentia all year, but the very small GSI values when compared to those from male *Ibacus peronii* suggest that those male *Ibacus* sp. sampled were not fully mature. It is obvious that *Ibacus* sp. mature and spawn somewhere outside of the areas studied. Coffs Harbour is

close to the southern end of this species distribution and future work should clearly concentrate on more northern locations to determine where and when *Ibacus* sp. matures.

The overall ratios of males to females for *Ibacus peronii* and *Ibacus* sp. were approximately 1:1. The widely differing ratios of males to females at different sampling times, particularly for *I. peronii*, may reflect behavioural differences between the sexes at different times affecting their susceptibility to trawling.

There was no significant geographical variation in the fecundity-size relationship for *Ibacus peronii* from Coffs Harbour and Lakes Entrance. These two locations are at either end of the fishery for *I. peronii* in eastern Australia and consequently occur at very different latitudes suggesting that latitude, and therefore water temperature, may not affect fecundity in this species. The lack of geographical variation in fecundity detected in our study allowed us to calculate a general fecundity-size relationship for *I. peronii* which shows a positive linear relationship. We found that fecundity of *I. peronii* was between approximately 5,500 and 37,000 eggs per brood. There was no apparent relationship between carapace length and egg-size suggesting that for *I. peronii*, the eggs from small females are equally as viable as those from larger animals.

The linear fecundity-size relationship for *Ibacus peronii* off the east coast of Australia is of interest to fisheries managers because the most fecund females in the population are the largest - who will not be protected by minimum legal size limits. It should be noted, however, that the relative contribution of eggs to the population of any size-class of animals is a function of their frequency of oviposition and the proportion of the population that they represent. In the present study, fecundity was estimated as numbers of eggs per brood. The next stage in estimating the total reproductive potential of this species is to estimate the size-structured biomass of

females, the number of broods per year, the percentage of infertile eggs, egg loss during incubation and the survival of larvae.

The preliminary results from the tagging project indicate that the morphologically similar *Ibacus peronii* and *Ibacus* sp. exhibit very different patterns of movement. *I. peronii* exhibits a nomadic pattern of movement, with tagged animals being recaptured close to, but in any direction, from their place of release. This pattern could possibly be interpreted as a homing one, with excursions away from shelter and subsequent return to that shelter or to others nearby. However the featureless sandy environments inhabited by *I. peronii* and the fact that *I. peronii* bury in the substratum for protection, suggests that this is not the case.

In stark contrast to *Ibacus peronii*, *Ibacus* sp. exhibited a migration of individuals northwards and generally into deeper water. The large proportion of recaptured tagged animals that exhibited this trend from each release location, suggests that this migration is a general pattern that is consistent for all *Ibacus* sp. throughout the year. The morphological similarity of these two species suggests that any alteration in behaviour due to tagging should have been similar in both species. This is obviously not the case as each species exhibited very different patterns of movement after tagging. In addition, it is highly unlikely that any bias was produced in the results because of unidirectional fishing effort. Fishing is known to occur north and south of all the release locations, yet not one *Ibacus* sp. was recaptured south of its release location.

The different patterns of movement exhibited by *Ibacus peronii* and *Ibacus* sp. suggest that despite being morphologically alike these species have evolved very different life-histories. *Ibacus peronii* is found predominantly in relatively shallow inshore waters up to 80m deep which are not subjected to any prevailing currents. The nomadic movement of *I. peronii* in this environment should therefore facilitate successful spawning, recruitment, genetic mixing and will optimize the

available food supply. *Ibacus* sp. are found in slightly deeper waters than *Ibacus peronii* ie. mid-shelf waters from 50-150m deep which are subjected to the prevailing southerly flow of the East Australian Current. It is hypothesized that this difference in environmental conditions has led to *Ibacus* sp. evolving a migratory pattern of movement northwards in order to facilitate larval transport southwards in the east Australian current. The processes stimulating lobster migrations can be either environmental, such as daylength, temperature or currents, or physiological, such as moult condition, reproductive condition or some hormonal trigger. The fact that *Ibacus* sp. migrate northwards throughout the year, and available evidence indicates that they are all immature in NSW, suggests that the "guide-post" for this migration is the southerly flowing East Australian Current.

The preliminary analsis of the growth data from the tagging project shows marked similarity between females of both species. Male *Ibacus peronii* seem to grow much slower than females. The preliminary von Bertalanffy plots suggest that females may get to a sexually mature size (approximately 50mm CL) at about 2 years old whilst males may reach 50mm after 5 years. Unfortunately, these plots are very problematic because they are based on data from only a limited size range of animals. Without growth data from younger bugs, the pattern of growth for bugs less than approximately 30mm will remain unknown.

It should also be remembered that the tagging data analysed at this point in time is a only a first examination of a very incomplete data set. Each month many more tagged bugs are returned, a small proportion of which have successfully moulted. A thorough treatment of the growth of these species can only be made toward the end of the tag return phase of this project in one or two years.

IMPLICATIONS AND RECOMMENDATIONS

1. The reproductive biology of *Ibacus* spp. along the N.S.W. coast is made complex by the fact that one of the species, *Ibacus* sp., appears to gain sexual maturity outside of the areas sampled. In the present study 95% of female *Ibacus peronii* became reproductively mature between 49.7mm and 51.1mm C.L. Male I. peronii were sexually mature as small as 38.5mm C.L. Using these results, and the proposition that lobster fisheries should be managed using size-limits that are set at the length at which 50% of females are mature, the legal minimum size-limit for *I. peronii* in N.S.W. should be set at 50.2mm C.L. and *Ibacus* sp. should not be landed at all. Given the morphological similarity of these two species, and the commercial importance of *Ibacus* sp. as a by-catch to the prawn trawl fleets in northern N.S.W., however, the minimum legal size-limit for *Ibacus* sp. in N.S.W. may have to be set at the same size as that implemented for *I. peronii*.

2. It is obvious that *Ibacus* sp. mature and spawn somewhere outside of the areas studied. Coffs Harbour is close to the southern end of this species distribution and future work should clearly concentrate on more northern locations to determine where and when *Ibacus* sp. matures. The different patterns of movement exhibited by *Ibacus peronii* and *Ibacus* sp. also suggest that despite being morphologically alike, these species have evolved very different life-histories.

3. The linear fecundity-size relationship for *Ibacus peronii* off the east coast of Australia is of interest to fisheries managers because the most fecund females in the population are the largest - who will not be protected by minimum legal size limits. It should be noted, however, that the relative contribution of eggs to the population of any size-class of animals is a function of their frequency of oviposition and the proportion of the population that they represent. In this study, fecundity was estimated as numbers of eggs per brood. The next stage in estimating the total

reproductive potential of this species is to estimate the size-structured biomass of females, the number of broods per year, the percentage of infertile eggs, egg loss during incubation and the survival of larvae.

4. The preliminary von Bertalanffy plots suggest a marked similarity in growth rates between females of both species. Male Balmain Bugs seem to grow much slower than females. The results suggest that females may get to a size at 50% sexual maturity (the above recommended legal minimum size of approx. 50mm CL) at about 2 years old whilst males may reach this size after 5 years.

ACKNOWLEDGEMENTS

The authors are grateful to Dennis Reid for statistical advice and to John Matthews for the photography used in the papers. Ove Hoegh-Guldberg, Mark Bradley, Matt Broadhurst and Steve Montgomery provided helpful discussions. We also thank the Victorian Department of Conservation and Environment for their assistance and the fishermens co-ops and fisheries officers for their aid in collecting tagged bugs. Most of all we are grateful to the following fishermen for their assistance and invaluable advice; Norm Shilling, Mark & Shane Huxley, Simon Tidswell, Les, Sel Turner, Daryl Sprague, Paul Andersen, Gary, Ted Kerslake and Wizard.

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APPENDICES

APPENDIX A

An optimal strategy for sampling oocytes in female Balmain Bugs Ibacus peronii Leach (Decapoda: Scyllaridae).

(DRAFT)

Stewart, J., Kennelly, S.J. & O. Hoegh-Guldberg

An optimal strategy for sampling oocytes in female Balmain Bugs Ibacus peronii Leach (Decapoda : Scyllaridae).

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SUMMARY:

Optimal numbers of replicates to estimate mean oocyte sizes in female Balmain Bugs (Ibacus peronii) were determined using analyses of variance of data from a pilot study. Mean oocyte size was different in different parts of the ovary in some animals but there were no differences within sections from the same part of each ovary. The optimal numbers of oocytes to measure was 219 or 55 per section to produce a standard error that was 5% or 10% of the mean respectively and for some purposes, only 20 oocytes per section needed to be measured. It is recommended that as many animals be sampled as possible, and that only a single section be taken from several parts of the ovary.

Key words: oocyte, size-frequency, histology, Ibacus peronii

Balmain Bugs (Ibacus peronii) are large, commercially exploited decapods belonging to the family Scyllaridae . They are generally trawled on coarse, sandy substrata by commercial fishers operating along the southern coastline of Australia and extending northwards to Geraldton in Western Australia and into northern New South Wales in the east (George & Griffin 1972). Balmain Bugs traditionally have been caught as by-catch during trawling operations for other species (Kennelly et al., 1993), but in recent years, fishermen have begun to fish specifically for them. This has led to concerns that stocks of Balmain Bugs are reaching maximal exploitation.

One management tool which seeks to protect the spawning population of this species involves the introduction of a legal minimum size. In many lobster fisheries, the legal minimum size is set at a value which allows at least 50% of females in the population to spawn at least once before recruitment into the fishery (Aiken, 1984). Little work has been done on the biology of Balmain Bugs and there exists no published information on the size at which sexual maturity occurs. We are therefore currently engaged in a study which involves histological examinations of the ovaries of Balmain Bugs in order to estimate the size at sexual maturity of females.

Methods used to monitor the maturity of gonads range from the visual staging of their external appearance to histological examination. Histological studies of gonads are more time-consuming and expensive than other studies, but are more precise because they provide very detailed information on the stage of development of individual oocytes. Size-frequency distributions of oocytes have been used to assess the stage of development, size/age at first maturity and the spawning strategies of

females of various marine animals such as teleost fish (De Vlaming, 1983), crabs (Armstrong, 1988) and urchins (Harvey & Gage, 1984; King et al. 1994). Sizes of oocytes are less subjective than certain other methods when assessing ovarian development and provide an insight into the dynamics of ovarian maturation. We have therefore chosen to use histology rather than whole oocytes in the present study so we could identify the stage of development of individual oocytes. Previous studies have emphasized the problems associated with varying oocyte sizes in different parts of ovaries, the methods of measuring irregularly shaped oocytes within ovaries and the bias produced by measuring oocytes that have not been sectioned through their centre (for a review see West, 1990).

The first step in a study which seeks to use histology to estimate size at sexual maturity is to develop the most efficient sampling protocol. Because of the time and expense involved in purchasing animals for analysis, dissecting them, preparing slides and measuring oocytes, it is important to maximize (i) the data obtained from each individual animal and (ii) the information gathered for the time spent on each part of the study. The choice of optimal numbers of replicates from each animal to be used can be calculated using cost-benefit analyses and analyses of variances of data from pilot studies (Snedecor & Cochran 1980, Winer 1971, Saila et al., 1976, Underwood 1981). These techniques have been successfully used in a variety of other marine studies (Kennelly & Underwood 1984, 1985, Fowler 1987, Kennelly et al., 1993). Here we describe an application of such analyses to data from a pilot study which determines the optimal numbers of replicate sections and oocytes required to estimate oocyte sizes in female Balmain Bugs.

The pilot study (see Table 1 for design) was done using 6 female Balmain Bugs (52.0 - 68.5mm carapace length). The animals used in this study were trawled from Lakes Entrance, Victoria and were selected to be at varying stages of maturity based on an initial macroscopic examination of the ovaries.

Each animal was dissected immediately after capture and the ovaries removed. The ovaries of Balmain Bugs are of the general decapod form (Barnes 1980, Phillips et al. 1980), consisting of two simple unconvoluted tubes joined by a transverse bridge which is approximately one third of their length from the anterior end. Portions of each ovary were removed which represented the left/anterior, left/posterior, right/anterior and right/posterior parts of the ovary. Each portion was fixed for one week in a solution of 10% formaldehyde, 5% acetic acid, 1% anhydrous calcium chloride and 84% seawater. After fixing, the tissue was dehydrated in ethyl alcohol, cleared in histolene and embedded in paraffin wax. Transverse sections were cut from each portion of ovary at a thickness of 6 micrometers. One slide was prepared for each portion of ovary (ie. 4 slides per animal) with at least five sections of ovary on each slide. Slides were stained with Gills' haematoxylin and eosin.

The sizes of oocytes were measured using an image processor. Oocyte size was measured by drawing around the perimeter of the oocyte and calculating the enclosed area in mm^2. Twenty oocytes were selected on the computer screen at random and measured, irrespective of whether the nucleus was visible, in each of five replicate sections on each slide, resulting in 400 oocytes measured per animal.

A three factor analysis of variance was done on the data from the pilot study. The factor "females" was treated as fixed in the analysis given that the number of females to be used in the full study is set at 10 per sample (due to the cost in purchasing animals).

The variance of the estimated mean square in this experiment can be determined from the mean squares in the analysis of variance, by methods discussed by Winer (1971) and Underwood (1981). The variance of the means of each section in each slide is estimated by dividing the mean square representing sections by the number of readings in each mean. This leads to the following formula for the estimated variance from sampling one portion of an ovary:

$$\text{Variance} = \frac{\sigma_e^2 + n_e.\sigma_s^2}{n_e.n_s} \qquad (1)$$

Where n_e is the number of replicate oocytes within each section, n_s is the number of replicate sections, σ_e^2 is the estimated variance among replicate oocytes and σ_s^2 is the estimated variance among each section within each slide.

A summary of the analyses of variance is given in Table 2. Oocyte size differed significantly between females, indicating that we should sample as many females as possible. As a consequence of these differences among females and the significant females/parts interaction, we re-analysed the data separately for each female. The resulting analyses indicated that oocyte size was different in different parts of the ovary in some animals, suggesting that all 4 parts of the ovary should be sampled. The mean sizes of oocytes for each part of ovary for each animal sampled are presented in Figure 1.

The analyses of variance indicated that there were no significant effects due to sections within different parts of ovaries for all animals. This, together with the very small variance due to sections (even smaller than the variance due to replicate oocytes), implied that replicate sections in each part of the ovary were unnecessary. This result, together with the fact that the numbers of females to be sampled in the full study is set at 10 per sample, means that a full cost-benefit analysis (see Underwood, 1981) comparing variances among sections is unnecessary and that all available time should be spent measuring oocytes.

The optimal number of oocytes to be measured was calculated from the variance equation (equation 1 above). Because the variance due to sections is negligible, and we only need to sample 1 section from each part of each ovary, the variance equation is simplified to:

$$\text{Variance} = \frac{\sigma_e^2}{n_e} \qquad (2)$$

From this equation, and using a standard error that is 5% of the mean size ($0.118mm^2$), the optimal number of oocytes to measure in any sampling period is 219 per section. Measuring 55 oocytes per section would result in a standard error that is 10% of the mean.

We measured the cross-sectional area irrespective of whether an oocyte was sectioned through its centre or not. This may have produced a bias reducing the estimated mean size of oocytes in a section, but any variation due to this factor was included in our random sampling. The resulting analyses of variance suggest that relatively small numbers of

oocytes (eg. 20 per section) can be measured to provide a reasonably precise estimate of oocyte condition. In substituting 20 oocytes into the variance equation, we estimate that we would be sampling oocyte size with a standard error that is 16% of the mean. This amount of variation about the mean is tolerable in reproductive studies where large differences in oocyte sizes are expected between mature and immature animals.

In terms of our future sampling of ovaries of Balmain Bugs, the results from this study indicate that there can be significant differences in oocyte size with respect to different parts of the ovary. This may be because we measured all oocytes regardless of where they were sectioned, but we consider that this method is more practical and less subjective than limiting measurements to oocytes in which the nucleus is visible (as suggested by West, 1990). Our study does indicate that single sections from each part of an ovary are representative of that part of the ovary and that sampling replicate sections from each part is unnecessary. As a consequence of this result, the time saved by sampling just one section per part of each ovary is very large and reinforces the importance of doing pilot studies such as this in designing more accurate and cost-effective sampling regimes.

Acknowledgements. This study was funded by a Fishing Research and Development Corporation grant (92/04). We thank Steve Montgomery and Charles Gray for critically reading the manuscript and Grant West for his helpful comments.

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Figure captions

Figure 1. Mean oocyte area (±S.E.) for each of 4 parts of ovaries from 6 Balmain Bugs. Numbers represent: 1 = the anterior/left part of the ovary, 2 = the posterior/left part of ovary, 3 = the anterior/right part of ovary, and 4 = the posterior/right part of ovary.

TABLE 1: Design of pilot study for estimating the optimal sampling regime for a study of sexual maturity in Balmain Bugs.

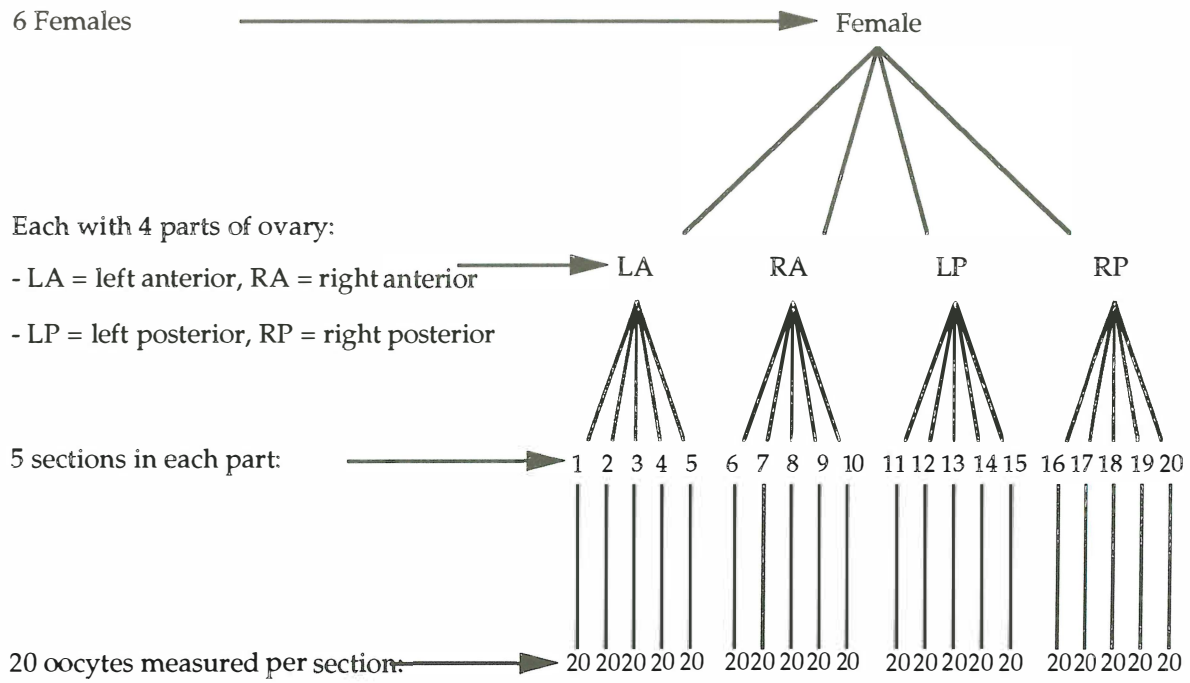
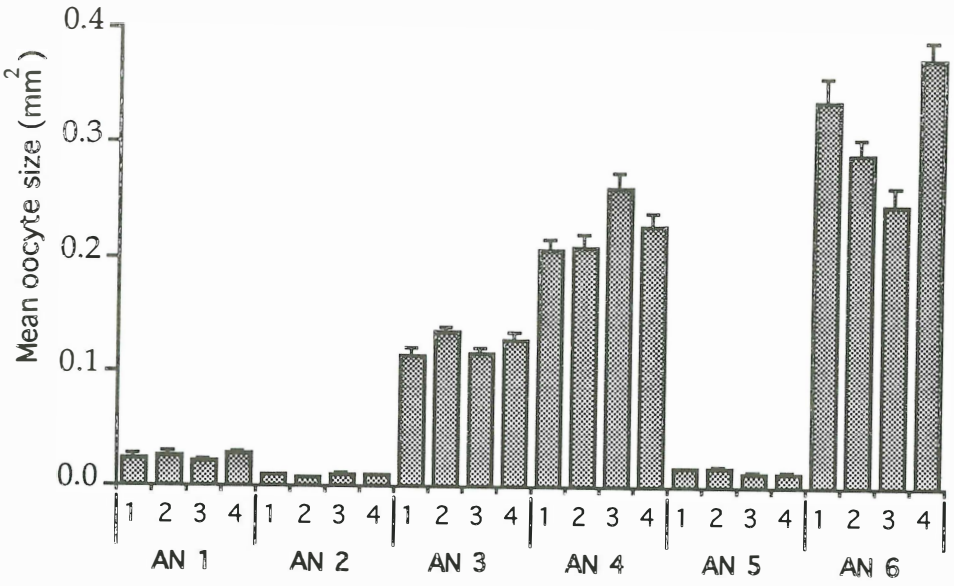


TABLE 2: Summary of analyses of variance of data from the pilot study. The lower part of the table shows the results for each animal, AN 1 to AN 6.

SOURCE OF VARIATION	d.f.	SS	MS	F	SIG
FEMALES (A)	5	32.45	6.49	855.877	**
PARTS (B)	3	0.12	0.04	5.406	**
AB	15	1.03	0.07	9.046	**
SECTIONS (C)	96	0.73	0.00758	0.997	ns
ERROR	2280	17.35	0.00761		

SOURCE OF VARIATION	d.f.	AN 1	AN 2	AN 3	AN 4	AN 5	AN 6
		F	F	F	F	F	F
PART	3	1.14ns	4.18*	2.19ns	6.78**	8.71**	9.99**
SECTION	16	0.93ns	1.44ns	1.12ns	0.74ns	0.49ns	1.10ns
ERROR	380						

ns = non-significant (p>0.05); *significant (p,0.05); **significant (p,0.01).


