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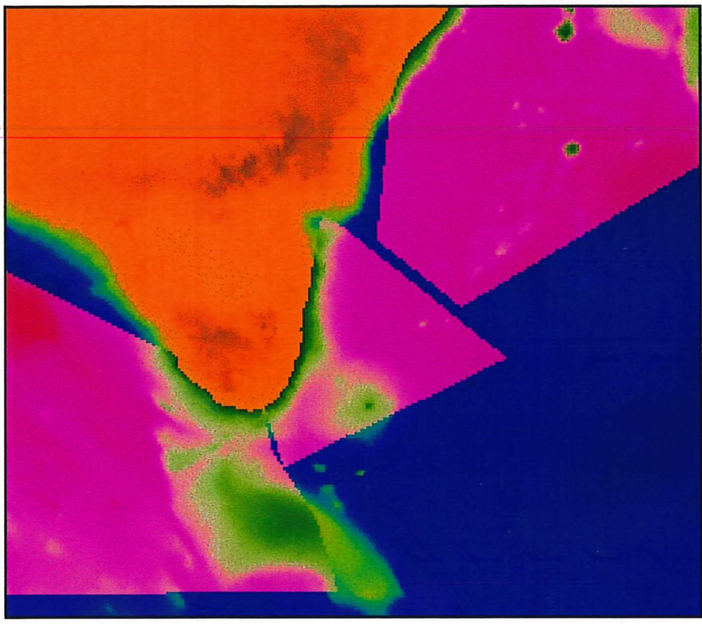

Quantitative Interpretation of Fine-Scale-Catch-Per-Unit-Effort for Southern Bluefin Tuna off South Eastern Australia

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CSIRO AUSTRALIA

MARINE RESEARCH

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project FRDC 93/077

NON TECHNICAL SUMMARY

93/077	**Quantitative Interpretation of Fine-scale Catch-Per-Unit-Effort for Southern Bluefin Tuna off South Eastern Australia**

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OBJECTIVES:

To conduct quantitative exploratory analyses of how catch rates of Southern Bluefin Tuna (SBT) are affected by environmental factors, such as temperature patterns and water depth, for the region south of Tasmania up to the southern half of New South Wales.

The selection of environmental factors is to be guided by analysing the collection of Observer Reports, from Australian observers placed aboard Japanese fishing vessels, to determine the environmental indicators and their importance in targeting operations and catch rates.

Variations of catch rates and size of SBT with time are to be assessed in relation to indices such as the Southern Oscillation Index (SOI) for regional changes in water masses, and in relation to local variations in the patterns of water mass distribution.

NON TECHNICAL SUMMARY:

An analysis of the historical data from the long-line Southern Bluefin Tuna (SBT) fishery off south eastern Australia was carried out to determine the temporal and spatial trends of catch-per-unit-effort (CPUE) in relation to environmental effects. Past studies of catch rates show that within a preferred temperature range, SBT aggregations are likely to be associated with meanders, frontal systems and upwellings. In addition in regions of topographic protrusions, aggregations are likely when these protrusions intercept seasonal migrations of the major frontal systems. Off SE Australia, the major frontal system associated with SBT catches is the Sub-Tropical Convergence Zone, a broad band of mixed subtropical and subantarctic waters extending from southern NSW to well south of Tasmania. A review of the Observer Reports indicated temperature as the top ranked fishing indicator with moon phase the next highest ranked indicator.

Off SE Australia, the preferred temperature ranges decreases proceeding from the north east to the south west sectors of the Tasmanian fishing zone. The range of 15.2 - 16.4^{0}C with an optimal value of 15.8^{0}C for the north east sector is not in disagreement with the much earlier observations of CSIRO researcher Hynd. Decreases of up to 2.6^{0}C are noted for the south west sector relative to the north east. There are two fishing seasons, a winter and a summer fishery, with larger fish being preferentially caught in the summer fishery off the southern and south-western sections.

Temporal trends indicate a sharp decline in the average weight of SBT caught, relative to other size classes, from 1989 up to 1995 with a slight increase in the median weight from 1991 to 1994; an alternate explanation is that the contribution of juvenile fish increased. Up to 1988 there was a range of small and large (>80 kg) fish being caught, however from 1989 onward, the catch of larger fish diminished. The last few years of the study period give no significant indication of the return of large fish as measured by their relative contribution to the catch histogram.

SBT caught for the spring/summer fishery also shows a decline in the contribution of larger fish to the total catch from 1991 onwards. Whilst small fish are found throughout the sector from south of Tasmania up to NSW, the distribution since 1989 shows a much more widespread and intense distribution of small fish particularly noticeable for the areas off south-eastern Tasmania. The distribution for 1994 and 1995 are less intense and in keeping with the lower intensity distributions of the 80's. In contrast, the distribution of large fish shows a distribution that is largely restricted to the region from south-west to south-eastern Tasmanian and the area off NSW.. Trends are difficult to discern but there is a suggestion that since 1989, the intensity of aggregations off NSW has been in continual decline - in contrast to the trend for the small fish. However there does not seem to be a clear general spatial pattern associated with this temporal trend.