Mean oocyte size (mm²)
0.4
0.3
0.2
0.1
0.0
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
AN 1
AN 2
AN 3
AN 4
AN 5
AN 6

APPENDIX B

Size at sexual maturity and observations on the reproductive biology of two species of scyllarid lobster from New South Wales and Victoria, Australia.

(DRAFT)

Stewart, J., Kennelly, S.J. & O. Hoegh-Guldberg

Size at sexual maturity and observations on the reproductive biology of two species of scyllarid lobster from New South Wales and Victoria, Australia.

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Running head: size at sexual maturity and reproductive biology of *Ibacus peronii* and *Ibacus* sp.

ABSTRACT

Descriptions are made of the reproductive biology of the scyllarid lobsters *Ibacus peronii* (Leach) and *Ibacus* sp. We provide the first documented observations on their reproductive anatomy, mating, oviposition and hatching. Size at physiological and physical maturity was determined for males and females of each species studied. Size at physiological maturity was determined via a histological examination of ovaries and testes and quantifying the smallest ovigerous females captured in the field. The size at physiological maturity (± 95% confidence intervals) was estimated to be 50.4mm ± 0.7mm carapace length (C.L.) for female *I. peronii* from Coffs Harbour, Australia and 50.2mm ± 0.4mm C.L. for female *I. peronii* from Lakes Entrance, Australia. Male *I. peronii* were estimated to be physiologically mature at 45mm C.L. from Coffs Harbour and 38.5mm from Lakes Entrance. All female *Ibacus* sp. sampled in the study were found to be immature. Size at physical maturity was estimated by analysing the relative growth rates of various body parts. The size at physical maturity for female *I. peronii* was 54.9mm ± 4.0mm C.L. from Coffs Harbour and 56.6mm ± 3.1mm C.L. from Lakes Entrance. It is recommended that a minimum legal size-limit for these species be based on the size at which 50% of females are physiologically mature. Based on this criteria, the minimum legal size-limit should be 50.2mm C.L. for *I. peronii*, and *Ibacus* sp. should not be harvested in N.S.W.

INTRODUCTION

Ibacus peronii and *Ibacus* sp. are commercially important scyllarid lobsters occurring off the east coast of Australia (George & Griffin 1972). Also referred to as "bugs", "shovelnosed lobsters", "flapjacks" and "sand lobsters", these two species are landed as a by-catch by prawn and fish trawlers along the east coast of Australia and are marketed as Balmain Bugs. *I. peronii* and *Ibacus* sp. are morphologically alike and have only recently been identified as different species. They overlap in their distributions, with *I. peronii* being found predominantly in relatively shallow inshore waters (less than 80m deep) from northern New South Wales around the south of the continent to Western Australia, whereas *Ibacus* sp. are found predominantly in mid-shelf waters (from 50m to 150m deep) in northern New South Wales and southern Queensland (Kailola et al. 1993).

Unfortunately very little is known about the biology of scyllarid lobsters. Studies on their reproductive biology have been infrequent and limited to a few commercially important species. Fecundities and spawning seasons have been described for the Mediterranean Locust Lobster *Scyllarides latus* Martins (1985), and the Slipper Lobster *Scyllarides nodifer* in the northeastern gulf of Mexico (Lyons 1970; Hardwick and Cline 1990). The Moreton Bay Bug *Thenus orientalis* has been well studied with its reproductive anatomy, fecundity and size at first maturity being documented (Kniepp 1974; Hossain 1978a, 1978b, 1979; Branford 1980 and; Jones, 1988). Despite the importance of *Ibacus* spp. as a fishery there have been no published studies on any aspects of their reproductive biology. If good management of the *Ibacus* spp. fishery is to occur, key parts of its biology must be documented. In addition, the general paucity of

information on the biology of the scyllaridae makes any study of these animals invaluable.

Along the east coast of Australia *Ibacus* spp. have historically been considered as an incidental by-catch when fishing for more lucrative species such as prawns. However, over the past few years, a combination of an expanding market, increased consumer awareness and higher prices has led to fishers in New South Wales and Victoria specifically targeting these animals. This increase in fishing effort, along with claims by fishers that the average size of landed *Ibacus* spp. has decreased, has led to concerns that stocks are being over-exploited. At present, there is virtually no management of the fishery in New South Wales except that females which are carrying eggs may not be landed. In Victoria there is no management strategy for *Ibacus* spp. Given the morphological similarity of these two species and their overlapping distributions in New South Wales, any new regulations which are designed to manage the fishery better will need to consider both species.

One management option for these species involves the introduction of a minimum legal size limit. *Ibacus* spp. are particularly hardy and survive trawling quite well (pers. obs.). Undersized animals that are released would therefore be likely to survive, grow, mature and increase the size of the spawning population and eventually the exploitable stock. Ideally, a legal minimum size should allow all individuals in the population the opportunity to spawn at least once before being recruited into the fishery (Bowen, 1971). Unfortunately, the economics of fisheries rarely allows for such an ideal minimum size limit and a compromise used in many lobster fisheries is to set the minimum size as the size at which at least 50% of the population has reached sexual maturity (Aiken, 1984). Such

management decisions are usually based on the size at which females reach sexual maturity because of (i) the importance of female fecundity and reproductive success to the next generation, and (ii) difficulties in staging the reproductive maturity of male decapods (Matthews 1954, Fielder 1964).

To assess the size at which large decapods become sexually mature, it is necessary to determine (i) the size at which physiological (or gonadal) maturity occurs and (ii) the size at which physical maturity occurs (ie. the size at which an animal is capable of mating, oviposition, brooding eggs, etc). Physiological and physical maturity in scyllarid lobsters may not occur at the same size (Jones, 1988), and both need to be known in order to ascertain the size at true sexual maturity.

Physiological maturity in female lobsters can be estimated by assessing the stage of development of ovaries (Fielder 1964, Silberbauer 1971). The methods used to assess ovarian maturation in lobsters have been well documented (Aiken & Waddy, 1980) and the most common methods are: (i) Staging based on the external appearance of the ovary; this method is relatively quick and can be done in the field, but is quite subjective. (ii) Staging based on the histology of the ovary; histological examinations of gonads are more time-consuming and expensive than simple macroscopic methods, but are more accurate in providing detailed information on the stage of development of individual oocytes (West, 1990) (iii) Size-frequency distributions of oocytes within the ovary; this method is often used as an objective means to study development within ovaries and has been used to quantify the spawning strategies of females of various marine animals such as teleost fish (De Vlaming, 1983), crabs (Armstrong, 1988) and urchins (Harvey & Gage, 1984; King et al., 1994), and (iv) The presence of externally

attached eggs is used to estimate the size at which female lobsters are physiologically mature (Kensler, 1967, Aiken & Waddy, 1980).

Physical maturation in crustaceans is often accompanied by a morphological transformation necessary for successful reproduction (Hartnoll, 1982). The size at which physical maturity occurs in lobsters has been historically studied by examination of the relative growth of externally visible features. Features used have been the egg-carrying pleopod endopodal setae (Street 1969, Pollock & Augustyn 1982), telson length (Hossain 1978b, Jones 1988) and abdominal width (Aiken & Waddy, 1980). Discontinuities in the linear relationships between these dimensions and body size are used to estimate size at physical maturity. One other method used to identify physical maturity is evidence of mating, such as the presence of spermathecae on females (Munro, 1974).

The aims of this study were to make the first documented observations on the general reproductive biology of *Ibacus peronii* and *Ibacus* sp., and to estimate the size at sexual maturity for males and females of both species in New South Wales and Victoria. Two techniques were used in the present study to estimate size at sexual maturity (i) a histological examination of the gonads, and (ii) assessing changes in the relative growth rates of various body parts associated with maturity. The results of the present study were then used to recommend legal minimum size limits for *I. peronii* and *Ibacus* sp. in New South Wales and Victoria.

MATERIALS AND METHODS

This study was done at two locations on the east coast of Australia, Coffs Harbour in New South Wales (30°18'S, 153°08'E) and Lakes Entrance in Victoria (37°53'S, 148°00'E) (Fig. 1). 120 female and 120 male *Ibacus peronii* and 60 female and 60 male *Ibacus* sp. were collected during one year. Twenty animals were collected every two months (ten males & ten females) from commercial trawlers and animals were chosen to represent the widest available size-range. Due to their differing distributions, *Ibacus peronii* were sampled from both locations while *Ibacus sp.* were only sampled at Coffs Harbour.

Observations on reproductive biology

The external sexual characteristics and internal reproductive anatomy of 120 female and 120 male *Ibacus peronii* and 60 female and 60 male *Ibacus* sp. collected in the field during one year were examined and described. Observations of mating, oviposition, incubation period and hatching were made on these animals and from 80 *I. peronii* kept in a flow-through aquaria at the Fisheries Research Institute for 12 months.

Size at sexual maturity

Size at sexual maturity for both species was estimated in terms of the size at which both physiological maturity and physical maturity occurred.

(i) Size at physiological maturity

Size at physiological maturity for females and males of both species was estimated via histological examination of ovaries and testes. This work

was done on the animals sampled above. Immediately after capture, the carapace length (C.L.) of each animal to be sampled was measured and its gonads removed. C.L. was measured to the nearest 0.1mm using dial calipers and was measured as the distance from the rostral sinus to the posterior edge of the carapace. Ovaries were staged according to a descriptive macroscopic staging technique after the methods of Fielder (1964) and Jones (1988). Testes were described in terms of their size, shape and colour. Gonads were then fixed for a period of one week in a solution of 10% formaldehyde, 5% acetic acid, 1% anhydrous calcium chloride and 84% seawater. After fixing, the tissue was dehydrated in ethyl alcohol, cleared in histolene and embedded in paraffin wax. Transverse sections were cut from each portion of gonad at a thickness of 6 micrometers. Slides were stained with Gills' haematoxylin and eosin.

The mean sizes of oocytes were determined from slides of each ovary sampled. A pilot study was done to determine the optimal sampling method for this work (see Stewart et al. in press) and resulted in us measuring twenty randomly chosen oocytes in one randomly chosen section of ovary for each female sampled. The sizes of oocytes were measured as the visible cross-sectional area (in mm^2) of each oocyte using an image processor. For each male sampled, the largest cross-section of spermatophore in the vas deferens was measured.

In total, slides of the ovaries of 110 female *Ibacus peronii* and 50 female *Ibacus sp.*, and slides of the testes of 117 male *I. peronii* and 52 male *Ibacus sp.* were examined. Females were assigned a stage of maturity based on the histology, oocyte size and amount of vitellogenesis within the ovaries. Males were said to be mature by the presence of spermatophores in the vas deferens. It was only possible to remove the gonads of animals

greater than about 35mm C.L.; animals smaller than this had very much reduced gonads and were classified as "immature".

Following the classification of each female into a stage of maturity, the size at which 50% of females were physiologically mature was estimated by firstly plotting the percentage of animals classified as being "mature" in 1mm size-classes. It was obvious from these plots that some large, and obviously mature, animals were not classified as being "mature". This is because once development of oocytes within the ovary was quite advanced (ie. stage 3) it was not possible to differentiate between redeveloping ovaries and virgin developing ovaries. To overcome this problem, and because all ovigerous *I. peronii*, and those with ovaries classified as being "mature" had ovigerous setae at least 10mm long, *I. peronii* with ovigerous setae ≥ 10mm long and previously classified as "developing" were reclassified as "mature". Historically, logistic curves have been fitted to this type of data to estimate the 50th percentile. Vieira & Hoffman (1977) however state that the Gompertz function often provides a better fit to biological data. The logistic function has its point of inflexion exactly half way between the two asymptotes and is symmetrical about this point, whereas the Gompertz function has no symmetry about its point of inflexion which is relatively smaller than that of the logistic function. The Gompertz function has been successfully fitted to this type of data for palinurid lobsters (Montgomery, 1992) and therefore a Gompertz curve was fitted to data in the present study using least-squares regression. The 50th percentiles (or size at 50% physiological maturity) were taken from the fitted Gompertz curves for female *I. peronii* from each location.

Observations in the field of the smallest ovigerous females were also used to estimate size at physiological maturity.

(ii) Size at physical maturity

The size at which female and male *Ibacus peronii* and *Ibacus* sp. are physically able to reproduce was estimated by examining changes in the relative growth rates of (i) pleopod endopodal setal length and (ii) telson setal length compared to C.L. Pleopod endopodal setal length was measured as the longest ovigerous setae on the endopods of the first pair of pleopods. Telson setal length was measured as the longest section of the setal fringe at the end of the telson. All measurements were made to the nearest 0.1mm using vernier dial calipers. These measurements were taken from 149 female and 56 male *I. peronii* from Coffs Harbour, 58 female and 44 male *I. peronii* from Lakes Entrance, and from 58 female and 48 male *Ibacus* sp. from Coffs Harbour. In any of the plots of these measurements against C.L. where a discontinuity was apparent, its location was estimated by fitting spline linear regressions to the data using SAS software. The point where these linear regressions join indicates the position of each discontinuity.

Size at physical maturity was also estimated from observations in the field of the smallest females carrying spermatophores.

RESULTS

Reproductive Anatomy & Observations of mating, oviposition, and hatching:

The reproductive anatomies of *Ibacus peronii* and *Ibacus* sp. were identical and the following description applies to both species. Both species

are dioecious and males and females are easily identified using the following morphological features.

1.- The genital openings of females are situated on the coxae of the third pair of walking legs. In males the genital openings are situated on the coxae of the fifth pair of walking legs.

2.- The pleopods of females are much larger than those of males. In particular, the endopod of the first pleopod in females is large and broad. The pleopodal endopods of mature females bear long ovigerous setae.

3.- The female has a small fixed claw attached to the dactylus of the fifth pair of walking legs.

The ovaries and testes are of the general decapod form (Barnes, 1980). Ovaries consist of paired tubes situated dorsal to the alimentary tract. They are joined by a transverse bridge approximately one third of their length from the anterior end and form an "H" shape. A thin oviduct passes from each ovary just posterior of the transverse bridge to the genital apertures on the coxae of the third pair of walking legs.

The testes, like the ovaries, are paired organs joined by a transverse bridge. Situated dorsally to the alimentary tract, they extend from the level of the eyes back to the abdomen. They are white in colour and are highly convoluted. The vas deferentia join each teste posterior to the transverse bridge and are divided into two recognisable parts. A highly convoluted and thin proximal vas deferens widens into a straight distal vas deferens opening at the genital aperture on the coxae of the fifth pair of walking legs.

Mating was not observed in either species of *Ibacus* studied, but observations of animals in the field, and of animals in aquaria, allow some insight into its mechanics. Spermatophoric masses were found on many female *Ibacus peronii* throughout the study, but not on any of the female *Ibacus* sp. examined. The spermatophoric mass was observed as two elongated bands, approximately 2 to 3cm long, on the ventral surface of the female. The exact location of these spermatophoric bands varied slightly, but they were always in the area of the females genital openings. The spermatophoric mass was observed to consist of lines of circular, white spermatophores surrounded by a clear gelatinous matrix. It was always stuck firmly to the ventral surface of the female and could not be easily removed. All females observed bearing spermatophores were hard-shelled and appeared not to have moulted for some time.

One female *Ibacus peronii* was captured in the process of oviposition. In this animal, some eggs had already been deposited on the endopods of the first set of pleopods, the spermatophoric mass was partially scraped away and the ovigerous setae on the pleopodal endopods were covered with a sticky white substance. The origin of this sticky substance is unknown, but it seems likely that it is used to attach eggs to the ovigerous setae. We hypothesize that fertilization occurs externally as the eggs are transported from the genital apertures to the ovigerous setae. The eggs are manipulated and presumably fertilized using the claw at the end of each fifth pereiopod. Ovigerous females in aquaria were observed to clean and groom their egg masses with this claw.

Newly deposited eggs of *Ibacus peronii* were roughly spherical and bright orange. Each egg mass contained between 5,000 and 37,000 eggs (see

Stewart & Kennelly, in prep). During incubation, the eggs develop two black eye spots and as hatching approaches, the eggs become clear/brown in colour and the two eye spots enlarge. Observations of *I. peronii* in aquaria suggests an incubation period of three to four months. Hatching of larvae was observed in several female *I. peronii* in aquaria. Hatching occurred during either day or night and larvae hatched as actively swimming prephyllosomae that transformed into phyllosomae after 15 to 20 minutes. This transformation was not achieved by a moult, but by actively "unfolding" the swimming legs. These phyllosomae were strongly attracted to light.

Although observations on mating, oviposition and hatching in *Ibacus* sp. were not made, the morphological similarity to *Ibacus peronii* suggests that these processes may be similar to those described above.

Size at sexual maturity

(i) Size at physiological maturity

Five stages of ovarian development were recognised and a macroscopic and histological description of each stage is given in Table 1. Size frequency distributions of oocytes from ovaries of each stage are presented in Fig. 2 and photographs of sections of each stage are presented in Fig. 3. Three broad categories of maturity were determined based on the stage of ovarian development defined above. The categories are:

1. Immature - corresponding to ovarian stage 1
2. Developing - corresponding to ovarian stages 2 & 3
3. Mature - corresponding to ovarian stages 4 & 5

In the few cases where an animal was classified into different categories based on macroscopic and histological evidence, the histological stage of development was used to categorize its maturity.

All 3 categories of maturity were found in samples of female *Ibacus peronii* at each sampling time. All female *Ibacus* sp. sampled throughout the study were classified as being immature, except for four that were classified as "developing" (ovarian stage 2). Many female *Ibacus* sp. sampled were large animals which had well developed external reproductive characteristics such as long ovigerous setae.

The size at which 50% of female *Ibacus peronii* were physiologically mature was estimated from the 50th percentiles of the Gompertz curves fitted to the reclassified maturity data (Fig. 4). The size at 50% physiological maturity (± 95% confidence intervals) for female *I. peronii* from Coffs Harbour is 50.4mm ± 0.7mm C.L., and from Lakes Entrance is 50.2mm ± 0.4mm C.L. These results indicate that there was no significant difference in the size at physiological maturity of females between the two locations.

The smallest ovigerous *Ibacus peronii* observed during the study were 50.9mm C.L. from Coffs Harbour and 49.7mm C.L. from Lakes Entrance.

Photographs of the testes, proximal vas deferens and distal vas deferens are shown in Fig. 5. All male *Ibacus peronii* that had testes big enough to be removed had spermatophores in their vas deferens, except one animal that was 40.1mm C.L. The smallest male *I. peronii* classified as being physiologically mature from Lakes Entrance was 38.5 mm C.L., and

from Coffs Harbour was 45.0mm C.L. The smallest male *Ibacus* sp. observed to be mature was 47.4mm C.L. Several other male *Ibacus* sp. up to 54.1mm C.L. did not have spermatophores in their vas deferens.

There was a positive relationship between the cross-sectional area of spermatophores versus C.L. for *Ibacus peronii* (t-test, P=0.012) and *Ibacus* sp. (P=0.018) (Fig. 6). Male *I. peronii* tended to have larger spermatophores than *Ibacus* sp. of the same size.

(ii) Size at physical maturity

All plots of pleopod endopodal setal length versus C.L. showed significant positive linear relationships (Fig. 7). A discontinuity was apparent in the relationships for female *Ibacus peronii* from Coffs Harbour and Lakes Entrance, and for male *I. peronii* from Coffs Harbour. The discontinuity (± 95% confidence limits) for female *I. peronii* from Coffs Harbour occurred at 54.9mm ± 4.0mm C.L., for female *I. peronii* from Lakes Entrance at 56.6mm ± 3.1mm C.L., and for male *I. peronii* from Coffs Harbour at 55.4mm ± 5.4mm C.L.

All plots of telson setal length versus C.L. showed significant positive linear relationships, except for male *Ibacus peronii* from Coffs Harbour which showed no significant relationship (Fig. 8). No discontinuities were apparent in any of these relationships.

The smallest size at which female *Ibacus peronii* were observed to have mated (ie. were carrying spermatophores) at Coffs Harbour was

50.9mm C.L. and at Lakes Entrance 50.3mm C.L. No female *Ibacus* sp. were observed carrying spermatophores.

DISCUSSION

Reproductive anatomy & observations of mating, oviposition, and hatching

The general reproductive anatomy of males and females of both species of *Ibacus* was similar to that described for the spiny lobsters (Fielder, 1964; Phillips et al., 1980) and other scyllarid lobsters (Matthews, 1954; Jones, 1988). It is assumed that this similarity means that many of the physiological processes observed in spiny lobsters will also apply to *Ibacus peronii* and *Ibacus* sp.

The five stages of ovarian development identified in this study closely resemble those described for the Moreton Bay bug *Thenus orientalis* (Jones, 1988). Ovarian development followed the same pattern described for lobsters (Aiken & Waddy, 1980) and could be separated into two distinct stages: (i) initial oocyte proliferation and growth (corresponding to ovarian stages 1 & 2), followed by (ii) vitellogenesis. Vitellogenesis could also be divided into two stages, 1° (ovarian stage 3), and 2° (ovarian stage 4) which culminates with oviposition.

Histological examination of ovaries indicated that the initial system of macroscopic staging was a reasonable indicator of vitellogenesis and oocyte size within the ovary. This means that in future studies of ovarian development in *Ibacus peronii*, macroscopic staging would provide a reasonably accurate assessment of ovarian development and take much less

time and money than full histological examinations. Nevertheless, a subset of each macroscopic stage of ovarian development in any such study should be examined histologically to ensure their validity.

The presence of a persistent spermatophoric mass on female *Ibacus peronii* is typical of the palinurid lobsters (Aiken & Waddy, 1980), but is different from the closely related *Thenus orientalis* which has a very short-term spermatophore (Jones, 1988). Those female *I. peronii* that were observed bearing spermatophores were hard-shelled and appeared not to have moulted for some time. This is in contrast to the nephropid lobsters and some palinurid lobsters which can only mate when the female is soft-shelled (Phillips et al., 1980). The observation of one female *I. peronii* during oviposition revealed that the protective matrix of the spermatophoric mass had been scraped away, and while this has also been observed in palinurid lobsters (Berry, 1970), the precise nature of fertilization remains unknown.

An incubation period of 3 to 4 months for *Ibacus peronii* was estimated in this study and is similar to many palinurid lobsters (Aiken & Waddy, 1980). However it is significantly greater than the scyllarid *Thenus orientalis* which has an incubation period of approximately 40 days (Jones, 1988). The hatching of *I. peronii* as prephyllosoma larvae is also in contrast to *T. orientalis* which is thought to hatch directly as a phyllosoma (Courtney & Cosgrove 1993). The scyllarid lobster *Scyllarides latus* has been observed to hatch as naupliosoma larvae which last approximately 40-60 minutes before moulting into phyllosomae (Martins 1985). However, the transformation of *I. peronii* from prephyllosoma to phyllosoma in the present study did not occur via a moult.

The complete larval development of *I. peronii* is unknown, but Ritz & Thomas (1973), have identified at least 7 developmental stages from plankton tows. The duration of larval life of *Ibacus peronii* can still only be estimated, although observations of ovigerous females in aquaria and data from Ritz & Thomas (1973) and from Phillips et al. (1981) on developmental stages of phyllosomae sampled off Western Australia, suggests a larval period of 3-4 months.

Size at sexual maturity

The estimates, with 95% confidence intervals, of the size at physiological maturity for female *Ibacus peronii* of 50.4mm ± 0.7mm C.L. for Coffs Harbour and of 50.2mm ± 0.4mm C.L. for Lakes Entrance (Fig. 4) suggest that there is no variation in the size at which ovarian maturity occurs at these locations for this species. The smallest ovigerous females observed (50.9mm C.L. from Coffs Harbour and 49.7mm C.L. from Lakes Entrance) and the smallest females observed to have mated (50.9mm C.L. from Coffs Harbour and 50.3mm C.L. from Lakes Entrance) are very close to the estimates of physiological maturity based on the histological study. This suggests that female *I. peronii* are able to mate and carry eggs as soon as ovarian maturity occurs.

No sign of ovarian development was observed in any female *Ibacus* sp. and while samples were taken regularly only from Coffs Harbour, samples taken further north from Ballina also lacked any sign of ovarian development. We conclude that female *Ibacus* sp. become mature outside of the main fishing areas in NSW. This may relate to the fact that the areas sampled were at the southern end of this species distribution (Kailola et al. 1993). There are several examples of crustacean species on the N.S.W. coast

that are essentially non-reproductive populations being seeded by northern populations and recruiting larvae from the southward flowing east Australian current (eg the Eastern King Prawn *Penaeus plebejus* (Ruello, 1975) and the Eastern Rock Lobster *Jasus verreauxi* (Montgomery, 1992).

Previous studies have emphasized the difficulty in defining stages of maturity in male scyllarid lobsters (Matthews, 1954; Jones, 1988), but our identification of spermatophores in the vas deferens at least permits the recognition of males that are potentially mature. The size at first physiological maturity for male *Ibacus peronii* from Coffs Harbour is therefore estimated to be 45.0mm C.L and from Lakes Entrance 38.5mm C.L. For male *Ibacus* sp. from Coffs Harbour this size is estimated to be 47.4mm C.L. Aiken & Waddy (1980) state that the ability to produce spermatozoa in male lobsters does not equate to being functionally mature, and while the presence of spermatophores in vas deferentia may not correspond to the ability to reproduce, the inability to identify any developmental stages of maturity in the testes means that the presence of spermatophores is the best assessment of physiological maturity available.

Size at physical maturity for female *Ibacus peronii* was estimated from discontinuities in the plots of pleopod endopodal setal length and C.L. (Fig. 7). Spline linear regressions revealed clear intersect points with 95% confidence intervals in these relationships for female *I. peronii* from Coffs Harbour of 54.9mm ± 4.0mm and from Lakes Entrance of 56.6mm ± 3.1mm C.L. The similar sizes at which these discontinuities occurred and their overlapping confidence intervals, suggests that there is no difference between the estimated size at physical maturity between Coffs Harbour and Lakes Entrance.

The lack of a discontinuity in the relationship between pleopod endopodal setal length and C.L. for female *Ibacus* sp. (Fig. 7) is puzzling because of its morphological similarity to *I. peronii*. More data on these morphometric relationships, particularly for larger animals, is needed to determine size at maturity using morphometrics for this species.

The existence of a discontinuity in the relationship between pleopod endopodal setal length and C.L. for male *Ibacus peronii* (Fig. 7) should be viewed with caution, as the linear regression calculated after the discontinuity is not statistically significant. However, the fact that some change in the relationship does occur at this point suggests that it has some basis in reality.

It is evident from the plots of telson setal length versus C.L. (Fig. 8), that the relative growth of telson setae does not change with C.L. This is in contrast to the results of other studies on scyllarid lobsters which have found discontinuities in the linear relationships between telson length and C.L., and have subsequently used these as estimates of physical maturity (Hossain, 1978; Jones, 1988).

The positive relationships between spermatophore cross-sectional area and C.L. for both species of *Ibacus* (Fig. 6) may actually be much tighter than the plots suggest, as the method of measuring cross-sectional areas may have produced some bias. Spermatophores are approximately spherical, and although the largest section of spermatophore was measured on each slide, if that particular section was not cut through the centre of the spermatophore, then it will have underestimated the spermatophore's true diameter. Despite this there was a definite increase in spermatophore size relative to C.L. for *Ibacus peronii* up to approximately 55mm C.L. There is

nothing in the literature reporting size-dependent viability of spermatophores, but spermatophores for this species may only be viable once they reach this size, in which case the size at functional maturity would be 55mm C.L. This compares well with the estimated size at physical maturity indicated by the morphometric data (Fig. 7). The best way to validate the viability of spermatophores would be to measure the sizes of spermatophores taken from inseminated females. If viable spermatophores are size-dependent, then the quite small spermatophores observed in all male *Ibacus* sp. would suggest that these animals were not functionally mature.

The results showed that for female *Ibacus peronii*, physiological maturity occurred at a slightly smaller size than physical maturity. This is in contrast to the results of Jones (1988) who found that physical maturity occurred at a considerably smaller size than physiological maturity in *Thenus orientalis*. It should be noted, however, that the discontinuities in the relationships between pleopod endopodal setal length and C.L. in the present study (Fig. 7) cannot be directly related to the ability to reproduce. It is possible that these changes in the relative growth rates of endopodal setae are related to some other factor, such as the egg-carrying capacity of *I. peronii*. In addition, our definition of a "mature" ovary in the histological study included those ovaries which were either in a spent or redeveloping condition. Therefore our estimates of size at physiological maturity are also estimates of the size at functional sexual maturity. This piece of evidence plus the smallest observed sizes of ovigerous females, and females bearing spermatophores, all suggest that female *I. peronii* are capable of mating and oviposition as soon as ovarian maturity occurs.

CONCLUSIONS

Observations on the reproductive biology of *Ibacus peronii* and *Ibacus* sp. in this paper have allowed some insight into its mechanics. The general reproductive anatomy has been shown to be somewhat similar to that of other scyllarid lobsters and also the palinurid lobsters. However, the processes of mating, fertilization, oviposition, incubation and hatching suggest that these species of *Ibacus* differ in many aspects of their reproductive biology.

The reproductive biology of *Ibacus* along the N.S.W. coast is made complex by the fact that one of the species, *Ibacus* sp., appears to gain sexual maturity outside of the areas sampled. In the present study 95% of female *Ibacus peronii* became reproductively mature between 49.7mm and 51.1mm C.L. Male I. peronii were sexually mature as small as 38.5mm C.L. Using these results, and the proposition that a fishery can be managed if size-limits are set at the length at which 50% of females are mature, the legal minimum size-limit for *I. peronii* in N.S.W. should be set at 50.2mm C.L. and *Ibacus* sp. should not be landed at all. Given the morphological similarity of these two species, and the commercial importance of *Ibacus* sp. as a by-catch to the prawn trawl fleets in northern N.S.W., the minimum legal size-limit for *Ibacus* sp. in N.S.W. may have to be set at the same size as that implemented for *I. peronii*.

Acknowledgements: This study was funded by the Australian Fishing Industry Research and Development Council (Grant No. 92/040). The authors are grateful to Dennis Reid for statistical advice and to John Matthews for the photography. Most of all we are grateful to the following fishermen for their assistance and invaluable advice; Norm Shilling, Mark

& Shane Huxley, Simon Tidswell, Paul Andersen, Ted Kerslake, Sel Turner and Daryl Sprague.

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Figure captions

Figure 1. Location of study sites

Figure 2: Pooled size-frequency distributions of oocytes from Ibacus peronii for each stage of ovarian development.

Figure 3. Ibacus peronii. Histological stages of ovarian development. **A.** Stage 1 ovary with previtellogenic oocytes (PO). **B.** Stage 2 ovary with previtellogenic oocytes and vitellogenic oocytes (VO) at the periphery. **C.** Stage 3 ovary with more and larger vitellogenic oocytes. **D.** Stage 4 ovary fully developed and packed with ova (OV). **E.** Spent ovary with residual oocytes (R) and resorbing ova (RO) surrounded by follicle cells (FC). There are large spaces within the ovary (SP) and the ovarian wall (OW) is relaxed. Scale bars = 100mm (A) and 250mm (B, C, D, E).

Figure 4. Gompertz curves fitted to the percentage of mature female Ibacus peronii from Coffs Harbour and Lakes Entrance in each 1mm size class based on reclassified maturity index. Size at physiological maturity is estimated from the 50th percentiles.

Figure 5. Ibacus peronii. Histology of the testes and vas deferentia. **A.** Section through the testes showing sacculi (S) containing developing spermatocytes (SP). **B.** Transverse section through the highly coiled proximal vas deferens (PVD) showing spermatophores (SPS). **C.** Transverse section through the distal vas deferens (DVD) showing typhlosole (T). Scale bars = 500mm.

Figure 6: Plots of the cross-sectional areas of spermatophores from male Ibacus peronii and Ibacus sp.

Figure 7: Plots and regressions of pleopod endopodal setal length versus carapace length for Ibacus peronii from Coffs Harbour and Lakes Entrance, and for Ibacus sp. from Coffs Harbour. Intersect values are in carapace length. ** denotes $P<0.01$, * denotes $p<0.05$, ns denotes not significant.

Figure 8: Plots and regressions of telson setal length versus carapace length for Ibacus peronii from Coffs Harbour and Lakes Entrance, and for Ibacus sp. from Coffs Harbour.

** denotes $P<0.01$, * denotes $p<0.05$, ns denotes not significant.

Table 1: Macroscopic and histological descriptions of ovarian stages of development for *Ibacus peronii* and *Ibacus* sp.

Stage	Macroscopic description	Histological description
1	Ovaries translucent/white, small straight & narrow. Individual oocytes are not visible.	All oocytes are previtellogenic & approximately equal in size. The maximum cross-sectional area of oocytes is approximately $0.03mm^2$ (0.2mm diameter).
2	Ovaries are creamy/yellow & small. Individual oocytes are not visible	There is a size-gradient of oocytes within the ovary. The germinal strand and radiating mass of previtellogenic oocytes is at the centre, with larger, more developed oocytes towards the edge of the ovary. Vitellogenesis has begun in up to approximately 30% of oocytes. The maximum cross-sectional area of oocytes is approximately $0.15mm^2$ (0.44mm diameter).
3	Ovaries are yellow/orange, swollen throughout their length but not bunched up. Individual oocytes are just visible through the ovary wall.	Vitellogenesis has begun in up to 80% of oocytes. Smaller previtellogenic oocytes are restricted to the germinal strand. The maximum cross-sectional area of oocytes is approximately $0.26mm^2$ (0.58mm diameter).
4	Ovaries are bright orange, swollen and bunched up filling all available space in the cephalothoracic region. Individual oocytes are clearly visible through the ovary wall.	Vitellogenesis is now 100% & there is no sign of the germinal strand. A large increase in oocyte size has occurred and the maximum cross-sectional area of oocytes has increased to $0.60mm^2$ (0.87mm diameter).
5	Spent. Ovaries are creamy/yellow, large but not bunched up and are flaccid. A few residual orange eggs can sometimes be seen through the ovary wall. The ovary is full of watery, granular looking material.	Spent. There are a few whole, residual oocytes present. Diffuse yolky oocytes undergoing reabsorption are evident as are large numbers of follicle cells surrounding them. There are large spaces within the ovary and the maximum cross-sectional area of whole oocytes is approximately $0.08mm^2$ (0.32mm diameter). The ovarian wall is thick and contracted.

Figure 1

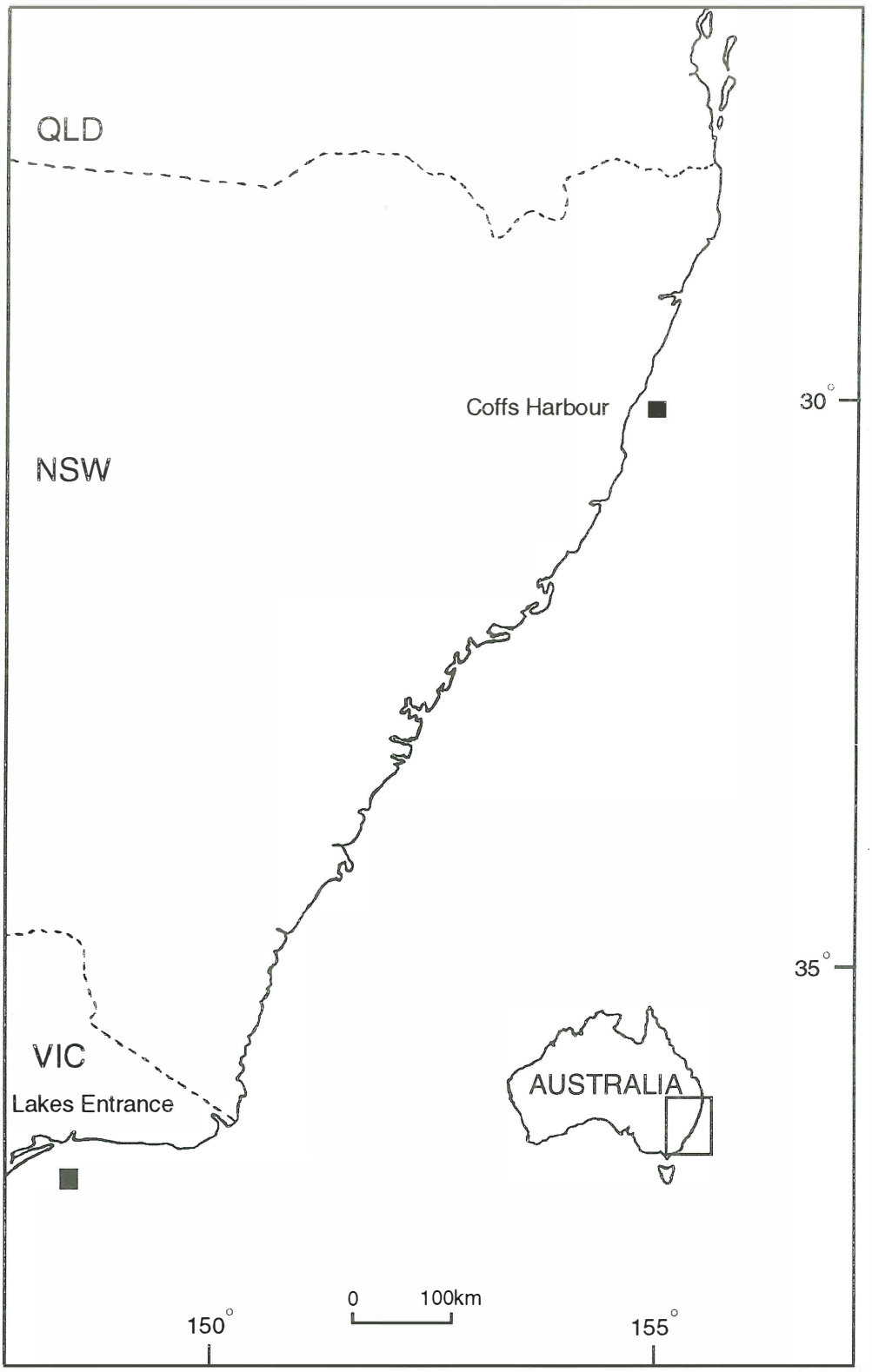
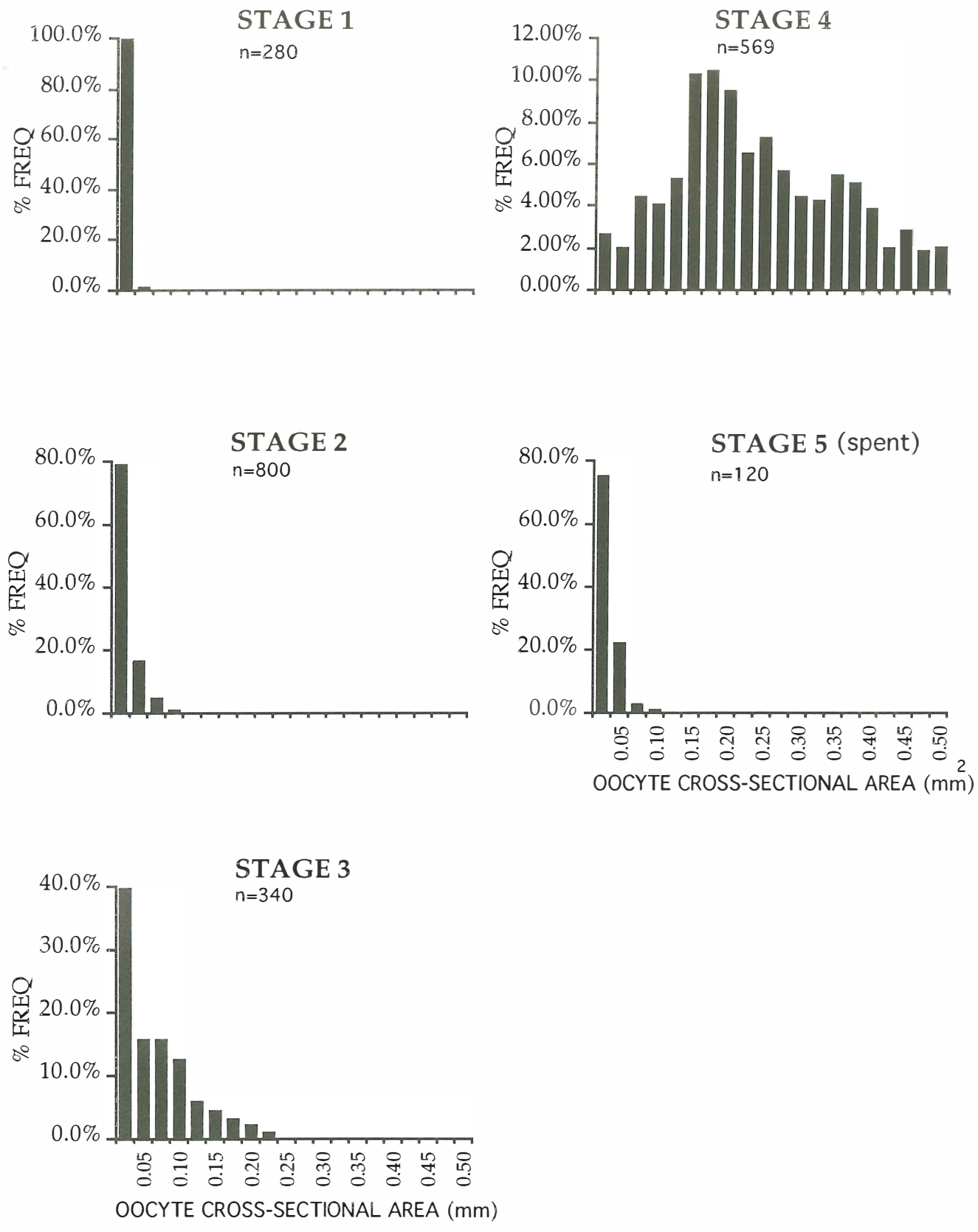
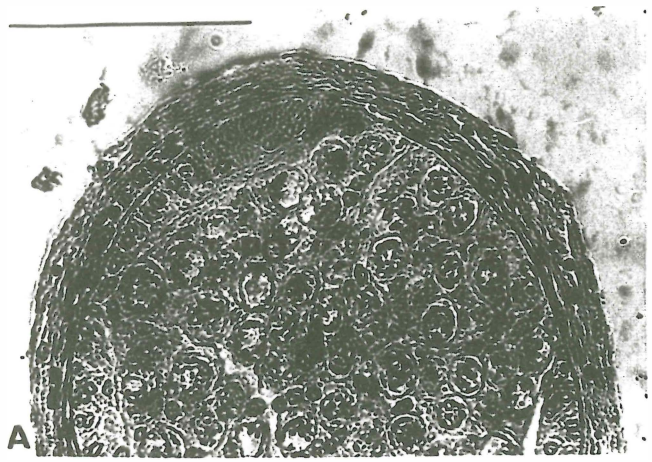
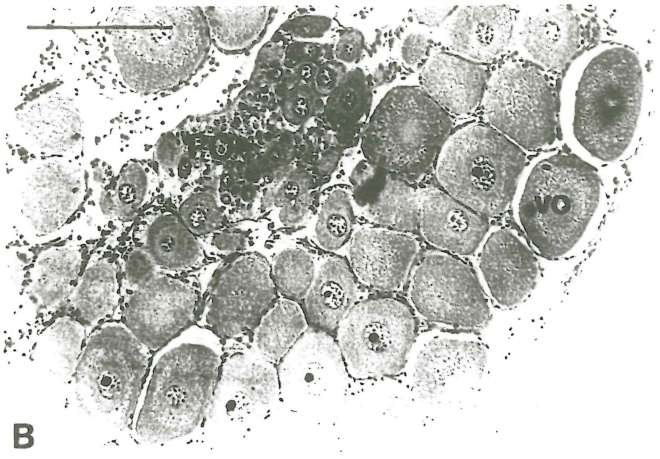