Yearly trends in CPUE show an overall cyclical variation beginning in 1980. When examined with respect to the weight of SBT, the cyclical trend is not obvious in the different weight classes. The 50-75kg size category is the only one to shows recent increases but all the other classes show a declining trend. The hypothesis that the trends for the juvenile fish reflect downstream effects of the western surface fishery is not supported by the observed substantial decline in this size class throughout the 80's when the surface fishery was in decline. Nonetheless they may well be a downstream effect which needs to be analysed as part of a wider study.

The spatial distribution by weight class show remarkable clusters of larger fish at the two extremities of the study region with gradations of weight proceeding into the middle of the area. Streams of larger fish are noticed along the shelf-break and outer offshore regions. The observation of catches of large fish off NSW in winter is hypothesised to be due to the increased productivity associated with the deep stirring of cooler waters by energetic eddies which is targeted by the large fish which migrate in the deep cooler waters up to that region.

Statistically, distributions of CPUE do not appear to be enhanced with moonphase although there is greater concentration of effort following the new moon and just before full moon with consequently greater overall catches during these periods of intensified effort. However mean values of CPUE, and average weights, do show a trend with highest catches occurring at the full moon phase, particularly the waxing phase. Whilst these increases are relatively small, they imply that such statistics as the mean are biased by an increase in the outliers of high catch rates during the full moon phase. This is interpreted as being due to an enhanced aggregation of larger fish during the full moon phase.

Yearly catch rates, and average weights, of SBT off eastern and southern Tasmania do appear to relate to the Southern Oscillation Index. Warm phases of SOI, when the index is negative and conditions off eastern Australia are relatively cool, are accompanied by increase catch rates and smaller fish, and vice-versa for the cool phase of SOI.

A variety of measures of the spatial structure of the environment were calculated from the satellite images of SST. Of these, the spatial structure, as measured by the principal angle of correlation, was influenced by the extent of warm, or cold, water masses in the regions. Significant correlation was also noted between the extent of warm/cold water masses (as measured by the median temperature) and the coherence of the spatial structure. The lack of significant correlation between CPUE for small SBT (under 25kg weight average) and the spatial structure variables, as opposed to some significant correlation with the variance of CPUE, indicates that the relative success, or otherwise, of catch rates are more *consistently* related to some environmental factors. The corollary inference is that variations of CPUE, at least for the years analysed (1990-1995) are influenced by factors other than those environmental factors used, or by other intrinsic variations occurring outside the fishing zone analysed.

In conclusion, there are substantial temporal and spatial variations in CPUE as well as the size of SBT. Of these variations, spatial temperature variations in the study zone, in association with bathymetry, appear to influence the general spatial distribution of CPUE and size of SBT. Catch rates and size of SBT off eastern and southern Tasmania are significantly correlated with the Southern Oscillation Index (SOI), opening the possibility of predicting catch rates through forecasts of the SOI index. A wider study examining the downstream effects of the western surface fishery off WA and SA is recommended to examine the impacts of regional variations in fishing activities. There is a noticeable increase in catch rates with full moon, particularly the waxing phase. Overall, the changes in mean catch rates with moonphase are small and reflect a bias by outliers of large catch rates which are inferred as being due to enhanced aggregations during full moon. Observations of large SBT in the northern section of the fishing zone appear to be related to the unique energetic oceanic conditions off southern NSW. However temporal variation in CPUE from 1990-1995 do not appear to be significantly correlated with the chosen environmental factors although the variance of CPUE is correlated to the extent of warm/cold water masses. The consistency of CPUE, rather than CPUE itself, appears to be more strongly influenced by local environmental factors.

1. Table of Contents

2. Abstract

An analysis of spatial and temporal variations in catch rates of Southern Bluefin Tuna (SBT) in relation to environmental factors was conducted for the region south of Tasmania up to the southern half of New South Wales. Substantial temporal and spatial variations were evident in catch-per-unit-effort (CPUE) as well as the size of SBT and attempts were made to relate these to environmental influences. Of these variations, spatial temperature variations in the study zone, in association with bathymetry, appear to influence the general spatial distribution of CPUE and size of SBT. Catch rates and size of SBT off eastern and southern Tasmania are significantly correlated with the Southern Oscillation Index (SOI), opening the possibility of predicting catch rates through forecasts of the SOI index. A wider study examining the downstream effects of the western surface fishery off WA and SA is recommended to examine the impacts of regional variations in fishing activities. There is a noticeable increase in the mean value of catch rates with full moon, particularly the waxing phase. Overall, the changes in mean catch rates with moonphase are small and reflect a bias by outliers of large catch rates which are inferred as being due to enhanced aggregations during full moon. Observations of large SBT in the northern section of the fishing zone appear to be related to the unique energetic oceanic conditions off southern NSW. Temporal variation in CPUE from 1990-1995 do not appear to be significantly correlated with the chosen environmental factors although the variance of CPUE is correlated to the extent of warm/cold water masses. The consistency of CPUE, rather than CPUE itself, appears to be more strongly influenced by local environmental factors.