QLD
Coffs Harbour
30°
NSW
35°
VIC
Lakes Entrance
AUSTRALIA
0
100km
150°
155°

Figure 2

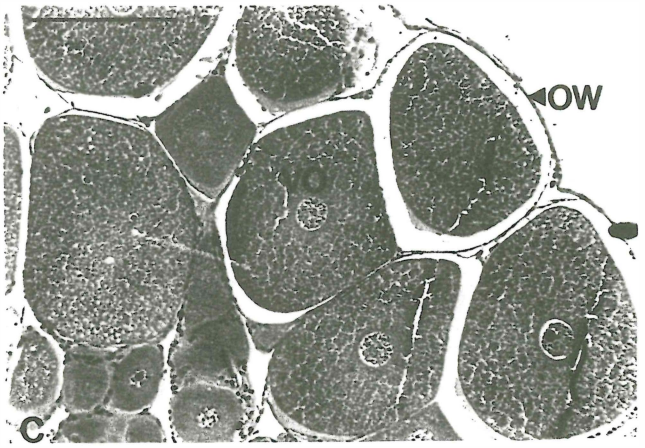

STAGE 1
n=280
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
% FREQ
STAGE 4
n=569
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
% FREQ
STAGE 2
n=800
80.0%
60.0%
40.0%
20.0%
0.0%
% FREQ
STAGE 5 (spent)
n=120
80.0%
60.0%
40.0%
20.0%
0.0%
% FREQ
0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50
OOCYTE CROSS-SECTIONAL AREA (mm2)
STAGE 3
n=340
40.0%
30.0%
20.0%
10.0%
0.0%
% FREQ
0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50
OOCYTE CROSS-SECTIONAL AREA (mm)

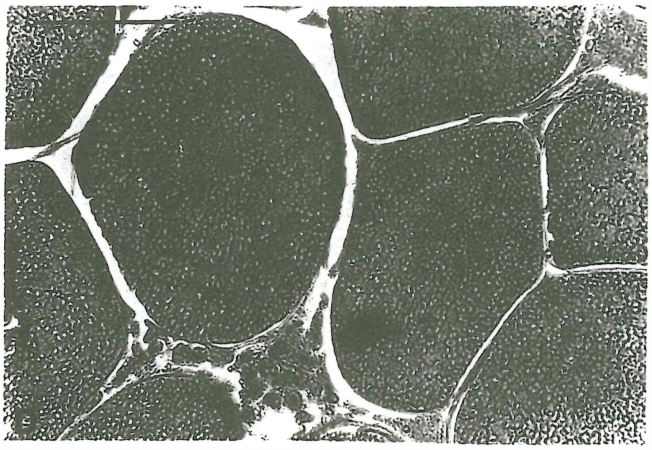


A



B





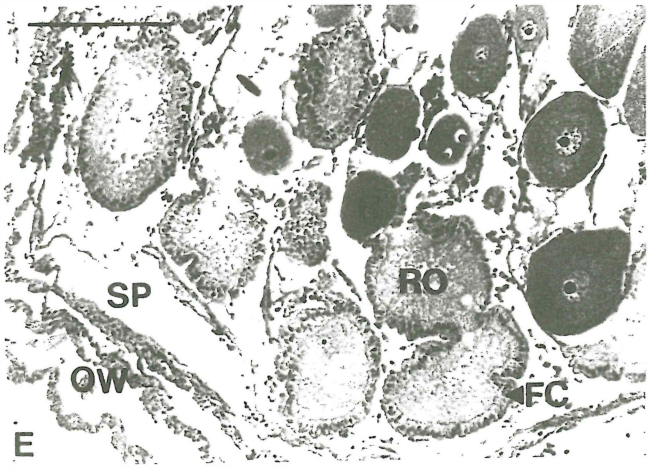
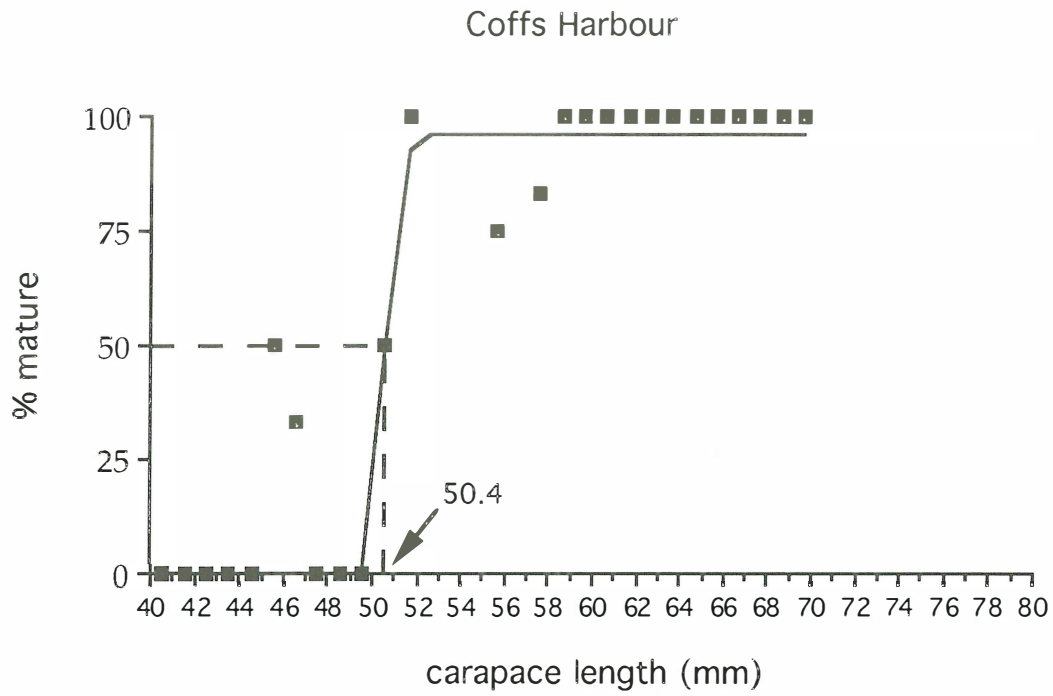
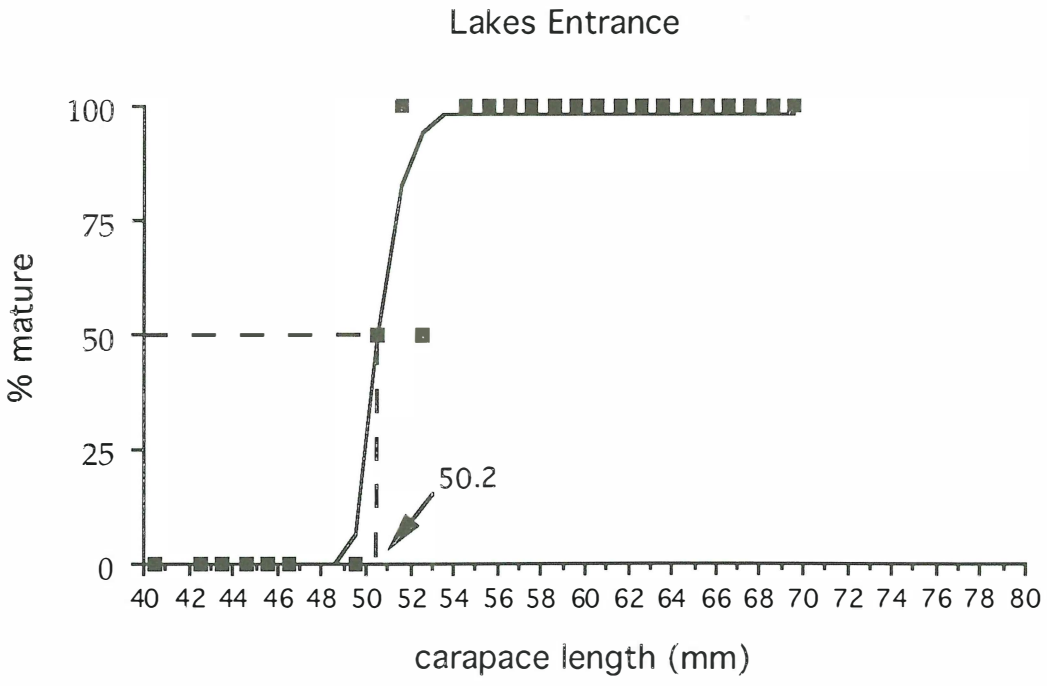
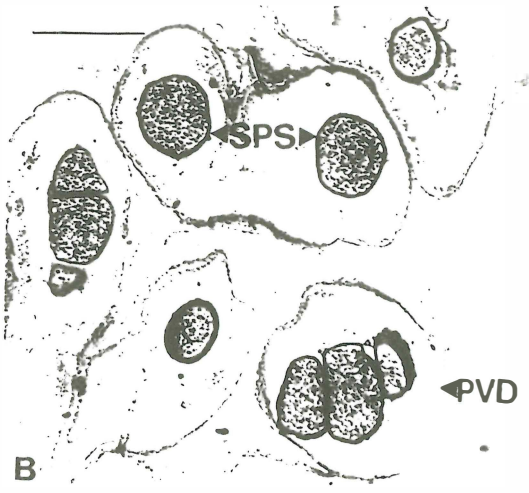


Figure 4


Coffs Harbour
100
75
50
25
0
% mature
50.4
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80
carapace length (mm)


Lakes Entrance
100
75
50
25
0
% mature
50.2
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80
carapace length (mm)


SP
S
A


SPS
PVD
B

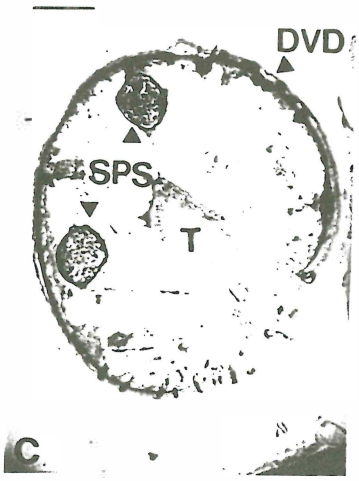
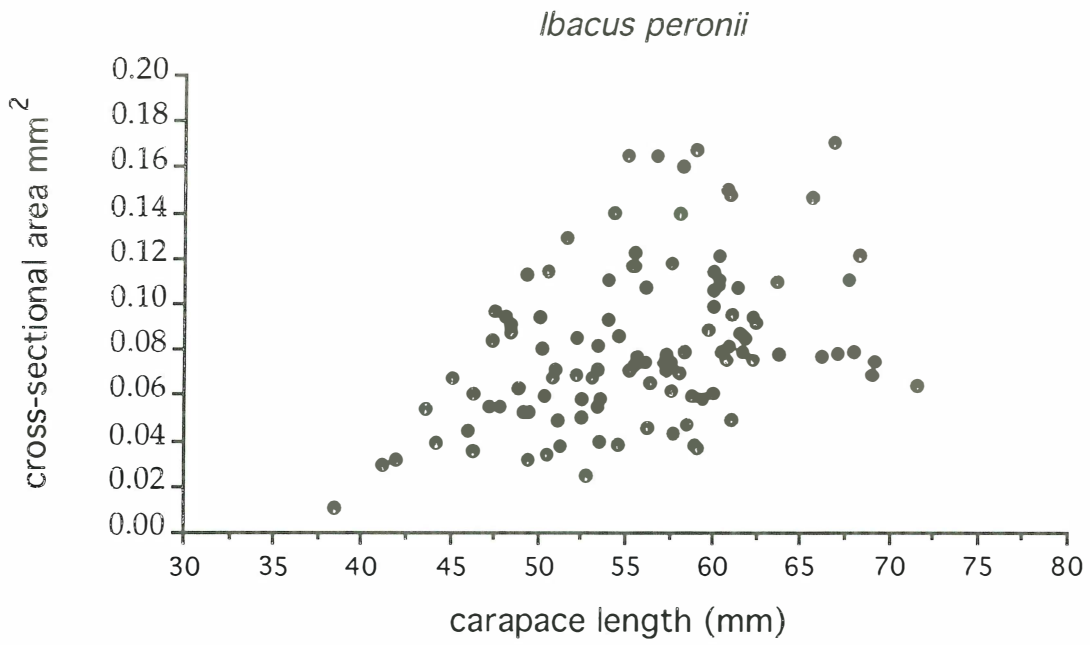

DVD
SPS
T
C

Figure 6


Ibacus peronii
cross-sectional area mm 2
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
30
35
40
45
50
55
60
65
70
75
80
carapace length (mm)

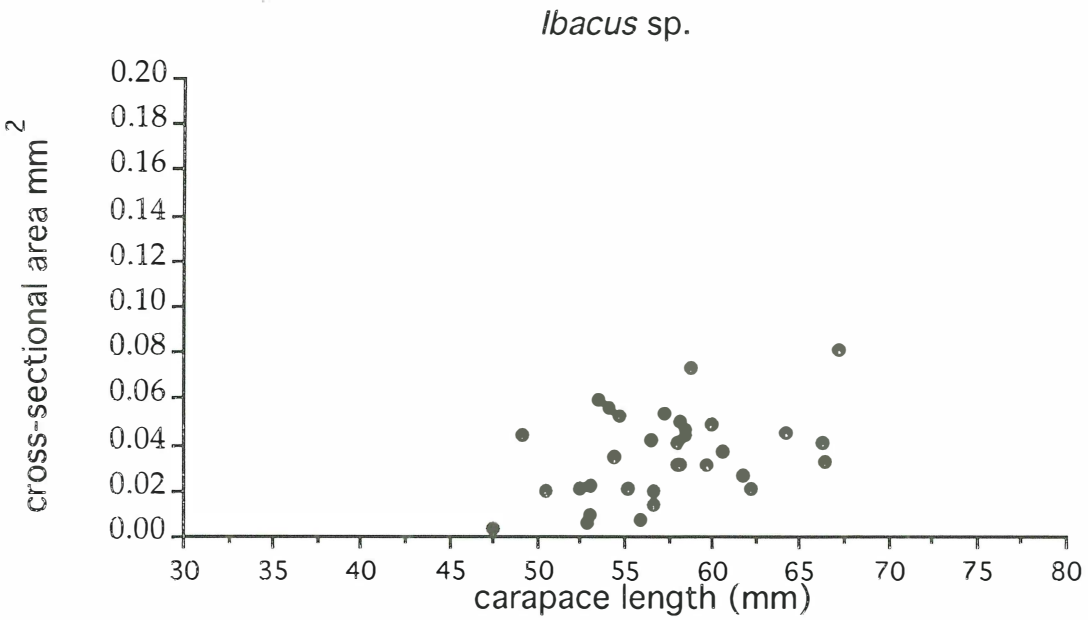

Ibacus sp.
cross-sectional area mm 2
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
30
35
40
45
50
55
60
65
70
75
80
carapace length (mm)

Figure 7:

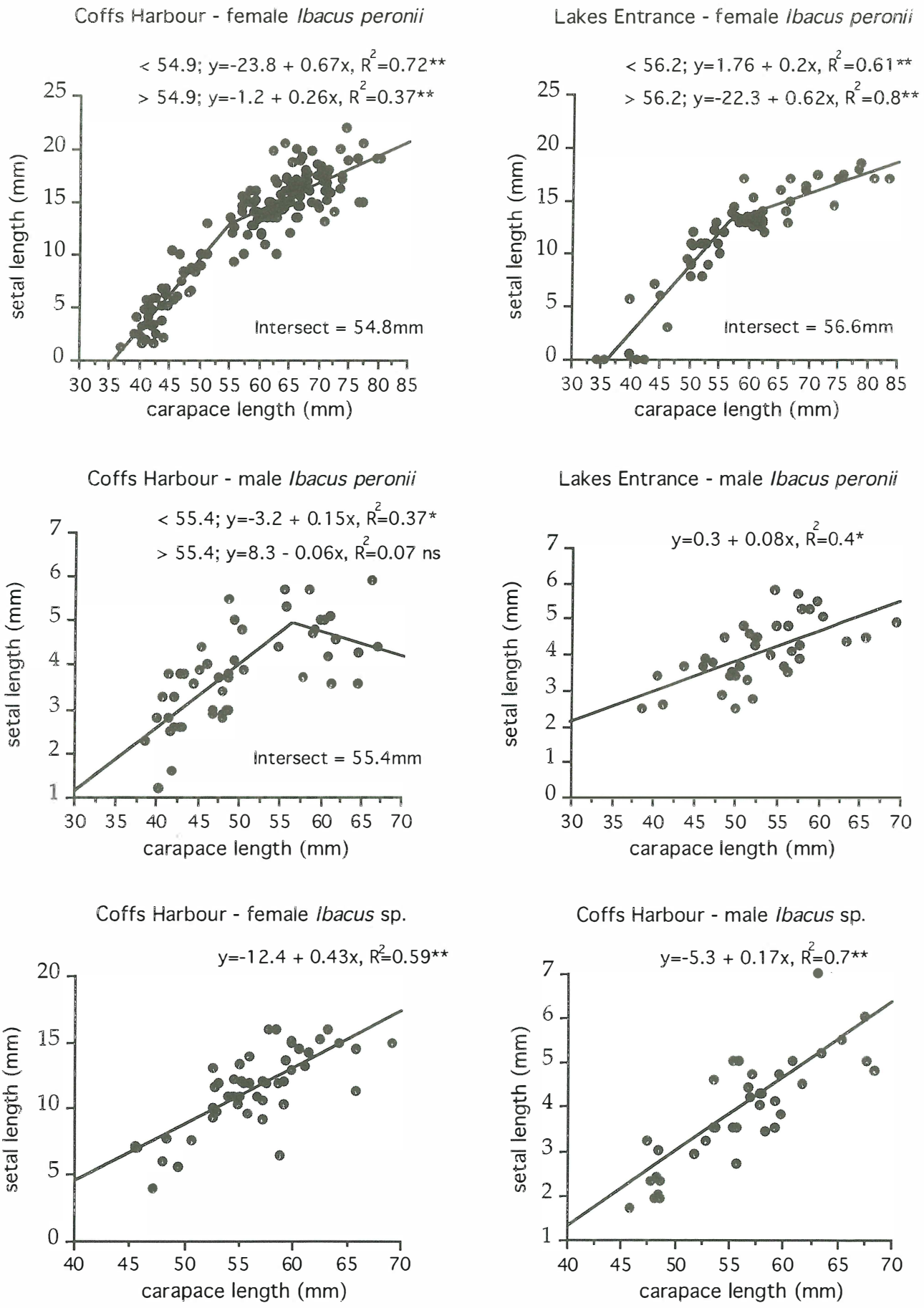
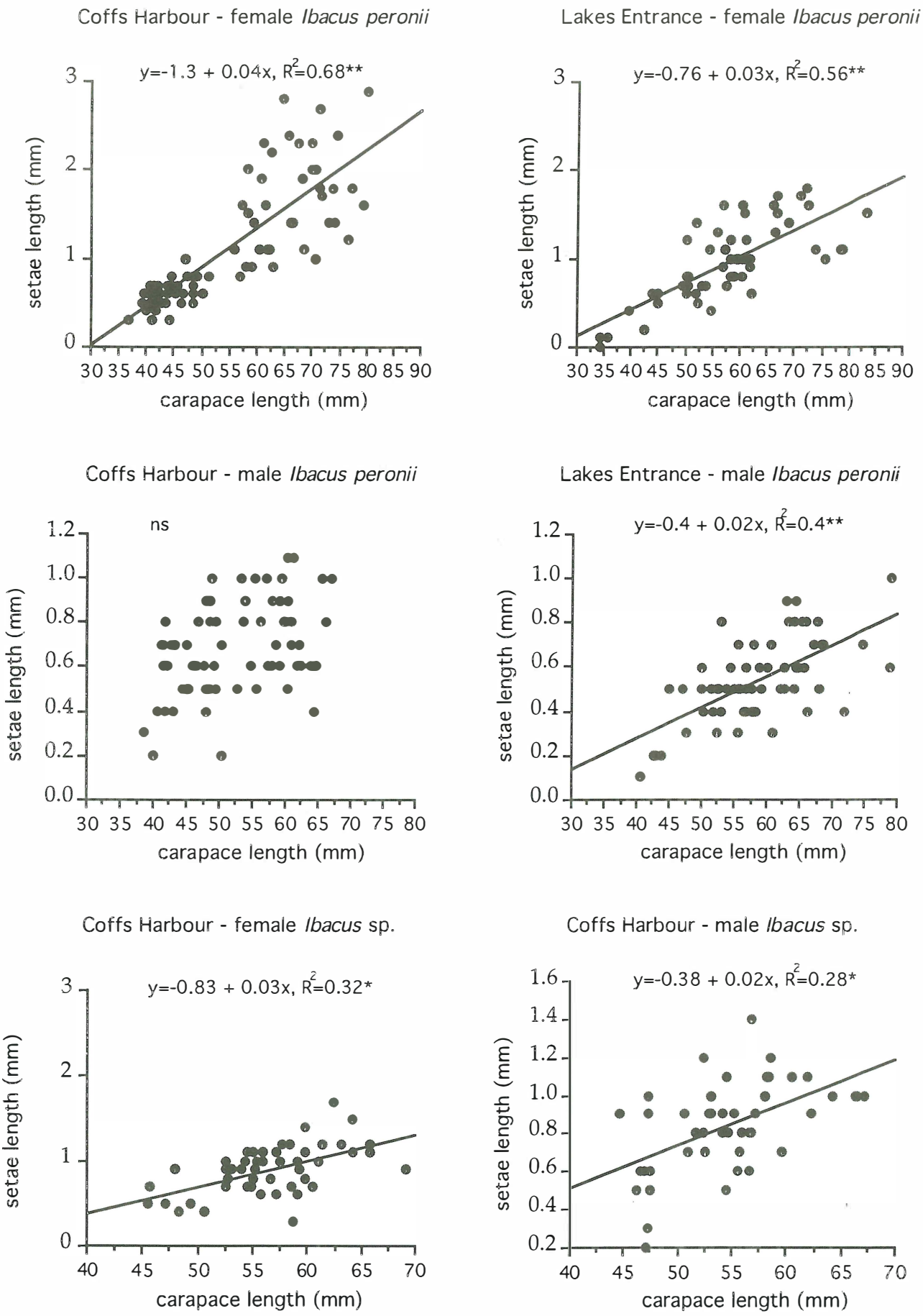

Coffs Harbour - female Ibacus peronii
< 54.9; y=-23.8 + 0.67x, R2=0.72**
> 54.9; y=-1.2 + 0.26x, R2=0.37**
Intersect = 54.8mm
setal length (mm)
carapace length (mm)
Lakes Entrance - female Ibacus peronii
< 56.2; y=1.76 + 0.2x, R2=0.61**
> 56.2; y=-22.3 + 0.62x, R2=0.8**
Intersect = 56.6mm
setal length (mm)
carapace length (mm)
Coffs Harbour - male Ibacus peronii
< 55.4; y=-3.2 + 0.15x, R2=0.37*
> 55.4; y=8.3 - 0.06x, R2=0.07 ns
Intersect = 55.4mm
setal length (mm)
carapace length (mm)
Lakes Entrance - male Ibacus peronii
y=0.3 + 0.08x, R2=0.4*
setal length (mm)
carapace length (mm)
Coffs Harbour - female Ibacus sp.
y=-12.4 + 0.43x, R2=0.59**
setal length (mm)
carapace length (mm)
Coffs Harbour - male Ibacus sp.
y=-5.3 + 0.17x, R2=0.7**
setal length (mm)
carapace length (mm)

Figure 8


Coffs Harbour - female *Ibacus peronii*
y=-1.3 + 0.04x, R^2=0.68**
Lakes Entrance - female *Ibacus peronii*
y=-0.76 + 0.03x, R^2=0.56**
Coffs Harbour - male *Ibacus peronii*
ns
Lakes Entrance - male *Ibacus peronii*
y=-0.4 + 0.02x, R^2=0.4**
Coffs Harbour - female *Ibacus* sp.
y=-0.83 + 0.03x, R^2=0.32*
Coffs Harbour - male *Ibacus* sp.
y=-0.38 + 0.02x, R^2=0.28*
setae length (mm)
carapace length (mm)

APPENDIX C

Reproductive cycles of Ibacus peronii (Leach) and Ibacus sp. (Decapoda: Scyllaridae) in two locations on the east coast of Australia.