Overall, the effect of environmental factors is scale-dependent; at scales involving regional variations in water masses, SOI-related effects are significant whilst at smaller scales, the structure of the water mass influences the consistency or otherwise of catch rates. The corollary inference is that variations of CPUE, at least for the years analysed (1990-1995) are influenced by factors other than those environmental factors used, or by other intrinsic variations occurring outside the fishing zone analysed.

3. Introduction

A critical aspect of current international interest in stock levels of southern bluefin tuna (SBT) concerns the interpretation of spatial and temporal changes in the distribution of various age classes. The interest is spurred by the expectation of a recovery with the international quota controls introduced since 1983 (Caton, 1991) and the subsequent reduction in the Australian purse-seine fishery. However the evidence of such a recovery, on a global scale, is masked by indications of more effective spatial targeting by the high-seas fleet in recent years (Campbell and Tuck 1996), compounded by the substantial interannual, and seasonal, variability in spatial distribution and intensity of aggregations of SBT in their feeding grounds (Campbell et al., 1996, Tuck et al., 1996).

On a global scale, trends of catch-per-unit-effort (measured as the number of tuna caught per 1000 hooks) show tantalising increases for certain fishing areas, the most notable of which is the feeding area comprising the Tasmanian fishing grounds. Here, the CPUE trend for young fish showed a promising increase which peaked in 1993 but has since declined. Part of the decline may well be due to the substantial increase in effort off this area for the same period but an alternate explanation, which is equally plausible in the absence of supporting analyses, is that the recent decline is due to natural environmentally-induced variations.

This report examines the trend and spatial distribution of catch rates of SBT off SE Australia with a view to interpreting the influence of environmental factors. The problem is one of disentangling environmental factors from a host of other factors. Foremost amongst these are the changes induced by fishing activities both locally and globally which induce depletion of stock levels, changes in the relative composition of different age classes, potential alterations in the local ecosystem composition (preys and predators) and density-dependent activities (such as feeding success, growth and social/schooling aggregations). Recent scientific analyses submitted as part of the scientific deliberations of the Trilateral negotiations show evidence for the alteration in growth parameters which has significant implications on estimates of parental biomass (eg Hearn and Polacheck, 1993). Our concern here is primarily with catch rates and their interpretation.

With the multiplicity of factors that need to be considered, the approach adopted here is what is termed *Exploratory Data Analysis* or EDA. The emphasis is on graphical display of potential associations using a variety of datasets and analyses. This phase is a precursor to the development of models guided by the understanding, and insights into, processes gained from EDA. Subsequent stages involve predictive studies to verify the process understanding incorporated in the models. We primarily limit ourselves here to the EDA phase but note that other projects such as the SeaWiFS fisheries oceanography project being conducted by a number of organisations (unpublished FRDC proposal) will attempt to make progress to the predictive stage.

4. Background

The role of environmental factors on pelagic fisheries has been the subject of considerable interest and study for much of the latter half of this century. The impact of the so-called El-Nino induced changes in upwelling off the Peruvian coast on the sardine and other associated marine resources is the best known example. Massive changes in upwelling caused by coupled trans-Pacific changes in atmosphere-ocean interactions cause direct and large-scale impacts on the Peruvian fisheries. On lesser scales, the effects of upwellings on a range of pelagic fisheries (discussed below) suggests direct links between upwelling, nutrient input to the photic zone, primary production and small pelagics. It is however fair to say that the role of environmental factors on larger pelagics has not been well documented.

Yamanaka (1978), in reviewing the work of Japanese scientists summarises two streams of research on tunas: 1) The "current system theory" in which the life cycle of tuna at various stages in its ecology are linked to special current systems, and 2) The theory that tuna aggregate in regions of upwelling and/or frontal systems with enhanced primary production. Yamanaka (1978) summarised the state of the work at that time by saying that much progress has not been made in the difficult task of studying the relationship between environmental factors and stock size. However, for fisheries operations, the frontal theory had much to offer if better facilities for the dissemination of satellite imagery were developed.