(DRAFT)

Stewart, J., Kennelly, S.J. & O. Hoegh-Guldberg

Reproductive cycles of *Ibacus peronii* (Leach) and *Ibacus* sp. (Decapoda : Scyllaridae) in two locations on the east coast of Australia.

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2. School of Biological Science, A08, University of Sydney, NSW, 2006.

Abstract

The reproductive cycles of the scyllarid lobsters *Ibacus peronii* (Leach) and *Ibacus* sp. were investigated at two locations, at Coffs Harbour and Lakes Entrance, off the east coast of Australia. The reproductive cycles of both males and females were estimated by sampling these populations every two months. The reproductive condition of females in each population was estimated by measuring the changes in the size of oocytes within ovaries, the gonosomatic index (GSI) and the proportion of ovigerous females in commercial catches. Male reproductive condition was estimated from GSI measurements and the presence of spermatophores within the vas deferentia. Female *I. peronii* exhibited a peak spawning season during the cooler months (from June to October) at both locations, with small amounts of spawning occurring during the rest of the year. The presence of well developed ovaries in ovigerous females suggests that some female *I. peronii* are able to produce two broods of eggs in the same year. Male *I. peronii* showed no reproductive cycle and were capable of spawning at all times of the year. No sign of ovarian maturation was observed in any female *Ibacus* sp. throughout the study, indicating that female *Ibacus* sp. mature and spawn somewhere outside of the study area. Male *Ibacus* sp. contained spermatophores in their vas deferentia at all times of the year, but it could not be determined whether they were sexually active. The overall ratios of males to females was approximately 1:1 for both species.

Introduction

Ibacus peronii and *Ibacus* sp. are the two most commercially important scyllarid lobsters in New South Wales, Australia (Kailola et al. 1993). Both species are landed as a by-catch in commercial quantities by inshore prawn and fish trawlers in New South Wales and by danish seiners, prawn trawlers and scallop dredgers in Victoria. *I. peronii* and *Ibacus* sp. appear identical to the untrained observer and have only recently been distinguished as different species. They differ in their distributions off the east coast of Australia, with *I. peronii* found in relatively shallow inshore waters from northern New South Wales around the south of Australia to Western Australia, and *Ibacus* sp. inhabiting mid-shelf waters in northern New South Wales and southern Queensland. These two species are marketed together as "Balmain Bugs" and are becoming an increasingly popular seafood. A developing market (and higher prices) during the past few years has seen stocks of "Balmain Bugs" put under increased fishing pressure, with some fishers specifically targeting them. Unfortunately very little is known about the reproductive cycles of these species. The spawning seasons for some other commercially important scyllarid lobsters have been documented elsewhere in the world (Martins 1985; Jones 1988; Hardwick & Cline 1990), but no study has examined the reproductive cycles of any species of *Ibacus*. The increasing importance of "Balmain Bugs" as a fishery in Australia means that a knowledge of their reproductive cycles is highly desirable so that more informed management decisions can be made.

Given the complete lack of knowledge concerning the reproductive cycles of *Ibacus peronii* and *Ibacus* sp., this study aimed to determine the reproductive cycles and sex ratios of these two species. The reproductive cycles were investigated

during a 12 month period using several techniques: (i) changes in the proportions of ovigerous females in commercial catches (ii) changes in the condition of the ovaries and testes and (iii) the presence/absence of spermatophores in the vas deferens of males.

Materials & Methods

This study was done at two locations off the east coast of Australia.: Coffs Harbour in New South Wales (30°18'S, 153°08'E) and Lakes Entrance in Victoria (37° 53'S, 148° 00'E) (see Fig. 1). Because of their different distributions, *Ibacus peronii* were sampled at both locations while *Ibacus* sp. could only be sampled at Coffs Harbour.

Specimens of both species were collected onboard commercial trawlers every two months from April 1993 to May 1994. The proportion of ovigerous females in each catch was calculated as the proportion of mature females (>51mm C.L. - their estimated size at sexual maturity) (see Stewart et al., in prep) that were carrying eggs. Plots of the proportion of ovigerous females throughout time were used to describe the spawning season at each location.

During each sampling period, the gonads of ten female and ten male *Ibacus peronii* and *Ibacus* sp. were collected for histological examinations and to calculate their gonosomatic indices (GSI's). Samples were collected to represent the widest size-range of animals available in each catch. Immediately after capture, each specimen was measured and its gonads removed. One half of each gonad was kept to calculate the GSI, and the other half of each gonad was examined histologically.

A pilot study using ten males and ten females over a wide range of sizes found no significant differences between the weights of the left and right sides of the ovaries, nor the left and right sides of the testes (t-tests, $p>0.05$).

Ovaries and testes kept for histology were fixed for a period of one week in a solution of 10% formaldehyde, 5% acetic acid, 1% anhydrous calcium chloride and 84% seawater. After fixing, the tissue was dehydrated in ethyl alcohol, cleared in histolene and embedded in paraffin wax. Transverse sections were cut from each portion of gonad at a thickness of 6 micrometers. Slides were stained with Gills' haematoxylin and eosin. Slides of the ovaries of 110 female and 127 male *Ibacus peronii* and 50 female and 52 male *Ibacus* sp. were examined to estimate their stage of maturation. The largest oocyte of 20 randomly selected oocytes in each section of ovary was used as an index of its maturity. Oocyte size was measured as the cross-sectional area, (mm^2), using an image processor. The stage of the reproductive cycle for the female population at any time was estimated by the mean maximum size of oocytes in mature females at that time (>51mm C.L.). Because all *Ibacus* sp. sampled showed little sign of ovarian development, the ovaries from female *Ibacus* sp. of all sizes were used for this work (ie. not just those that were >51mm C.L.). Males of both species were determined to be potentially reproductively active by the presence of spermatophores in cross-sections of their vas deferentia.

GSI's were calculated for each animal (male & female) used in the histological study where it was sure that the whole gonad was removed. One half of the dissected ovary or teste was dried in an oven at 60° celsius for a period of one week. GSI was then calculated to be:

$$GSI = \frac{\text{dry gonad wt}}{(\text{C.L.})^3} \times 10^5$$

Carapace length (C.L.) was cubed to keep the units the same as gonad weight, and a multiplier of 10^5 was used to make the numbers easier to present. Plots of mean GSI for each sex for each sampling period were used to describe the reproductive cycle during one year.

Sex ratios were determined from 3653 *Ibacus peronii* and 1035 *Ibacus* sp. examined onboard commercial trawlers during the study.

Results

Ovigerous female *Ibacus peronii* were found at both locations throughout the year but there was a tendency for more ovigerous females to be in the catch during the cooler months (Fig. 2). A much greater percentage of mature females at Coffs Harbour were ovigerous during this time (mean ± S.E. of 63% ± 9.8%), than at Lakes Entrance, (31% ± 0.6%). No ovigerous *Ibacus* sp. were observed during the entire study.

Oocyte development in *Ibacus peronii* from Lakes Entrance reached a mean maximum size in June (Fig. 3b). The peak spawning period occurred from June until October (Fig. 2b). This pattern of oocyte development was similar for *I. peronii* from Coffs Harbour, with mean maximum oocyte size peaking around April/June (Fig. 3a), just prior to the peak spawning period (detected in 2a), and redeveloping again after October. For *Ibacus* sp. there was little oocyte development throughout

the year, with the mean maximum sizes of oocytes being an order of magnitude smaller than those for *I. peronii* (Fig. 3c).

Plots of the mean GSI values for mature male and female *Ibacus peronii* from Lakes Entrance and Coffs Harbour, and for all *Ibacus* sp. are presented in Fig. 4. The patterns of mean female GSI's during the year were similar to those for mean maximum oocyte sizes (Fig. 3), with ovaries reaching a peak in development in June at Lakes Entrance and in April/June at Coffs Harbour. Female *Ibacus* sp. had very low GSI values all year. Male *I. peronii* showed very little variation in mean GSI during the study, with the exception of a slightly lower value in December at Coffs Harbour (Fig. 4b). This constancy in GSI for males was consistent with the histological work in which males were observed to contain spermatophores in their vas deferentia all year. Male *Ibacus* sp. produced very low GSI values (Fig. 4c) but were also found to have spermatophores in their vas deferentia all year.

The ratios of males to females for *Ibacus peronii* and *Ibacus* sp. sampled during the study varied widely at different sampling times, however the overall ratios were approximately 1:1 (Table 1).

Discussion

The above results indicate that *Ibacus peronii* from Coffs Harbour and Lakes Entrance spawns mainly during the cooler months of the year (winter to early spring) and some lower level spawning occurs throughout the rest of the year (Figs. 2, 3 & 4). A similar pattern in spawning activity has also been observed for the scyllarid lobster *Thenus orientalis* (Jones, 1988), but for that species, peak

spawning occurred during mid-summer, not in the cooler months as detected for *I. peronii* in the present study.

Although similar patterns of spawning were evident for *Ibacus peronii* from Coffs Harbour and Lakes Entrance throughout the year, there were some differences which suggest a slightly different spawning strategy between the two locations. During the peak spawning times, a mean maximum (± S.E.) of 63% ± 9.8% of mature female *I. peronii* were ovigerous at Coffs Harbour, but at Lakes Entrance this mean maximum was only 31% ± 0.6% (Fig. 2). In addition, the peak spawning period at Coffs Harbour was from June to August/September, whereas at Lakes Entrance this period extended until at least October. The resultant pattern is a more protracted, but less intense, peak spawning period at Lakes Entrance than at Coffs Harbour. Lakes Entrance is much further south than Coffs Harbour (Fig. 1) and is therefore more likely to experience much colder water. Development time is strongly correlated with temperature in ectotherms (eg. copepods, Mclaren et al.1969; echinoderms, Hoegh-Guldberg & Pearse 1995, and; *Thenus* spp. Cosgrove & Courtney 1993). One hypothesis is that Lakes Entrance's colder water could be responsible for the more prolonged incubation period.

The maximum mean sizes of oocytes (Fig. 3) and the mean GSI values throughout the year (Fig. 4) indicated that they were reasonable indicators of ovarian maturity in *Ibacus peronii*. Ovarian development was shown to peak just prior to the peak period of oviposition (Fig. 2) with little development occurring in subsequent months. The longer standard errors that occurred during some sampling periods (Figs. 3 and 4) reflect small sample sizes and the fact that sampling included some animals which had spawned and some animals which not yet spawned at those particular times.

Male *Ibacus peronii* were potentially reproductively active all year at both locations - (the mean GSI's were consistent throughout the year (Fig. 4a & b) and spermatophores were present in the vas deferentia of all males during each sampling period). The presence of ovigerous females throughout the year supports the conclusion that male *I. peronii* are capable of mating at any time of the year. We assume that spermatogenesis occurs continuously after maturation, as is the case for spiny and clawed lobsters (Fielder, 1964; Farmer, 1974).

Successive spawnings by individual female *Ibacus peronii* in the one year were not found in the present study, but the presence of well-developed ovaries in some egg-bearing females suggests that it could be possible. The scyllarid *Thenus orientalis* is thought to be capable of producing two broods of eggs in the one year in Queensland, Australia (Jones 1988).

Unfortunately it was not possible to determine the reproductive cycle of *Ibacus* sp. in this study. No ovigerous females were observed and even large animals with well developed sexual characteristics (such as long ovigerous setae on their pleopods), showed little sign of ovarian development. The mean maximum sizes of oocytes (Fig. 3c) remained very small all year, as did their mean GSI values (Fig. 4c). Male *Ibacus* sp. contained spermatophores within their vas deferentia all year, but the very small GSI values when compared to those from male *Ibacus peronii* suggest that those male *Ibacus* sp. sampled were not fully mature. It is obvious that *Ibacus* sp. mature and spawn somewhere outside of the areas studied. Coffs Harbour is close to the southern end of this species distribution (Kailola et al. 1993) and future work should clearly concentrate on more northern locations to determine where and when *Ibacus* sp. matures.

The overall ratios of males to females for *Ibacus peronii* and *Ibacus* sp. were approximately 1:1 (Table 1). Similar 1:1 ratios have been found for other scyllarid lobsters such as *Scyllarides latus* (Martins, 1985), *Scyllarides nodifer* (Hardwick & Cline, 1990) and *Thenus orientalis* (Jones, 1988). Because all samples in the present study were taken by the rather non-selective fishing method of trawling, these sex ratios should reflect those in the natural populations. The widely differing ratios of males to females at different sampling times, particularly for *I. peronii*, may reflect behavioural differences between the sexes at different times affecting their susceptibility to trawling.

This study has determined the reproductive cycle of the commercially important *Ibacus peronii* off Eastern Australia, and so provides an important first step in understanding this species hitherto unknown reproductive biology. It may be concluded that *I. peronii* spawn all year round with a peak during the cooler months, from June to October. The sex ratios for *I. peronii* and *Ibacus* sp. is approximately 1:1. We have also provided some preliminary information on the reproductive cycle of *Ibacus* sp. in N.S.W. Unfortunately, the full reproductive cycle of *Ibacus* sp. could not be determined in the present study. It is postulated that *Ibacus* sp. mature and spawn in more northern locations and future work to determine the reproductive cycle of *Ibacus* sp. should clearly concentrate on more northern locations.

Acknowledgements: This study was funded by the Australian Fishing Research and Development Council (Grant No. 92/040). Our thanks go to Norm Shilling, Shane & Mark Huxley, Simon Tidswell, Daryl Sprague and Sel Turner for their invaluable advice and assistance.

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Stewart, J., Kennelly, S. J. and O. Hoegh-Guldberg (in prep) Size at sexual maturity and observations on the reproductive biology of two species of scyllarid lobster from New South Wales and Victoria, Australia.

Figure captions

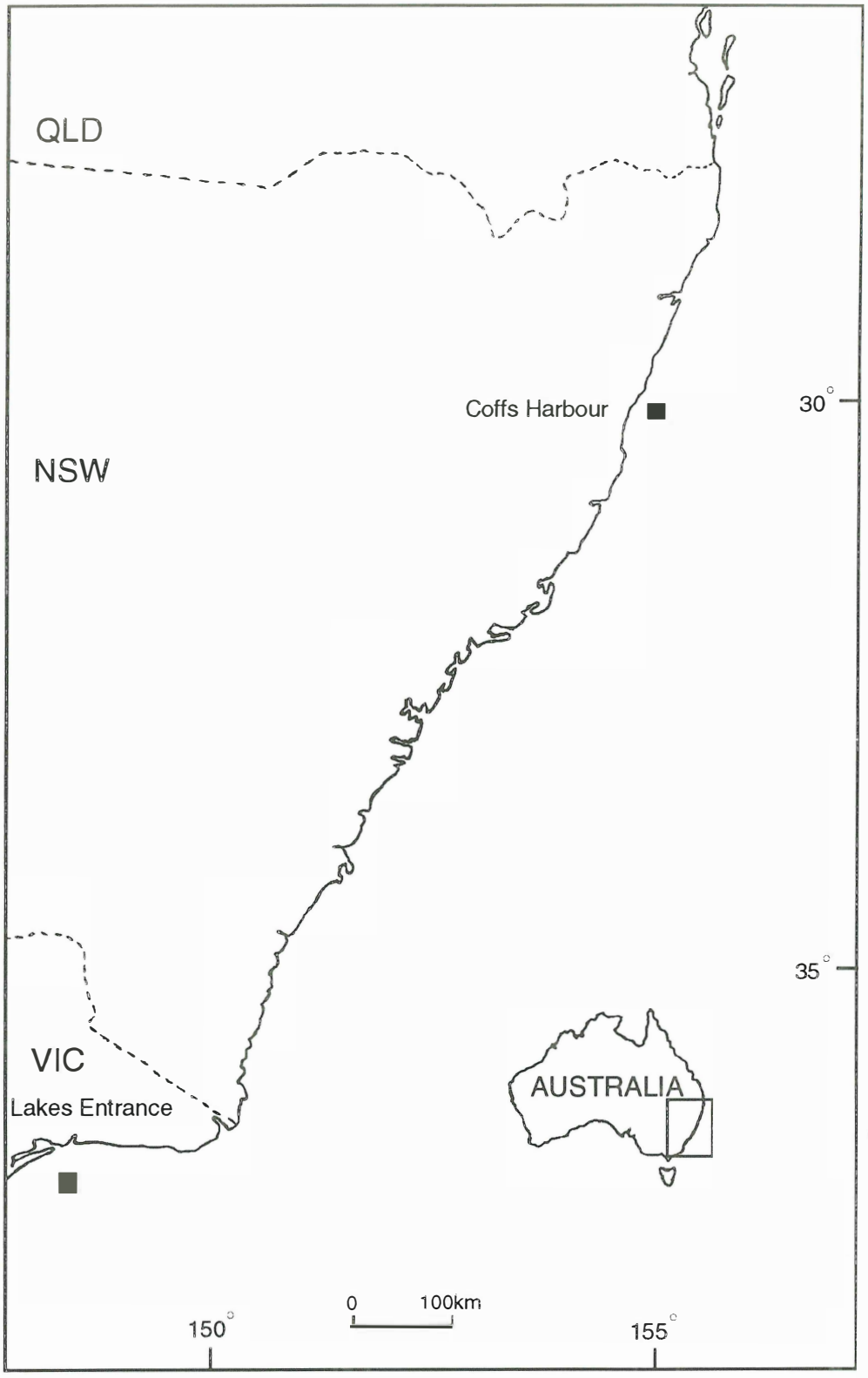
figure 1. Location of study sites

figure 2. The percentage of mature female *Ibacus peronii* carrying eggs (mean ± S.E.) at Coffs Harbour and Lakes Entrance throughout 1993/94. N.B. months with zero values were not sampled.

figure 3. Maximum sizes of oocytes (mean ± S.E.) for mature *Ibacus peronii* from Coffs Harbour and Lakes Entrance, and for *Ibacus* sp. from Coffs Harbour. N.B. no sample for June *Ibacus* sp. from Coffs Harbour.

figure 4. GSI values (mean ± S.E.) for mature female *Ibacus peronii* from Coffs Harbour and Lakes Entrance, and for *Ibacus* sp. from Coffs Harbour. N.B. no sample for June *Ibacus* sp. from Coffs Harbour.

Figure 1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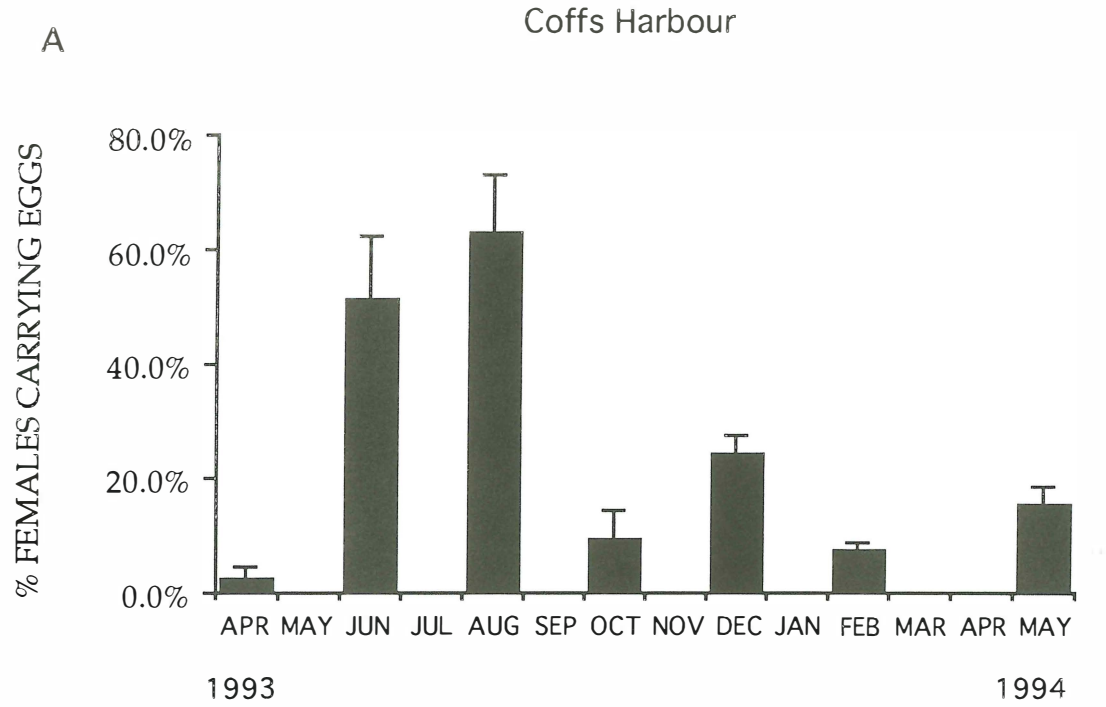
Coffs Harbour
30°
NSW
35°
VIC
Lakes Entrance
AUSTRALIA
0
100km
150°
155°

Figure 2


A
Coffs Harbour
% FEMALES CARRYING EGGS
80.0%
60.0%
40.0%
20.0%
0.0%
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
1993
1994

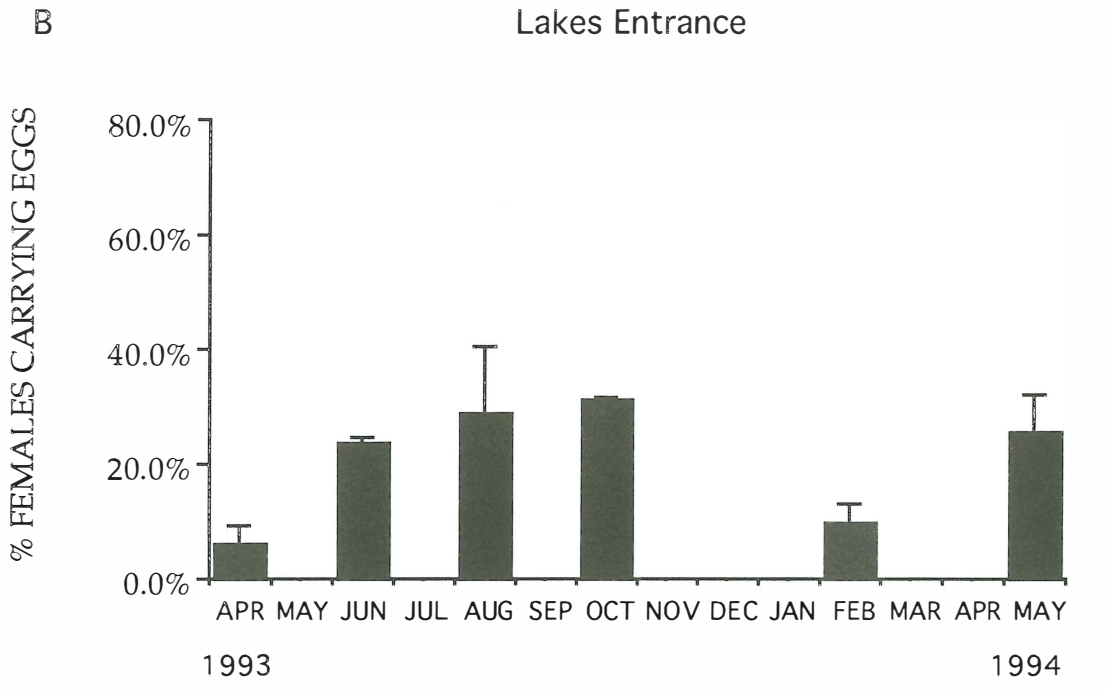

B
Lakes Entrance
% FEMALES CARRYING EGGS
80.0%
60.0%
40.0%
20.0%
0.0%
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
1993
1994

Figure 3

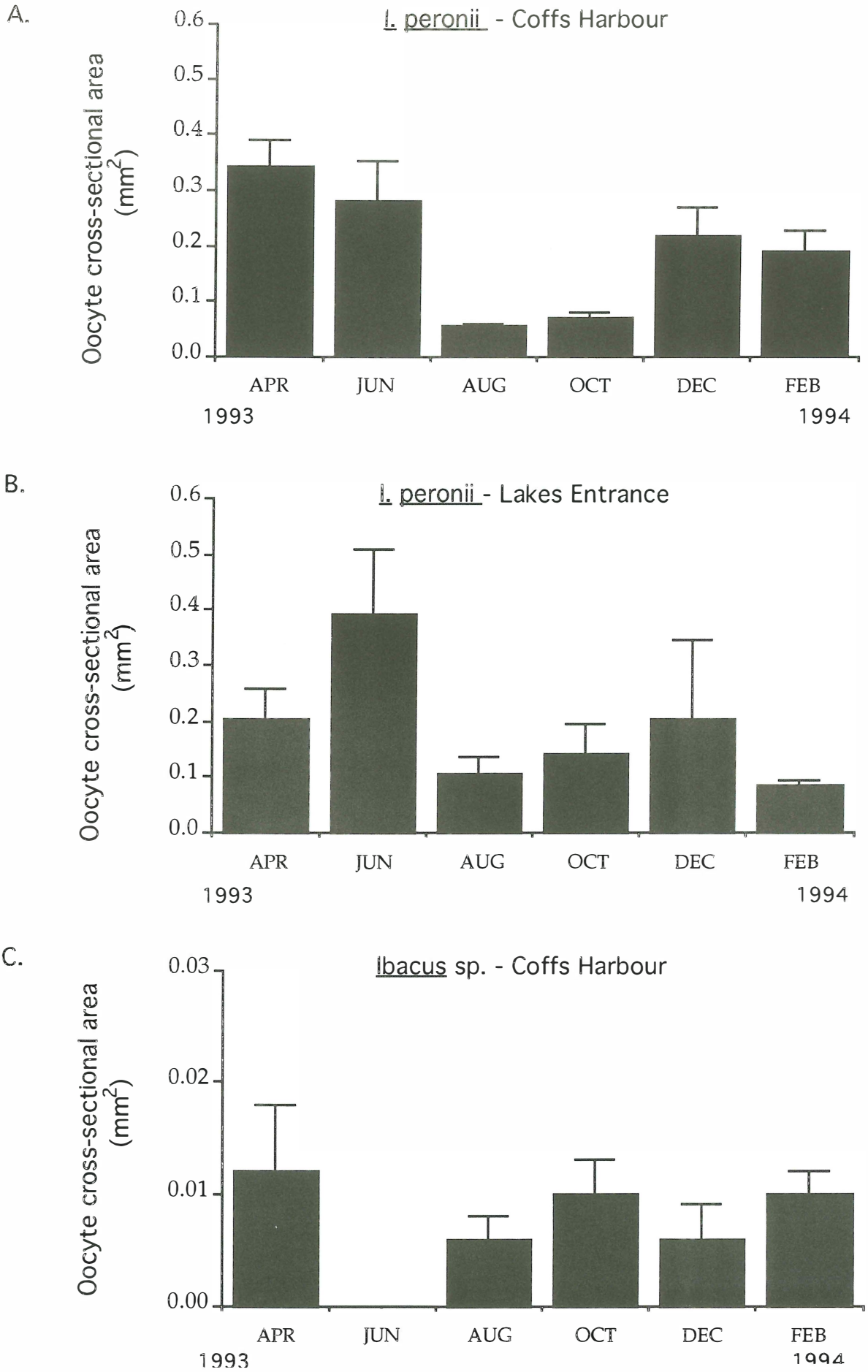
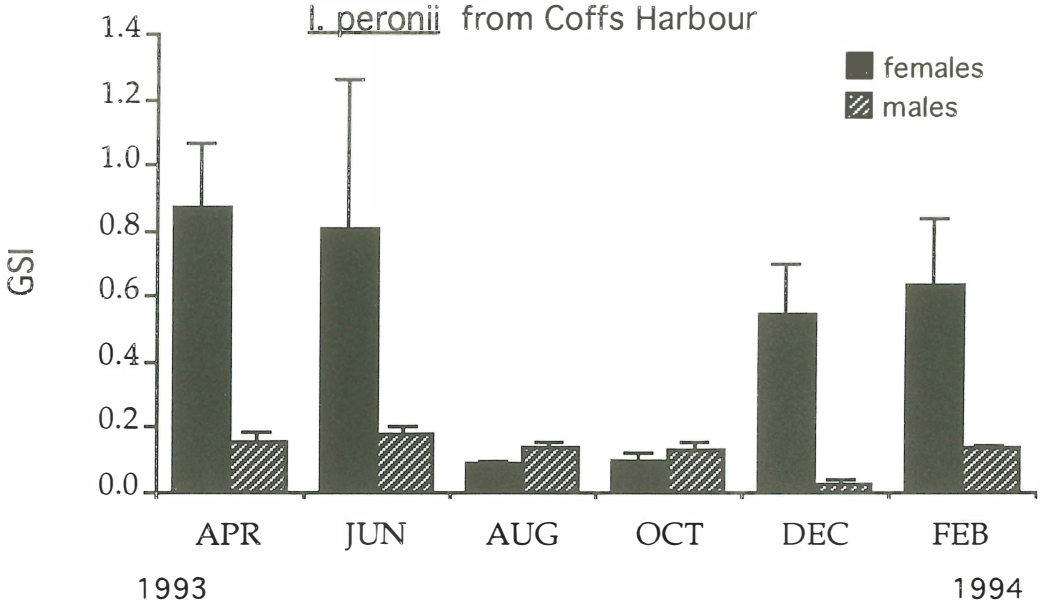
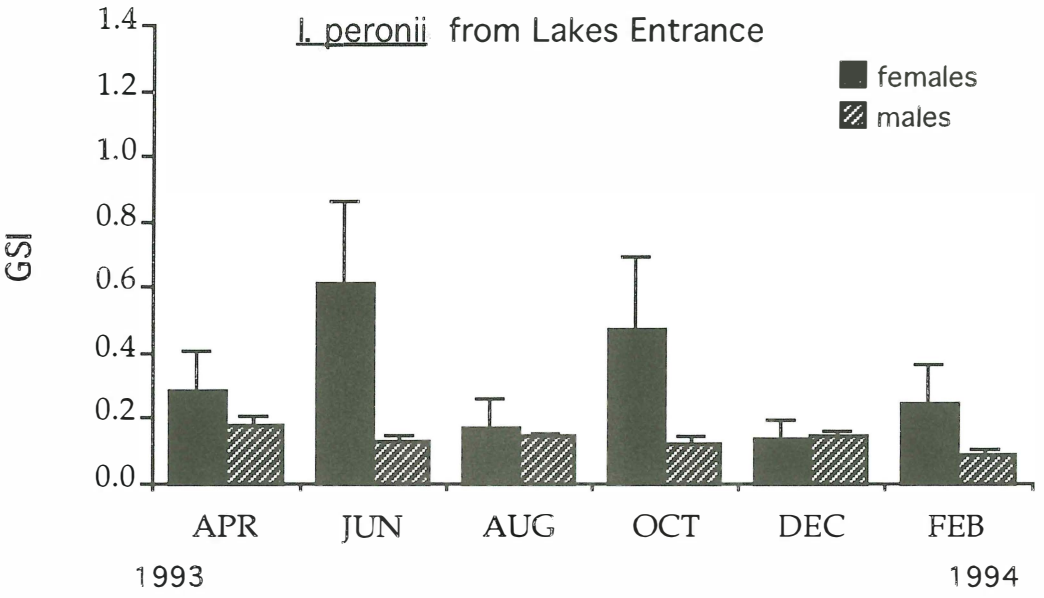

A.
I. peronii - Coffs Harbour
Oocyte cross-sectional area (mm2)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
APR
JUN
AUG
OCT
DEC
FEB
1993
1994
B.
I. peronii - Lakes Entrance
Oocyte cross-sectional area (mm2)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
APR
JUN
AUG
OCT
DEC
FEB
1993
1994
C.
Ibacus sp. - Coffs Harbour
Oocyte cross-sectional area (mm2)
0.03
0.02
0.01
0.00
APR
JUN
AUG
OCT
DEC
FEB
1993
1994

Figure 4

A.


I. peronii from Coffs Harbour
females
males
GSI
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
APR
JUN
AUG
OCT
DEC
FEB
1993
1994

B.


I. peronii from Lakes Entrance
females
males
GSI
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
APR
JUN
AUG
OCT
DEC
FEB
1993
1994

C.

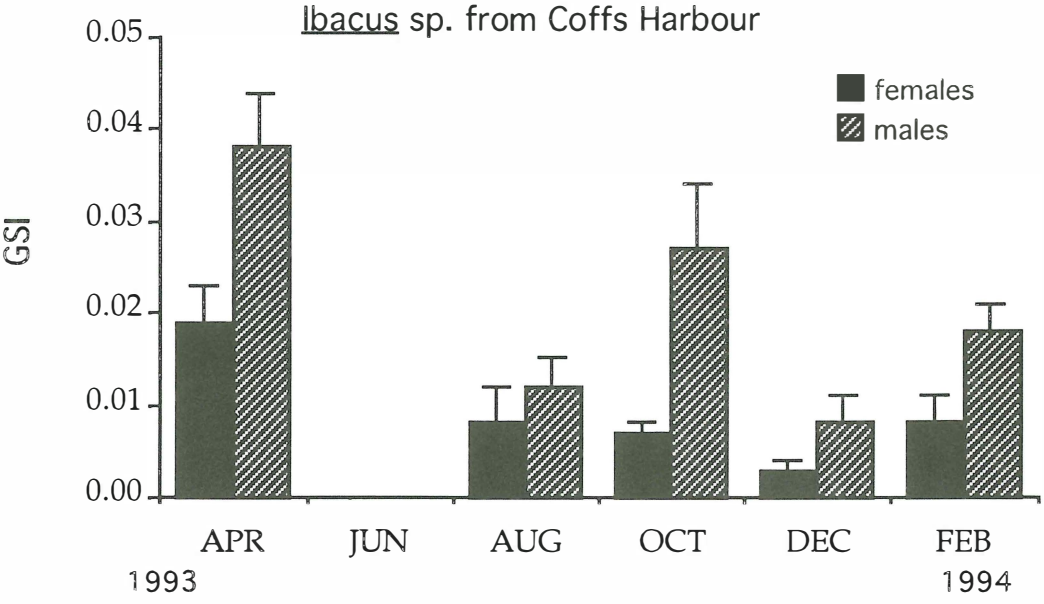

Ibacus sp. from Coffs Harbour
females
males
GSI
0.05
0.04
0.03
0.02
0.01
0.00
APR
JUN
AUG
OCT
DEC
FEB
1993
1994

Table 1: Ratios of Males (M) to Females (F) for Ibacus peronii and Ibacus sp. from Coffs Harbour and Lakes Entrance during 1993/94.

Species/port	Ratio	APR'93	JUN'93	AUG'93	OCT'93	DEC'93	FEB'94	MAY'94	TOTAL
I. peronii Coffs Harbour	M:F	17:23	85:39	90:91	72:107	105:90	167:177	373:302	909:829
I. peronii Lakes Entrance	M:F	125:74	123:81	151:102	93:159	--	62:115	421:409	975:940
Ibacus sp. Coffs Harbour	M:F	105:108	68:85	47:53	8:11	55:67	95:107	124:122	502:553

APPENDIX D

Fecundity and egg-size of the Balmain Bug Ibacus peronii (Leach) (Decapoda: Scyllaridae) off the east coast of Australia.

(DRAFT)

Stewart, J. & Kennelly, S.J.

Fecundity and egg-size of the Balmain Bug *Ibacus peronii* (Leach) (Decapoda : Scyllaridae) off the east coast of Australia.

John Stewart and Steven J. Kennelly

Fisheries Research Institute, NSW Fisheries, PO Box 21, Cronulla, NSW 2230, Australia

Running Head: Fecundity and egg-size of *Ibacus peronii*

Abstract:

Samples of egg-bearing female Balmain Bugs *Ibacus peronii* (Leach) were collected from Coffs Harbour, NSW and Lakes Entrance, Victoria to estimate their fecundity and egg-size. Fecundities ranged between 5,500 and 37,000 eggs per brood with a mean egg diameter of 1.18mm ± 0.013mm. Fecundity did not vary significantly between the two locations ($P>0.05$) and the data were combined to provide a general fecundity-size relationship for *I. peronii*. This relationship is described by the positive linear regression $y = 943x - 45296$ ($r^2 = 0.676$, $p<0.01$).

Introduction:

Fecundity and egg-size are two of the most important life-history variables for any commercially exploited species, and their estimation is of interest to not only the evolutionary ecologist but also the manager of the resource (Stearns, 1976). Life-history theory hypothesises that the partitioning of resources to egg production has evolved as a trade-off between numbers of eggs and egg-size such that the life-history strategy of any particular species has evolved to optimize recruitment for that species in its particular environment (Svardson, 1949). From a management perspective, estimates of fecundity and egg-size can be combined with data on the size at sexual maturity and size-distributions of mature animals to develop egg-per-recruit models (Pollock & Goosen, 1991). These may then be used to assess the effects that various management strategies (like minimum legal size limits) may have on the egg production of a population.

The Balmain Bug *Ibacus peronii* is a commercially exploited marine decapod belonging to the family Scyllaridae. Distributed from northern New South Wales around the south of Australia to Western Australia, they are fished by prawn and fish trawlers in New South Wales and Victoria. In recent years they have been subjected to increasing levels of exploitation which has led to concerns that stocks are being over-exploited. One management strategy that is being considered to protect the breeding population is the introduction of a minimum legal size limit. To predict the effects that such a strategy may have on subsequent recruitment, an understanding of their life-history is necessary, together with an estimate of their fecundity and its relationship to female body-size.

Unfortunately, there are no studies available on the reproductive biology of *Ibacus peronii*. In fact, there has been very little work done on the reproductive biology of any of the scyllarid lobsters and consequently very little is known about fecundities, egg-sizes or life-history strategies in this family. Jones (1988) estimated fecundity in the Moreton Bay Bug *Thenus orientalis* to be in the order of between 5,000 and 50,000 eggs per brood, while Martins (1985) estimated fecundity in the Mediterranean Locust Lobster *Scyllarides latus* to be much greater (151,000 and 356,000 eggs per brood). Scyllarid lobsters are closely related to the spiny lobsters (family Palinuridae) whose fecundities, egg sizes and other life-history variables have been extensively studied (Kensler 1967, Phillips et al. 1980, Pollock & Goosen, 1991). Like spiny lobsters, scyllarid lobsters carry and protect their eggs under the tail until they hatch. Like most studies on spiny lobsters, in the present paper we define fecundity as the total number of eggs produced by a female in one brood, and this is estimated by counting the number of externally attached eggs beneath the tail of each female.

Here we determine the fecundity of *Ibacus peronii* over the available size-range of spawning females at two locations at either end of its distribution off the east coast of Australia. Mean egg diameter for females of different sizes was also estimated to complement the fecundity data and so provide some information on the possible life-history strategy of this species.

Materials & Methods:

This study was done at two locations at either end of the fishery for *Ibacus peronii* on the east coast of Australia. The two locations were at Coffs Harbour in New South Wales (30°18'S, 153°08'E) and Lakes Entrance in

Victoria (37°53'S, 148°00'E) (Fig. 1). Estimates of fecundity were made for 33 ovigerous females from Coffs Harbour and for 42 ovigerous females from Lakes Entrance. Samples of eggs were taken while onboard commercial trawlers between April 1993 and May 1994. The carapace length (C.L.) of each female was measured, to the nearest 0.1mm using dial calipers, as the distance between the rostral sinus and the posterior margin of the carapace. The pleopods and attached egg mass from each female were removed soon after capture and fixed in a solution of 10% formaldehyde, 5% acetic acid, 1% anhydrous calcium chloride and 84% seawater.

In the laboratory, eggs were carefully stripped from the pleopods using fine forceps and any setal material or extraneous matter was removed. The entire egg mass was placed in water in a Folsom splitter and split volumetrically into equal portions. Between one quarter and one sixteenth of each egg mass was counted using a binocular microscope and the total number of eggs from each female was calculated by simple proportion.

Fecundity-size relationships for *Ibacus peronii* from each location were estimated by plotting graphs of fecundity versus carapace length and fitting linear regressions to the data. The slopes and y-intercepts of the regressions for each location were compared using analysis of covariance.

The diameters of ten randomly selected eggs were measured to the nearest 0.01mm from each sample using a binocular microscope with an eyepiece graticule. The data from both locations was combined and used to compare mean egg-size and carapace length.

Results:

Fecundity was estimated to be between 5,848 and 36,688 eggs per brood for *Ibacus peronii* from Coffs Harbour and between 5,488 and 31,008 eggs per brood for those from Lakes Entrance (Table 1).

Both locations showed significant positive linear relationships between fecundity and carapace length ($p<0.01$) (Figs. 2a & b). The two regression lines ($y = 1035x - 52121$ for Coffs Harbour and $y = 903x - 42556$ for Lakes Entrance) showed no significant differences in either slope ($p=0.46$) or y-intercept ($p=0.53$), indicating that there was no significant geographical variation in these fecundity-size relationships. The data from both locations were therefore pooled to provide a general fecundity-size relationship for *I. peronii* which is described by the regression $y = 942x - 45296$ (Fig. 3).

There was no apparent relationship between mean egg diameter and carapace length (Fig. 4).

Discussion:

The results from this study showed firstly that there was no significant geographical variation in the fecundity-size relationship for *Ibacus peronii* from Coffs Harbour and Lakes Entrance (compare Figs. 2a & b). These two locations are at either end of the fishery for *I. peronii* in eastern Australia and consequently occur at very different latitudes (Fig. 1) suggesting that latitude, and therefore water temperature, may not affect fecundity in this species. Whilst other studies on lobsters have found no

significant geographical variation in fecundities, eg. the Western Rock Lobster *Panulirus cygnus* (Morgan, 1972), other species, such as the Norway Lobster *Nephrops norvegicus*, have shown marked geographical variation in fecundity (Thomas, 1964).