The extensive experience of Japanese longline skippers combined with the detailed historical data contained in logbooks submitted to Japanese research organisations have allowed Japanese researchers to gain valuable insights into environmental effects on local distributions. Warashina et al (1989) summarise much of this understanding in detailing two hypotheses based on examinations of sea surface temperature, bottom topographic data and logbook data. The two hypotheses are:

1. Seamounts, plateaus and other topographic structure provide regions of aggregation when they intercept the seasonal migration of major frontal systems such as the subtropical convergence zone.

2. In areas of strong boundary current regimes such as the Agulhas Current, productive zones (in terms of primary productivity) formed from meanders or frontal systems, associated with the boundary current, provide sites of aggregation of SBT.

Reports by Australian Observers aboard longline vessels indicate that off South Africa abnormally cold conditions will inhibit the appearance of fish normally found in a region. Thus whilst the presence of topographic structures or frontal systems provide sites for aggregation, a prerequisite for the appearance of SBT is water temperatures within a suitable range associated with the fish. Whilst these observations by the Japanese researchers provide valuable insights into the spatial dynamics of SBT, Warashina et al (1989) summarise the state of research, and the necessary future research, by hypothesising that higher primary production may be associated with the dynamic meanders of boundary currents and detailed study of this hypothesis using satellite ocean colour data was required; biological factors of size and maturity and availability of food organisms were also suggested as worthy of future research.

A number of studies of other pelagic species also highlight the role of oceanographic features in inducing aggregations. Off Chile, thermal fronts and upwellings are postulated to provide aggregation sites for albacore (Barbieri et al 1989), and small pelagic species (Castillo et al 1996). Concentration of salmon fishing effort around topographic features and thermal boundaries off Vancouver Is. Canada (Borstad et al 1989). A number of other studies also show that good fishing areas for a range of pelagic fish such as skipjack tuna, yellowfin tuna and albacore are located near thermal fronts and upwellings (Laurs & Lynn, 1977, Breaker, 1983, Laurs, Fielder & Montgomery, 1984, Maul et al. 1984, Fielder, Smith & Laurs, 1985, Fielder & Bernard, 1987, Ramos et al. 1996). For skipjack tuna (*Katsuwonus Pelamus),* Barkley et at (1978) use laboratories studies to infer that small skipjack tuna are able to inhabit the warm surface waters of the tropical and subtropical ocean but larger skipjack fish require cooler waters with unusually higher concentrations of dissolved oxygen.

Much of the early Australian work on environmental effects on SBT off eastern Australia was initiated by Hynd (1968) who trialed the use of airborne infra-red radiation mapping in assisting fisheries operations. This work was initiated in response to observations by fishermen that off NSW SBT aggregated in frontal regions where the surface temperature ranged from 16.7 to 20°C. Preliminary trials with the instrument successfully identified frontal areas in the preferred temperature range where SBT were subsequently caught. The mapping program, whilst relatively crude (30nm transect separations) was capable of identifying frontal regions as well as movements of the major water masses. The chronology of SBT movement off NSW, according to Hynd (1968) is that at the start of the season around August - September, SBT travel from the south till they reach the 17°C isotherm. This isotherm was usually located near Jervis Bay at that time of the year. Once the SBT reach this isotherm they form rippling schools but whilst travelling up from the south they occur as small feeding schools. The most productive fronts were suggested as being in the range 18-19°C. The southward progression of the 21°C isotherm signified the end of the fishing season for SBT but Hynd did not provide an indication when this was likely to occur. The mapping program showed major changes in water masses, due to upwelling and intense currents, taking place within a period of days, and that mapping at half-monthly intervals was not adequate to track such events.

The mapping program continued in 1968 (Hynd, 1969) and confirmed the findings of the previous year. Most catches were in the vicinity of fronts and generally in the "blue water" side of the front rather than the "dirty" or "green water" side. Hynd (1969) also made the observation that whilst fronts visible to the spotters may not always be accompanied by temperature changes, fronts separating waters of distinct colour change were associated with temperature fronts. The temperature maps were estimated to increase the fishing efficiency by 15 - 20% and to reduce search costs by 20%.

A key aspect of the distribution of SBT off NSW became apparent during the 1973 - 74 when catch rates of young fish (2+ & 3+ year olds) declined dramatically compared to the late 60's and 71 - 72. Hynd (1974) shows that the waters off NSW were several degrees warmer compared to previous seasons and above the level at which young fish are generally caught (about 20°C) in schools. Aerial spotting and airborne mapping further offshore (up to 110nm compared to the usual limit of 40-50nm) identified larger fish (4+ - 8+ year olds). Rochford (1981) in a later analysis shows that the anomalous conditions are associated with anomalously high temperatures in the north-eastern Coral Sea in preceding years. Using total catch as an index of abundance, Rochford (1981) shows a possible correlation between the warm years of 1970, 1973 and 1976 and low total catches of SBT off NSW. These three years were all associated with prior warming events in the Coral Sea suggesting possible advection of anomalies from the Coral Sea. Rochford (1981) proposes retention of the anomalous waters in anticyclonic warm core eddies and their slow propagation (one year or more) from an origin in the Coral Sea as the likely mechanism to explain the persistence of the NSW anomalies (In a later publication, Rochford (1983), suggests that the warm core eddies have their origin solely within the waters of the East Australian Current - this is more in keeping with current understanding of the eddy dynamics.). Rochford (1981) also identified a gradual warming over the period 1966-1977 of about 3°C which is not in disagreement with the observed long-term decline of catches off NSW over the same period. Edwards (1979) also provides some evidence of the long-term warming trend observed by Rochford (1981).