The lack of geographical variation in fecundity detected in the present study allowed us to calculate a general fecundity-size relationship for *Ibacus peronii* (Fig. 3) which shows a positive linear relationship. Similar linear relationships have been found for the Moreton Bay Bug *Thenus orientalis* (Jones 1988) and for many of the palinurid lobsters (Phillips 1980). We found that fecundity of *I. peronii* was between approximately 5,500 and 37,000 eggs per brood (Table 1) and because the size-range sampled (56.6mm to 83.6mm carapace length) is close to the entire size-range of spawning females for this species (unpub. data) these estimates are likely to be close to the true limits for this species. Fig. 4 indicates that there was no apparent relationship between carapace length and egg-size suggesting that for *I. peronii*, the eggs from small females are equally as viable as those from larger animals.

Our estimates of fecundity and the sizes of eggs (mean diameter of 1.18mm, S.E. = 0.013mm), are similar to those determined for the closely related *Thenus orientalis*, in Queensland, Australia - Jones (1988) estimated fecundity for *T. orientalis* to be between 5,000 and 50,000 eggs per brood with a mean egg diameter of 1.12mm. In contrast, however, estimates of fecundity for the Mediterranean Locust Lobster *Scyllarides latus* are an order of magnitude greater than these estimates (between 151,000 and 356,000 eggs per brood, with eggs approximately 0.6 to 0.7mm diameter - Martins, 1985). In the context of life-history strategies (see Pianka, 1970), these results indicate that the lower fecundity and larger eggs of *I. peronii* and *T.*

orientalis put these species closer to a k-selected, (or brooding) strategy than *S. latus*. That is, *I. peronii* and *T. orientalis* produce fewer but larger eggs, which may produce larger and more robust larvae that are more likely to survive until settlement (Pollock & Goosen, 1991).

The linear fecundity-size relationship for *Ibacus peronii* off the east coast of Australia is of interest to fisheries managers because the most fecund females in the population are the largest - who will not be protected by minimum legal size limits. It should be noted, however, that the relative contribution of eggs to the population of any size-class of animals is a function of their frequency of oviposition and the proportion of the population that they represent (Aiken & Waddy, 1980). In this study, fecundity was estimated as numbers of eggs per brood. The next stage in estimating the total reproductive potential of this species is to estimate the size-structured biomass of females, the number of broods per year, the percentage of infertile eggs, egg loss during incubation and the survival of larvae.

Acknowledgements: This study was funded by the Australian Fishing Research and Development Council (Grant No. 92/040). Our thanks go to Norm Shilling, Shane Huxley, Simon Tidswell, Daryl Sprague and Sel Turner for their invaluable assistance in collecting samles. We are grateful to Dr Ove Hoegh-Guldberg for critically reading the manuscript.

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Cosgrove, M. G. & Courtney, A. J. 1993. A Guide to Identifying Scrubbed Bugs. Queensland Department of Primary Industries.

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Captions to figures.

Figure 1. Location of study sites.

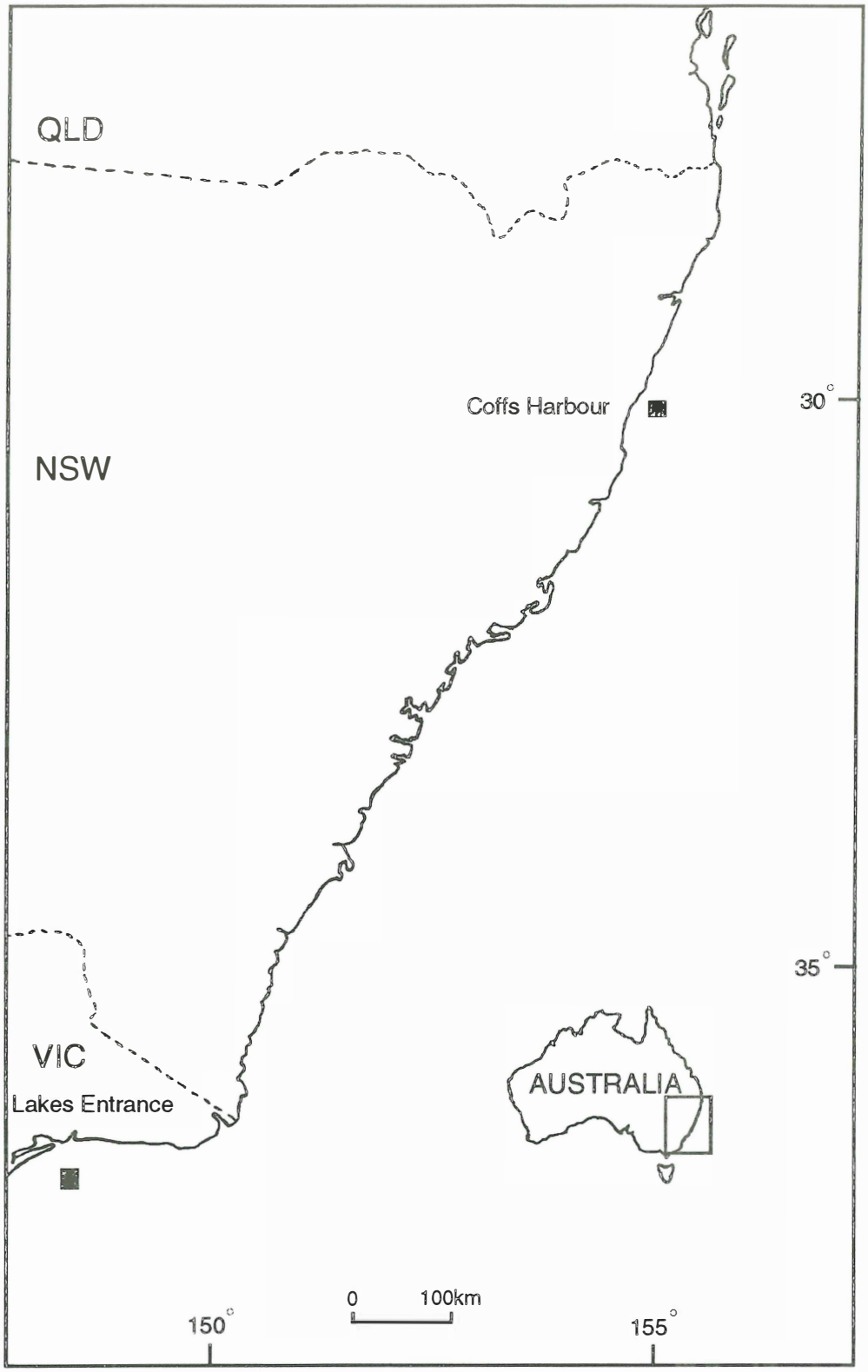
Figure 2. Regression of the fecundity of female *Ibacus peronii* against carapace length for (a) Coffs Harbour and (b) Lakes Entrance.

Figure 3. Regression of the fecundity of female *Ibacus peronii* against carapace length for both locations.

Figure 4. Mean egg diameters ± standard errors versus carapace length for *Ibacus peronii* from Coffs Harbour and Lakes Entrance.

Table 1.
Summary of the sizes, fecundities and egg-sizes of ovigerous Ibacus peronii from Coffs Harbour and Lakes Entrance. Standard errors are given in parentheses.

		Carapace length (mm)		Estimated fecundity		Mean egg diameter (mm)
Port	N	range	mean	range	mean	
Coffs Harbour	33	56.7 - 83.6	70.4 (1.1)	5,848 - 36,688	20,731 (1364)	1.18 (0.09)
Lakes Entrance	42	56.6 - 80.0	63.7 (0.8)	5,488 - 31,008	15,005 (971)	1.17 (0.07)


QLD
Coffs Harbour
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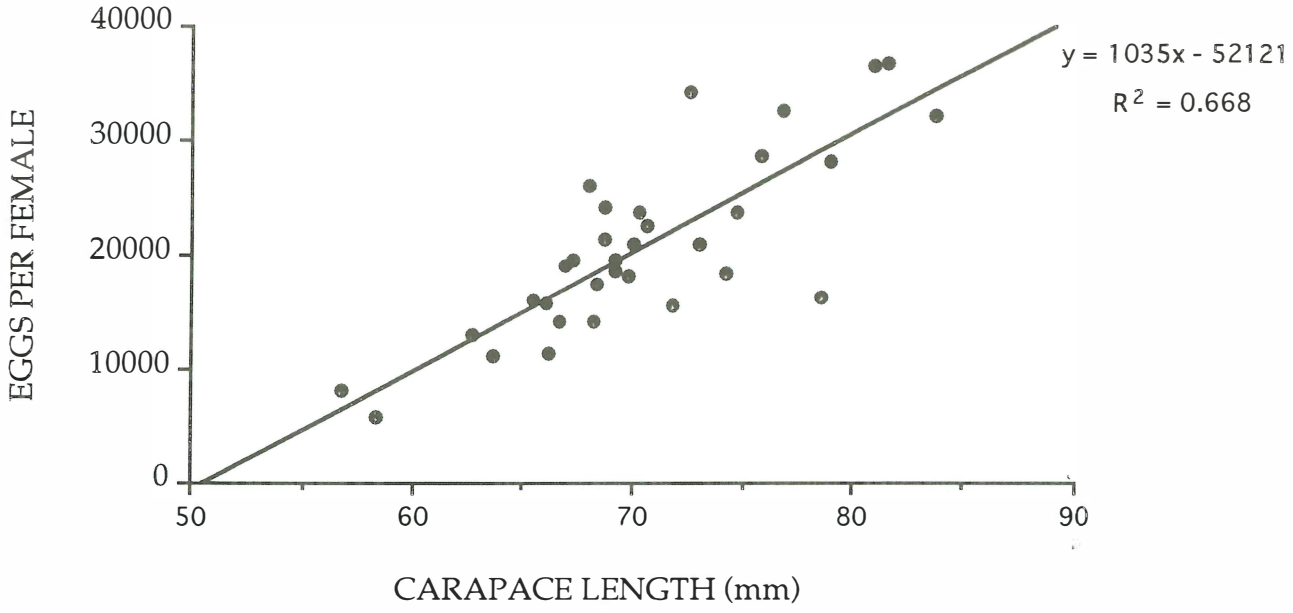
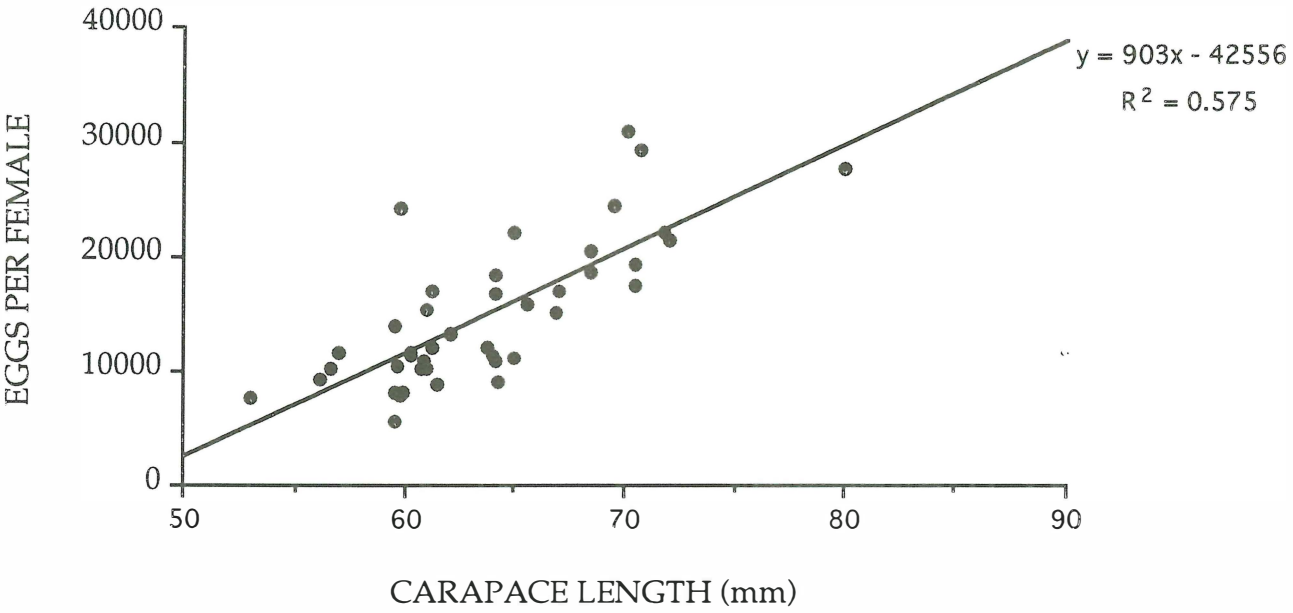
NSW
35°
VIC
Lakes Entrance
AUSTRALIA
0
100km
150°
155°

Figure 2

A


40000
30000
20000
10000
0
EGGS PER FEMALE
50
60
70
80
90
CARAPACE LENGTH (mm)
y = 1035x - 52121
R2 = 0.668

B


40000
30000
20000
10000
0
EGGS PER FEMALE
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60
70
80
90
CARAPACE LENGTH (mm)
y = 903x - 42556
R2 = 0.575

Figure 3

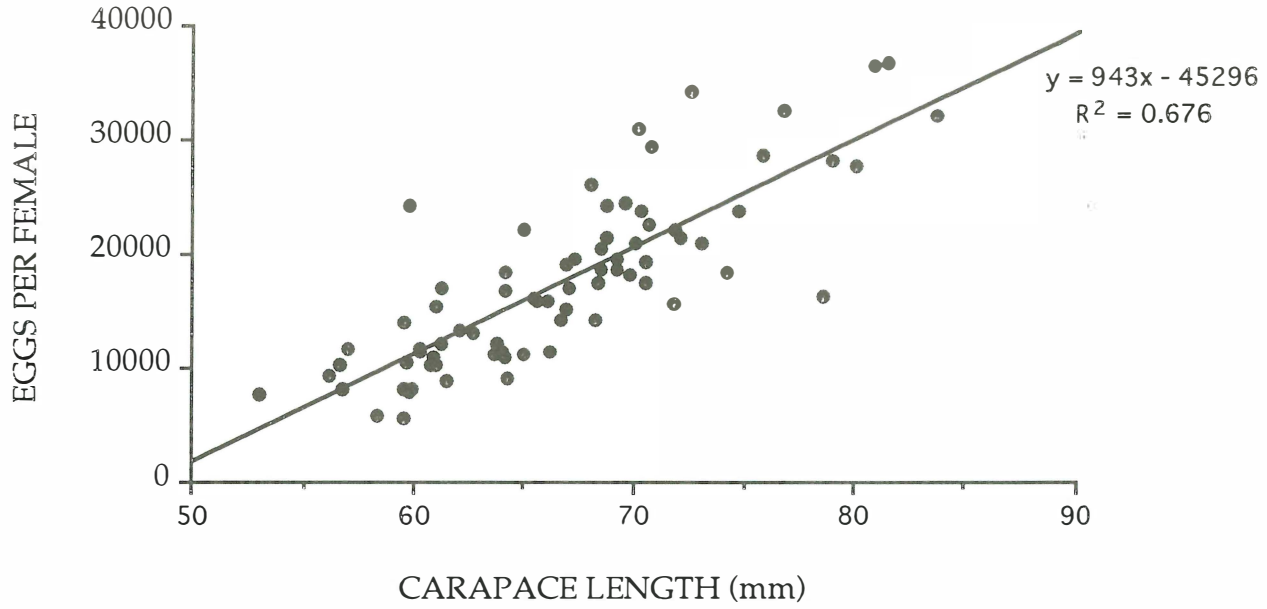
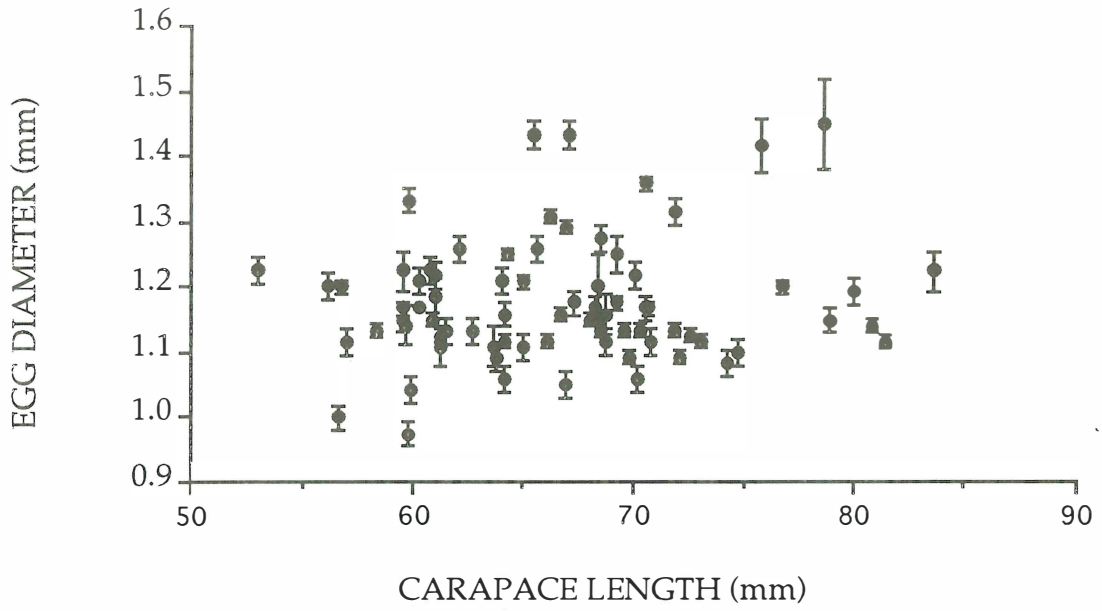

40000
30000
20000
10000
0
EGGS PER FEMALE
50
60
70
80
90
CARAPACE LENGTH (mm)
y = 943x - 45296
R2 = 0.676

Figure 4


EGG DIAMETER (mm)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
50
60
70
80
90
CARAPACE LENGTH (mm)

APPENDIX E

Preliminary estimates of movement patterns of Balmain and Smooth Bugs

(1st DRAFT)

Preliminary estimates of movement patterns of Balmain and Smooth Bugs (1st draft)

Introduction:

Knowledge of the movements of exploited marine animals is vital to a proper understanding of the dynamics of stocks and therefore their good management. Herrnkind 1980 categorizes the movement patterns of lobsters into three types: (i) migration - the movement of a population (or a distinct part of it) within some confined time period and over relatively long distances; (ii) nomadism - the wandering of individuals without any clear start and end points; and (iii) homing - the periodic (often daily) excursions from shelter to some nearby area, with subsequent return to that shelter or others nearby. Each pattern of movement is thought to have evolved in order to enhance or facilitate some biological need such as food, shelter, genetic mixing, reproduction, recruitment, etc. (Herrnkind, 1980). Different species may exhibit any, or all, of these patterns of movement throughout their life-histories.

Most studies which have assessed patterns of movements in lobsters have used tag/recapture data (for a review see Herrnkind 1980). A well executed tagging study provides precise information on the time at liberty, distance and direction moved, rate of movement and the biological state of the animal at release and recapture. When examining tag/recapture data for patterns of movement, Herrnkind (1980) warns of two factors that need to be considered: (i) possible alteration of behaviour due to tagging; and (ii) directional fishing pressure biasing recapture locations.

There have been few studies on the pattern of movements of scyllarid lobsters. Two species, *Scyllarides nodifer* (Hardwick & Cline, 1990) and *Scyllarides latus* (Spanier et al., 1988) are thought to exhibit seasonal migratory behaviour between shallow and deep water. These two species differ from species of *Ibacus* in that they live in areas of reef and stay in shelters for long periods, whereas species of *Ibacus* inhabit relatively featureless sandy environments (George & Griffin, 1972). *Thenus* spp. inhabit similar environments to species of *Ibacus* and exhibit a nomadic pattern of movement (Jones, 1988).

This chapter provides an assessment of the patterns of movement exhibited by both *I. peronii* and *Ibacus* sp. during a tag/recapture study. Possible reasons for these patterns are discussed, along with possible mechanisms stimulating and guiding this movement.

Materials & Methods

All data on movement were drawn from recaptured tagged *I. peronii* and *Ibacus* sp. The tag/recapture study was done out of four ports along the east coast of Australia: Ballina, Coffs Harbour and Newcastle in NSW, and Lakes Entrance in Victoria. Tagging was done approximately every two months throughout the period April 1993 to May 1994, and was done onboard commercial fishing trawlers during their normal fishing operations. Bugs were tagged with standard plastic T-bar tags made by Hallprint Pty Ltd. Each tag was approximately 4cm long, with 2cm of blue plastic tag bearing an identifying number and the words "NSW FISH". Tags were inserted dorsally into the musculature at the interface between the carapace and abdomen, at a point midway between the midline and the left hand edge of the animal (Fig. 1). A total of 3892 *I. peronii* and 716 *Ibacus* sp.

were tagged during the study. All bugs that appeared to be in good health and greater than approximately 30mm carapace length (C.L.) were sexed, measured, and tagged. Bugs smaller than approximately 30mm C.L. were not tagged because it was considered that they would not survive tagging. All bugs caught were sexed and measured. All bugs in this study were measured by C.L. which is the distance measured dorsally from the rostral sinus to the posterior edge of the carapace (Fig. 1). Lengths were measured using vernier dial calipers and were measured to the nearest 0.1mm. Tagged bugs were kept alive onboard the fishing trawler in tanks of circulating seawater and were released at the end of the nights fishing. To minimise predation of tagged bugs upon release, and to prevent predation as they sank to the bottom, all bugs were released on the sea floor using a release cage that was opened once it reached the bottom.

The tagging programme was widely publicised by way of a tag return poster distributed at the start of the study (Fig. 2). The poster outlined the details of the study and the reporting procedure for any tagged bugs caught. A reward of $5 was offered for the return of each recaptured tagged bug with the tag in place and information on where and when it was caught. In addition to the poster, each fisherman received a letter informing them of the study. Extensive liaison with fishermen at each port ensured a high rate of return of recaptured tagged bugs.

Recaptured tagged *I. peronii* and *Ibacus* sp. that were returned with the date and location of their recapture were used to calculate the time at liberty, distance and direction moved and the rate of movement of each animal.

Results

These results are preliminary and only include recaptures up to the end of 1994. An anticipated high recapture rate during the next 12 months will provide us with more detailed information on the patterns of movements displayed by tagged *Ibacus peronii* and *Ibacus* sp.