Whilst the datasets we present analyses for do not extend back to the 60's and 70's, the studies by Hynd and Rochford provide some evidence, or at the very least, testable hypotheses for the effect of environmental factors on the abundance, or perhaps catchability, of SBT off NSW. Given the lack of an Australian fishery off Tasmania for the corresponding period, there are no corresponding studies of the environmental effects on catch rates of SBT for that region.

In summary, most studies are unanimous that pelagic fish all have a preferred range of temperature (with the range differing depending on the age of the fish), with a suggestion for at least one species that dissolved oxygen may also present constraints for the adults of the species. Within the preferred temperature range, aggregations of fish are likely to be associated with meanders, frontal systems and upwellings. In addition in regions of topographic protrusions, aggregations are likely when these protrusions intercept seasonal migrations of the major frontal systems.

Given the comparative lack of research on the Tasmanian sector of the SBT fishery, the initial plan was to review the available detailed Observer reports on fishing activities compiled by the AFZ (Australian Fisheries Zone) Observers placed aboard selected Japanese longline vessels operating in the Australian EEZ. These reports up to those submitted for the 1995 field year were collated and analysed by Mr Russell Bradford of CSIRO whose full report is included in Sections 5 and 14. The results of that report along with the review of the literature presented above were then used to guide the subsequent analysis of the logbook data. Results of these analyses form the principal conclusions of this study.

5. Information from Observer Reports

Under the principals embodied in the United Nations Conventions on the Law of the Sea, Australia may authorise access by foreign fishing interests to fishing resources which are under-utilised by the domestic industry. This convention is the basis for Australia's jurisdiction of the 200 mile Australian Fishing Zone (AFZ).

Two agreements exist allowing foreign fishing vessels access to the tuna fishery. The first is a bilateral agreement between the Commonwealth of Australia and the Government of Japan which is based on access fees. A global limit of 11,750 t on the catch of SBT was set for 1993 through trilateral negotiations between Australia, Japan and New Zealand. Under the Bilateral agreement, a maximum of 250 Japanese vessels are allowed to fish the Japanese quota of 6,065 t (1991/92) of SBT in the Australian Fishing Zone. In 1991, area restrictions were in force allowing a maximum of 60 vessels off the east coast of Australia at any one time, 50 in the area off the west coast, and 24 off the coast of Tasmania. Time and quota restrictions are also enforced on fishing within the Tasmanian sector.

The second agreement is a joint venture agreement between the Tuna Longline Development Co-operation Pty Ltd and the Australian government. Under this agreement a total of 21 Japanese vessels (1991) are allowed access to the south-east region of the AFZ for SBT during specified times. As a condition of these agreements, vessels are required to allow observers on board to monitor compliance with the restrictions on fishing within the Australian Fishing Zone.

The Australian Fisheries Management Authority (AFMA) runs the Observer Program in consultation with state fisheries departments and relevant research organisations such as CSIRO Division of Fisheries and Bureau of Rural Resources (BRR). Both the CSIRO and BRR provide specific advice and requests on the scientific data to be collected depending on the immediate and long-term priorities of the program. The broad objectives of the Observer Program are:

1. *Monitor compliance of vessels with their fishing agreements.*
2. *Collect vessel activity and catch data which is not normally obtainable through logbook data.*
3. *Collect data for research programs supporting good fisheries management and for other agencies, relevant to environmental awareness and management.*
4. *Collect information on gear used on the vessels or innovative techniques used to target commercial fish.*

The majority of the fishing masters employed by the Joint Venture vessels have been fishing for SBT for several years. The techniques they use to target the fish have been gained through experience and by consultation with other fishing masters. Therefore, some of the targeting practices are intuitive to the fishing masters and do not easily lend themselves to categorisation. For this reason the interpretation of the data within the Observer's reports are subjective and may not necessarily be the intended meaning of the observer. Full debriefing of the observers would aid in extracting a more concise understanding of the targeting practices, as well as a full appreciation of the knowledge passed on by the fishing masters.

This report aims to consolidate and summarise the data on southern bluefin tuna targeting practices by Japanese longline vessels as outlined in the AFMA Observer reports and AFMA summaries of those reports. The focus has been restricted to Japanese longline activity in the Tasmanian sector of the AFZ (Area G).

The Tasmanian SBT fishing season occurs in two distinct periods, the Tasmanian summer season (TSS) ranges from November to January of the following year; the Tasmanian winter season (TWS) falls between May and July of the same year. The winter season is the most important, with fish of a higher fat content (i.e. more valuable) being caught at this time of year. A higher fat content has been related to fish caught in cooler waters. However the role temperature may play in raising fat content may be due to other temperature-related factors; for example, differences in prey items. The Tasmanian SBT fishery is centred along the east coast, with some fishing to the south-west of the state (Fig. 1). The majority of fishing occurs within the area enclosed by latitude 42°00'S to 44°00'S and longitude 148°00'E to 151°00'E.

5.1. Gear Details:

5.1.1. Mainline length

The average length of mainline set was 128.56 km. However, this length varied dramatically between boats, ranging from 60 km to 210 km. The length of the mainline does not appear to vary with the area being fished. It is quite common though for the fishing master to vary the length of the longline from day to day and depending on the weather conditions. A shortened line is often used, during severe weather or in areas prone to strong currents, in an effort to reduce the amount of tangling and/or breakage.

5.1.2. Number of branchlines

Six snoods, or branchlines, per basket was the trend for targeting SBT, however there was some variation, with the number of hooks varying between 5 and 7. The number of snoods was occasionally increased in bad weather, to make up for the loss in total number of hooks due to shortening of the mainline. Note was also made of one vessel which decreased the number of snoods in bad weather.

5.1.3. Snood length (branchline)

Snood length was quite variable throughout the JV fleet; the average length was 36.3m. There was a trend towards longer snoods being used the further south a vessel fished, however, the trend was very weak. Summary report AA93(1) (see Section 14) noted an approximately 10m difference in the average length of the snood between the TWS and TSS, 33.5m and 42.5m, respectively. Snood length did vary within baskets on the same longline, although the normal set-up was for snoods of equal length or for two to three different lengths. Putting longer snoods on the first and last hook placing would reduce the overall depth range that the basket was fishing. Many fishing masters set the first and last hooks slightly shallower in order to target shark.

5.1.4. Line setting and hauling

The timing of setting and hauling was highly variable. However, if conditions were good the majority of the setting and hauling took place at approximately 0430 and 1415 h respectively. Setting could occur at any time between 0100 - 1200 h depending on the speed of hauling from the previous night. Line breakages and tangles have the potential to extend the hauling period over 24 hours.

The direction of setting was almost always in a north-south or south-north direction. During the peak times of the season the vessels would be setting their lines within three nautical miles of each other. The high density of vessels restricted the amount of leeway to set the lines in a more random fashion. Towards the end of the season, though, the vessels would disperse in search of better fishing grounds. This resulted in an increase in the number of setting occurring in an "L"-shape.

The duration of line setting was approximately 5 - 6h at a speed of about 10 knots. Whereas hauling could take anywhere between 9 to 14 h depending on the number of tangles, breakages and fish caught. Hauling was generally done at a speed of 2 to 5 knots.

5.1.5. Soak time

Soak time, the time from the finish of line setting to the start of hauling, was fairly consistent between the three zones shown in figure 1, averaging 4.5 h. To some extent soak time is dependant on the length of the longline and whether hauling begins where setting finishes. The majority of JV vessels began their hauling with the last hook put in the water. Therefore, the first hooks brought up have had the shortest soak time. Note was made in one report (east coast Australia, not Tasmania) that tuna being hauled aboard dead (i.e. were caught at the time of setting) had preferred squid bait, while those fish hauled onboard alive (i.e. caught during hauling) had preferred mackerel bait. This report also noted that the fresher the bait the better.

5.1.6. Min/max hook depth

The depth at which the hooks fished was also highly variable, ranging between 67.8 - 124.5m. The majority of reports indicated no set reasoning which dictated the positioning of hooks in the water column. However, several reports mentioned that the fishing master would try to position the hooks at the bottom of the plankton layer occurring at the top thermocline. Additionally, there was a trend in the south western sector for hooks one and six to be set deeper (91 m) cf those in the south eastern sector (60 m).

5.1.7. Bait Species:

The bait species most often in use in the Tasmanian sector of the AFZ were squid, jack mackerel, horse mackerel, and pilchard in order of importance. Squid were most often put on the hooks fishing the shallowest depths. Bait was generally alternated, very few vessels baited all the hooks with the same species. Artificial lures, mainly squid, were used on some vessels with varying degrees of success. Several fishing masters used a small luminous bead or other similar fish attractant immediately above the baited hooks. In general, artificial lures were thought to be more expensive and not as successful as fresh bait.