Of the 3892 *Ibacus peronii* and 716 *Ibacus* sp. tagged and released between April 1993 and May 1994, 382 (9.8%) *I. peronii* and 77 (10.8%) *Ibacus* sp. were recaptured by the end of 1994 (Table 1). Of these, 374 *I. peronii* and 70 *Ibacus* sp. were returned with information on the date and location of recapture. Distances moved were calculated as the shortest distance between the release and recapture locations. This is likely to have underestimated the actual distances and rates of movements of recaptured tagged *Ibacus* as it is unlikely that movement occurred in a direct line.

Recaptured tagged *Ibacus peronii* were at liberty for an average of 144 days (S.E. = 6.8 days) during which time they moved an average of 0.28km (S.E. = 0.07km) (Table 2). There were no trends in the directions of movement of recaptured tagged *I. peronii*. There were no apparent differences in movements of recaptured tagged male and female *I. peronii*.

Recaptured tagged *Ibacus* sp. were at liberty for an average of 171.2 days (S.E. = 16.9 days) during which time they moved an average of 27.6km (S.E. = 4.8km) (Table 3). Of the 70 *Ibacus* sp. returned with date and location of recapture 33 had moved greater than 10km, all of them northwards and generally into deeper water. The furthest distance moved by an *Ibacus* sp. from each release site is shown in Fig. 3. The greatest distance moved by a recaptured tagged *Ibacus* sp. was approximately 260km having been tagged

off Coffs Harbour in NSW and being recaptured off Southport in Queensland 364 days later. There was a large variation in the rates of movement of recaptured tagged *Ibacus* sp., with some animals moving less than 5km in 125 days, and others moving at up to 0.71km per day (Table 3). There were no apparent differences in movements of recaptured tagged male and female *Ibacus* sp.

Discussion

These preliminary results indicate that the morphologically similar *Ibacus peronii* and *Ibacus* sp. exhibit very different patterns of movement. *I. peronii* exhibits a nomadic pattern of movement, with tagged animals being recaptured close to, but in any direction, from their place of release. This pattern could possibly be interpreted as a homing one, with excursions away from shelter and subsequent return to that shelter or to others nearby. However the featureless sandy environments inhabited by *I. peronii* (George & Griffin, 1972) and the fact that *I. peronii* bury in the substratum for protection (pers. obs.), suggests that this is not the case. A nomadic pattern of movement has also been described for the closely related *Thenus* spp. in Queensland Australia (Jones, 1988) although the distances moved by recaptured tagged *Thenus* spp. were an order of magnitude greater than those observed for *I. peronii* in the present study.

In stark contrast to *Ibacus peronii*, *Ibacus* sp. exhibited a migration of individuals northwards and generally into deeper water. The large proportion of recaptured tagged animals that exhibited this trend from each release location, suggests that this migration is a general pattern that is consistent for all *Ibacus* sp. throughout the year.

The problems recognized by Herrnkind (1980) when analysing tag/recapture data for patterns of movement are unlikely to have affected the preliminary results described here. The morphological similarity of these two species suggests that any alteration in behaviour due to tagging should have been similar in both species. This is obviously not the case as each species exhibited very different patterns of movement after tagging. In addition, it is highly unlikely that any bias was produced in the results because of unidirectional fishing effort. Fishing is known to occur north and south of all the release locations, yet not one *Ibacus* sp. was recaptured south of its release location.

As mentioned in the introduction, each pattern of movement described by Herrnkind (1980) is thought to have evolved in order to satisfy some biological need. The different patterns of movement exhibited by *Ibacus peronii* and *Ibacus* sp. suggest that despite being morphologically alike these species have evolved very different life-histories. *Ibacus peronii* is found predominantly in relatively shallow inshore waters up to 80m deep (Kaiola et al. 1993) which are not subjected to any prevailing currents. The nomadic movement of *I. peronii* in this environment should therefore facilitate successful spawning, recruitment, genetic mixing and will optimize the available food supply.

Ibacus sp. are found in slightly deeper waters than *Ibacus peronii* ie. mid-shelf waters from 50-150m deep (Kaiola et al. 1993) which are subjected to the prevailing southerly flow of the East Australian Current. It is hypothesized that this difference in environmental conditions has led to *Ibacus* sp. evolving a migratory pattern of movement northwards in order to facilitate larval transport southwards in the east Australian current. A

similar migratory pattern has been demonstrated for the eastern king prawn *Penaeus plebejus* off the east coast of Australia (Ruello, 1975).

The processes stimulating lobster migrations can be either environmental, such as daylength, temperature or currents, or physiological, such as moult condition, reproductive condition or some hormonal trigger (Herrnkind, 1980). The fact that *Ibacus* sp. migrate northwards throughout the year, and that it is thought that they are all immature in NSW (see reproductive chapters) suggests that the "guide-post" for this migration is the southerly flowing East Australian Current. This pattern of migration is similar to that detected for some palinurid lobsters which have been observed to move into the prevailing currents (Street, 1970, 1971).

The different patterns of movement, and differences in reproductive biology, of *Ibacus peronii* and *Ibacus* sp. are discussed in detail in the general discussion of this report, particularly with respect to life-history strategies and their implications for managing the stocks of both species.

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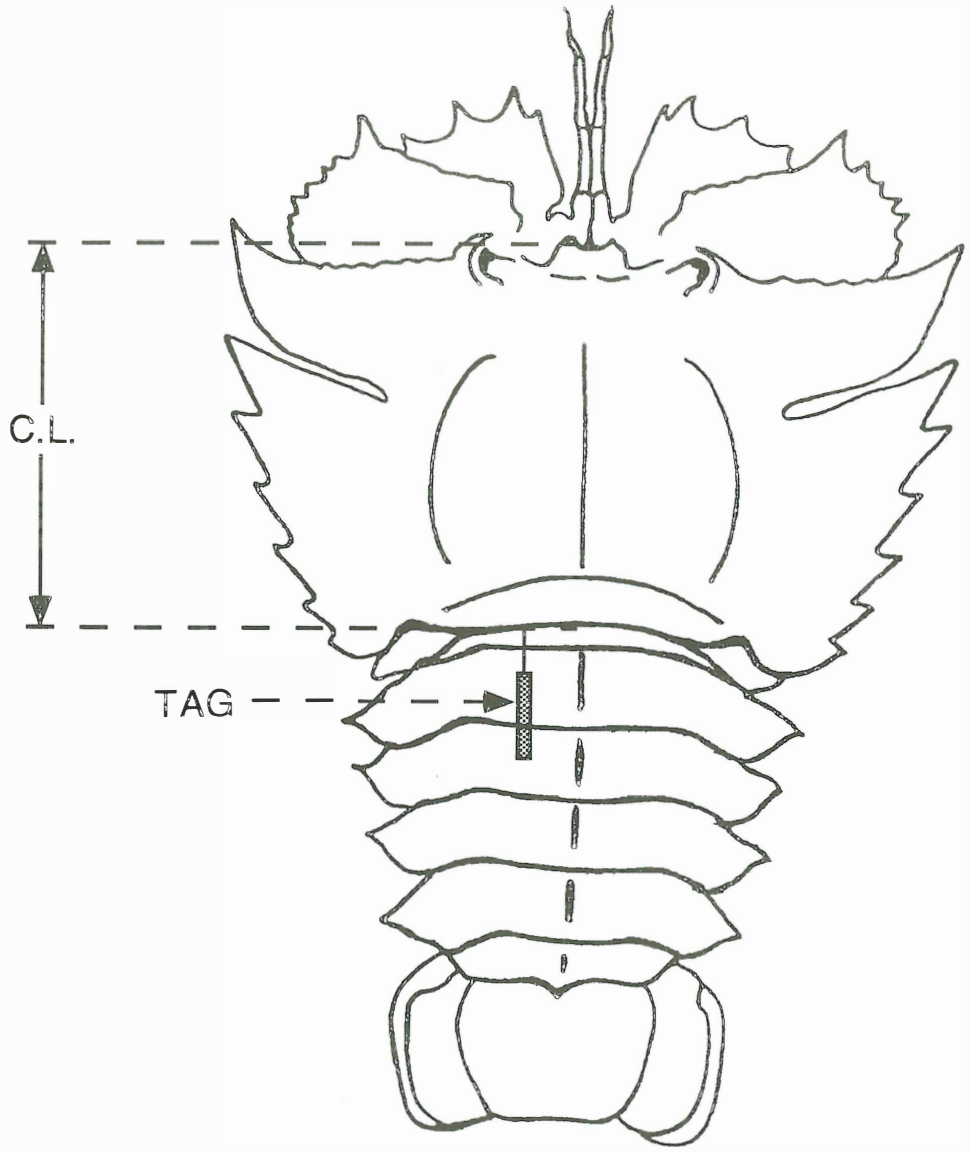
Figure captions

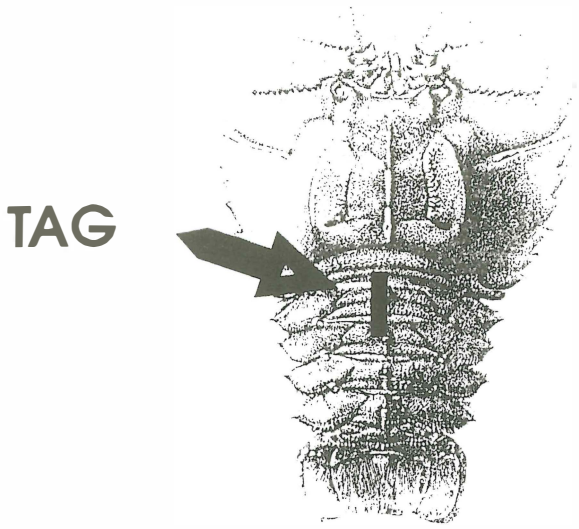
figure 1. Dorsal view of *Ibacus peronii* showing position of tag and measurement of Carapace length (C.L.).

figure 2. Poster advertising the tag/recapture study

figure 3. The greatest movements of recaptured tagged *Ibacus* sp. from each release site.


C.L.
TAG

TAGGING STUDY ON BALMAIN BUGS



Balmain Bugs are being tagged to study their growth and movements.

The diagram above shows the position of the blue plastic tag bearing a number, and the words "NSW FISH".

A reward of $5 is offered for THE RETURN OF EACH TAGGED BUG WITH THE TAG IN PLACE, together with the following information:

1. DATE OF CAPTURE
2. EXACT LOCATION
3. DEPTH
4. YOUR NAME AND ADDRESS

We will send you information on where and when your bug was tagged, and how much it had grown.

You can return the tagged bugs and the above information to:

IN N.S.W.:
- YOUR LOCAL FISHERMANS CO-OPERATIVE, OR
- JOHN STEWART AT THE FISHERIES RESEARCH INSTITUTE, 202 NICHOLSON PARADE, CRONULLA, NSW 2230.
PHONE: (02) 527-8411.

IN QUEENSLAND:
- TONY COURTNEY AT THE QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES,
PHONE: (07) 203-1444.

Your cooperation will contribute to the success of this program

Thank You!

NSW **FISHERIES RESEARCH INSTITUTE**

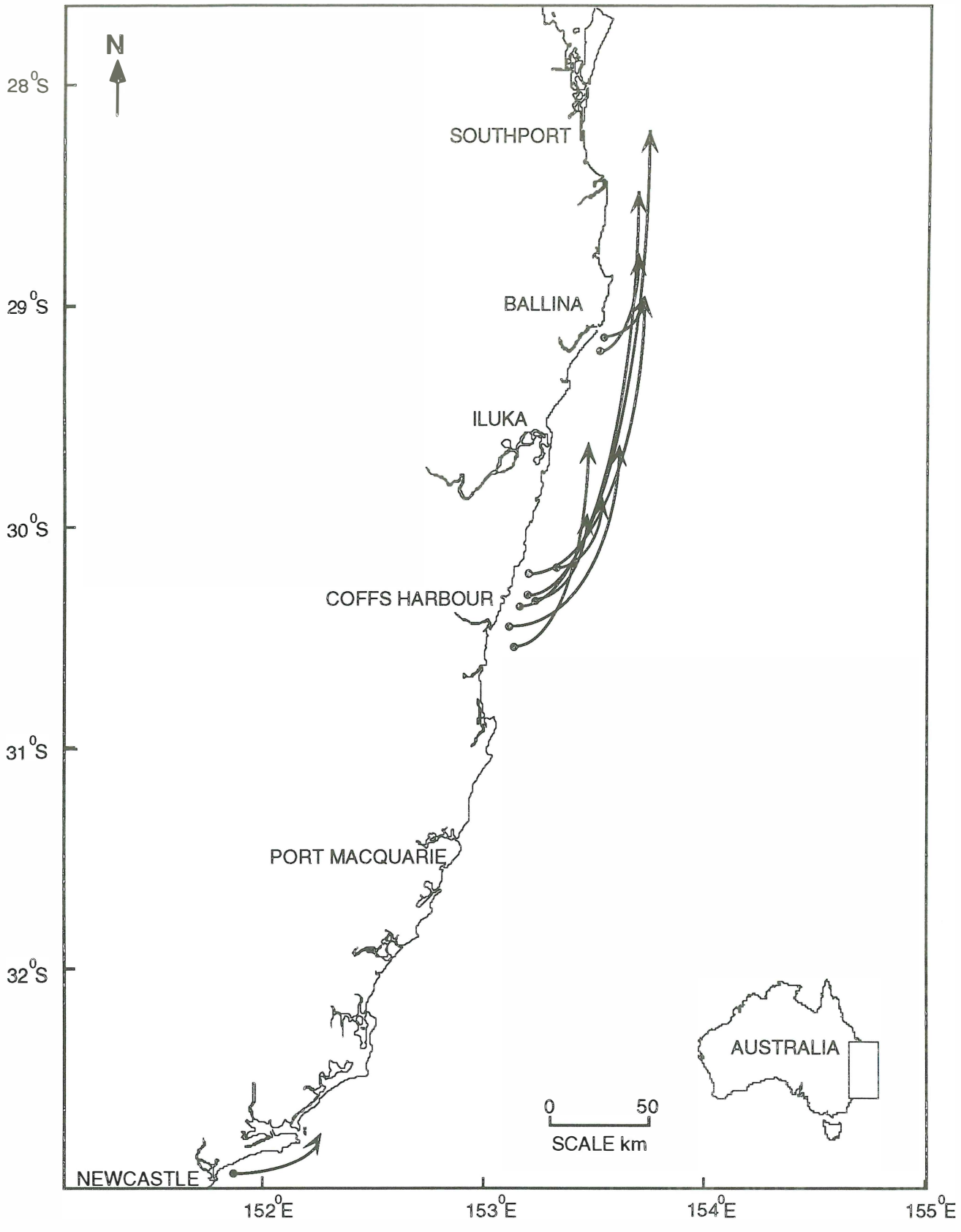

N
28°S
29°S
30°S
31°S
32°S
SOUTHPORT
BALLINA
ILUKA
COFFS HARBOUR
PORT MACQUARIE
NEWCASTLE
AUSTRALIA
0
50
SCALE km
152°E
153°E
154°E
155°E

Table 1. Numbers of Ibacus peronii and Ibacus sp. tagged and recaptured at each port.

PORT	No. Ibacus peronii tagged	No. Ibacus peronii recaptured	No. Ibacus sp. tagged	No. Ibacus sp. recaptured
Ballina	10	2 (20%)	190	19 (10%)
Coffs Harbour	1656	112 (6.8)%)	521	57 (10.9%)
Newcastle	218	9 (4.1%)	5	1 (20%)
Lakes Entrance	2008	259 (12.9%)	N/A	N/A
Total	3892	382 (9.8%)	716	77 (10.8%)

Table 2. Means, standard errors and ranges for time at liberty and distances moved for recaptured tagged Ibacus peronii from each port.

PORT	Time at liberty (days)			Distance moved (km)		
	mean	S.E.	range	mean	S.E.	range
Ballina	188.5	38.5	150 - 227	0	0	0
Coffs Harbour	151.5	10.6	2 - 468	0.25	0.13	0 to 11
Newcastle	357.8	29.4	172 - 497	0	0	0
Lakes Entrance	141	8.3	23 - 571	0.3	0.09	0 to 12.6
Total	144	6.8	2 - 571	0.28	0.07	0 to 12.6

Table 3. Means, standard errors and ranges for time at liberty, distances moved and rates of movement for recaptured tagged Ibacus sp. from each port.

PORT	Time at liberty (days)			Distance moved (km)			Rate of movement (km/day)		
	mean	S.E.	range	mean	S.E.	range	mean	S.E.	range
Ballina	126.2	32.7	4 - 359	6.5	3.4	0 - 26	0.02	0.01	0 - 0.19
Coffs Harbour	180.7	19.3	2 - 576	32	6.1	0 - 200	0.15	0.02	0 - 0.71
Newcastle	445	N/A	N/A	42.6	N/A	N/A	0.10	N/A	N/A
Total	171.2	16.9	2 - 576	27.6	4.8	0 - 200	0.13	0.02	0 - 0.71

APPENDIX F

Preliminary estimates of the growth of Balmain and Smooth Bugs

(1st DRAFT)

Preliminary estimates of the growth of Balmain and Smooth Bugs (1st draft)

Because tagged bugs are continuing to be returned by fishers in quite large numbers, the following contains only a preliminary analysis of the growth information collected so far. Rather than do complete analyses twice, we have decided to leave the full analysis of the tagging data until the tag return rate has declined to a low level. At that time, we will complete the full manuscript of this aspect of the work and provide copies to FRDC.

Introduction

Knowledge of the growth rates of crustaceans is important for an understanding of their population dynamics (Morgan 1980). Determining the growth rates of crustaceans poses special problems because of its discontinuous nature and the difficulty in ageing them. Growth can only occur during periods of moulting, or ecdysis, during which time all hard parts of the exoskeleton which may be used to age the animal are lost. Crustacean growth is therefore defined as a function of the size increment at each moult and the frequency of moulting, both of which can vary depending on the size and sex of the animal (for reviews see Aiken 1980 and Hartnoll, 1982). Despite the difficulties involved in estimating growth rates in crustaceans, the various techniques used to estimate growth in lobster-like animals have been widely documented (for reviews see Mauchline, 1977; Morgan, 1980; and Phillips et al., 1992).

One of the most important ways of studying growth is to examine the growth of tagged animals in the wild. The only absolute growth data available from recaptured tagged animals are the size at the time of tagging and the increment size over the period between tagging and recapture. Tagging studies need to assume that tagging does not influence growth, and that the tag is retained over a series of

moults when the exoskeleton is shed. Growth from tagging data is usually modelled using the von Bertalanffy growth curve (von Bertalanffy, 1938) where $y = L_{\infty}(1-e^{-kt})$. L_{∞} represents the maximum attainable size, k represents rate of growth and t is time or age.

Materials and Methods

Details of the tag/recapture study are described in detail in Appendix F which examines the movement data obtained from the tagging project. Data from recaptured tagged bugs provided information on moult increment and moult frequency. In this preliminary examination of the data obtained so far, we describe growth using the von Bertalanffy growth function as modified by Francis (1988). This technique provides the parameters K and L infinity for the Von Bertalanffy curve and also provides some estimation of growth variability between animals. The technique is available on the Fortran program GROTAG available from Francis (1988).

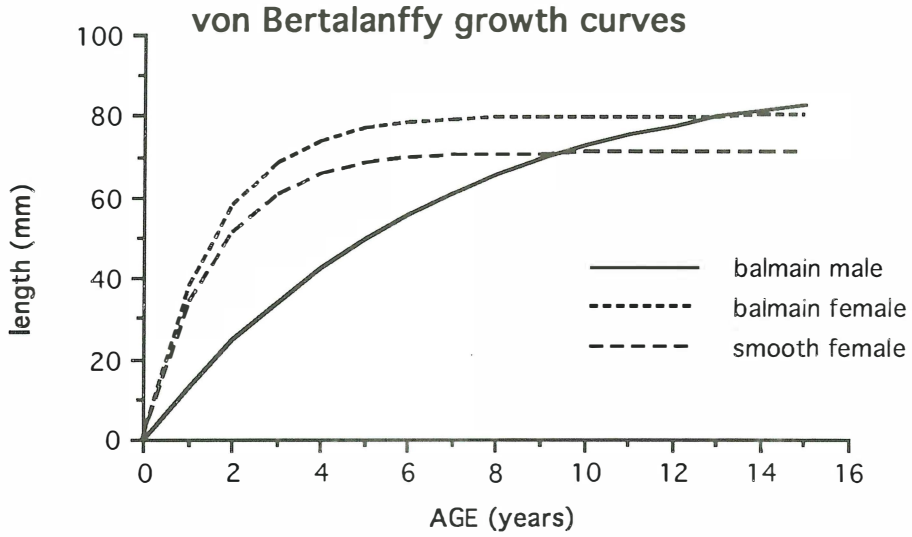
Results

Table 1 shows the values for K and L infinity that were derived from analysis of the available tag returns. There were insufficient data for even a preliminary analysis of the growth of male smooth bugs. Von Bertalanffy growth curves using the values in Table 1 are presented in Fig. 1. Females of both species showed similar growth rates whilst male Balmain Bugs grew much slower.

Table 1 - Summaries of results from GROTAG analyses of tagging data available thus far.

		L infinity	K
Balmain Bugs	Male	91.88	0.157
	Female	79.95	0.65
Smooth Bugs	Female	70.92	0.65
	Male	insufficient returns so far	

Fig. 1



Discussion

The preliminary analysis of the growth data from the tagging project shows marked similarity between females of both species. Male Balmain Bugs seem to grow much slower than females. The von Bertalanffy plots suggest that females may get to a sexually mature size (approx. 50mm CL) at about 2 years old whilst males may reach 50mm after 5 years. Unfortunately, these plots are very problematic because they are based on data from only a limited size range of

animals. Without growth data from younger bugs, the pattern of growth for bugs less than approx. 30mm will remain unknown.

It should also be remembered that the data analysed here is a only a first examination of a very incomplete data set. Each month many more tagged bugs are returned, a small proportion of which have successfully moulted. A thorough treatment of the growth of these species can only be made toward the end of the tag return phase of this project in one or two years.

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