5.2. Indicator Rankings:

The AFMA Observer reports list a number of indicators used by the fishing master to target southern bluefin tuna. These indicators are given a ranking, in order of importance, by the observer based on discussions with the fishing master. Table 1 contains the averaged ranking for each indicator. Not all indicators are used by every fishing master; in addition, targeting of SBT off the east coast of Tasmania is limited by the space allocated to each vessel, thereby reducing the importance of the indicators. A discussion of the use of each of the indicators follows.

5.2.1. Sea surface temperature

Sea surface temperature was the most important indicator of a good fishing zone. The overall ranking for this indicator was 1.1 (n = 40). Temperatures on average ranged between 13.7 and 15.4°C. The optimum temperature for each particular region with the range of temperatures reported is given in Table 1. The optimum temperatures given by the fishing masters varied greatly, however the most important temperature-dependant feature was to find a temperature gradient. Many reports stated that the fishing master would attempt to locate a warm core eddy which was partially isolated in colder waters. The mainline was then set in a way which maximised the number of hooks along the gradient between the two different water masses.

• Table 5-1 Averaged rank of each target indicator outlined in the AFMA Observer reports.

Indicator	Averaged Ranking	n
sea surface temperature	1.1	40
moon phase	2.2	26
currents and eddies	2.7	21
"other"	2.8	15
upwelling	3.8	12
baitfish	4.2	18
bottom topography	4.5	13
whales and dolphins	4.7	13
birdlife	5.2	13

5.2.2. Moon Phase

The couple of days leading up to and following the full moon were considered the best times for catching SBT and many other species. The moon also played a part in determining the depth to which the hooks would be targeting (i.e. higher up in the water column during a full moon) and the best time at which to set the line (set somewhat earlier during a full moon so that the hooks are in the water at peak feeding times).

5.2.3. Currents/Eddies

Currents/eddies ranked 2.7 in importance. In addition to the comments regarding bottom topography, currents can dictate in which direction to set the mainline. For example, setting parallel to the currents would often result in tangles. Eddies appear to be a sought after phenomenon by many of the fishing masters; note was made by some of the observers that eddies which have just recently formed (i.e. well defined) were the preferred type. However, Nigel Brothers indicated that a transition zone with an angle of approximately 45° is optimal - steeper transition zones can be areas of high current.

5.2.4. Other

The 'other' category ranked fourth overall (2.8) in importance. Indicators which are included in 'other' are: previous history (supplied either through the company head office, or from the fishing master's own records of past fishing expeditions in the area) and advice from other fishing masters. The fishing masters rely heavily on these indicators because the density of vessels working in the one area restricts the amount of free movement the vessels have in order to locate a good fishing area. Within the north east and the south west sectors there was generally more room to search for the tuna. In these areas the importance of historical records decreased, while the importance of temperature related factors increased. However, the Japanese fishing masters work very much as a team and are constantly in contact with one another. It is not uncommon for a boat to locate a good area then call other boats to the area. This results in the original boat having little room to manoeuvre when the other boats arrive. One report mentioned that the fishing masters felt that if a good area was located they should saturate the area with hooks and bait to simulate an area of high productivity, aiming to attract other fish to the area.

• Table 5-2 Average temperature range and the optimum temperature for the sectors of the Tasmanian fishing zone.

	Temperature range °C		
Zone	Minimum (n)	Maximum (n)	Optimum
North-East	15.2 (5)	16.4 (6)	15.8
South-East	13.6 (9)	15.8 (9)	14.7
South-West	12.6 (5)	14.2 (5)	13.4

5.2.5. Upwelling

Areas of upwelling are traditionally thought to be productive waters. The increased productivity of upwelling waters and their influence on currents and eddies would appear to indicate profitable fishing grounds. Upwelling, however, was not a particularly sought after feature of the water column by many of the fishing masters.

5.2.6. Baitfish

Baitfish ranked 4.2 in importance. Concentrations of baitfish and/or plankton are a sign of a productive area. Although this indicator did not rank very high in comparison to sea surface temperature and 'other' it was considered an important characteristic. Some of the fishing masters would stay in an area where baitfish/plankton were concentrated even though the present catch rate was low, feeling that the fish would eventually come to that area. The depth at which baitfish and plankton were located on the sonar would indicate to which depth the hooks should be fishing.

In addition to baitfish some reports indicated that the fishing master considered sighting flying fish a good sign.

5.2.7. Bottom topography

Although bottom topography did not rank very highly (4.5) on the list of indicators it was considered an important feature to take note of. Bottom topography would, indirectly, influence the direction of line setting through its effects on the direction and strength of currents. Sea floor ridges may also produce areas of local upwelling.

5.2.8. Whales/Dolphins

Whales/dolphins averaged to 4.7 in importance. Good and bad comments were made with regards to whales. Killer whales were generally regarded as bad due to their habit of eating the hooked fish and also of rounding the fish up into a relatively small area. Other whales, though, were often thought of as a sign of a productive area. Dolphins were also a sign of a productive area although they were not regarded as either a good or a bad sign.

5.2.9. Birdlife

The presence of absence of birdlife did not attract many comments in the AFMA Observer reports with regards to their importance as an indicator of a productive SBT fishing ground. Several observers, however, did note that small black birds were considered a bad sign, while small white birds and albatross were a good sign.

5.3. Conclusions

Based on the intelligence presented in the AFMA Observer reports there appears to be little difference in fishing gear between Joint Venture fishing vessels. The gear set-up was conservative with few novel or innovative techniques being employed. Lures were used by some vessels, however, the limited success and high cost of artificial lures does not make them an attractive alternative to fresh bait at this point in time. The most important feature of the fishing gear was its quality and level of maintenance. Good quality gear which was well maintained was less prone to breakages; thus reducing the amount of time spent searching for lost line.

Indicators could be divided into three groups based on their averaged ranking. Sea surface temperature was placed in a group by itself. The importance of this indicator to the targeting of SBT cannot be overlooked. Even in the highly restricted fishing conditions of the east coast of Tasmania, temperature was used to locate the areas of highest anticipated yield. Ocean fronts with their associated temperature gradient were regarded as the most productive areas in which to set the mainline.

The second group of indicators consisted of moon phase, currents/eddies and “other”. The importance of each varied according to the local conditions. However, past experience and the collective knowledge of the fishing masters may be under-estimated in the ranking process. For instance, some reports note that fishing masters searched for isolated warm core eddies which were viewed as providing favourable fishing conditions along the edge of the eddy - a feature noted by Young and Lyne (1993) for the long-lived EAC eddy which propagated down the Tasmanian coast in 1991. Repeated reference was made by the observers to the high degree of communication between the fishing masters on the fishing grounds. This indicator may be central to the success of the Joint Venture vessels.

The low rating of bottom topography is surprisingly but this could also reflect the fact that the position of front and eddies may be strongly coupled to bottom topography and hence that the surface temperature patterns are relatively fixed (we shall return to this point later in the report). The enhancement of catches near the full moon phase is an accepted feature of this fishery although no commonly accepted explanation of the phenomenon is available.

The preferred temperature ranges shows decreases in the "optimal" temperature and temperature ranges proceeding from the north-east to the south-west sectors of the Tasmanian fishing zone. The range of 15.2 - 16.4 with an optimal value of 15.8^{0}C for the north east sector is not in disagreement with the much earlier observations of Hynd. Decreases of up to 2.6^{0}C are noted for the south west sector relative to the north east. This is a significant finding to which we will return to later in the report.

Other noteworthy features of this fishery are the two fishing seasons, a winter and a summer fishery, with larger fish (including what are termed jumbos) being preferentially caught in the summer fishery off the southern and south-western sections.

6. Databases Used in Analyses

The database compiled on SBT is arguably one of the most comprehensive available for any pelagic fish (Betlehem and Preece, FRDC report in press). The database includes logbook records for vessels operating in the AFZ which are lodged with the Australian Fisheries Management Authority. CSIRO has procured this database and maintains a copy in an Oracle database at its Hobart laboratories. This database is regularly updated at the end of each fishing season. The analyses reported here concentrate on the logbook records from 1979, when the Australian Fishing Zone was declared, to 1995. (It became apparent during the analysis that the records for 1995 may not have been complete and thus the analyses for 1995 must be interpreted cautiously).

We used the reported noon time position as the location for the catch, thus there is an uncertainty in our analyses of the precise location of individual catches due to the long spatial scale of the longline sets (>100 km). In computing the average weight of SBT for each catch record only those records for which non-zero catch numbers and non-zero catch weights were recorded were used. As discussed in a later section, the relative portion of these zero catch records varies with latitude because other species of fish are caught.

The attributes of the catch record used comprised: the day, month, year, longitude, latitude, number of SBT caught, total weight of SBT caught, total number of fish caught (of all species) and number of hooks used. Derived attributes computed included the average weight of SBT caught (= total weight of SBT caught/number of SBT caught) and CPUE as number of SBT caught per 1000 hooks.

6.1. Sea-surface temperature data

Sea-surface temperature data were obtained from the archive at the Remote Sensing Facility at the CSIRO Marine Laboratories. These data processed by Rathbone and Parslow (1997) used composites of images over a 15 day period filtered with a histogram filter designed to eliminate cloud and to select a reasonable maximum temperature. Images were produced every 5 days using the 15 day filter window. The list of images so computed are listed in Section 15.

Each image occupies a longitude range from 140 to 159.5^{0}E and a latitude range from 32.5 to 50°S. The image resolution was 0.04 degrees in longitude and latitude (roughly 4.8km in north-south range)

The files were manipulated to convert from the image format to a geographical format. This allowed the catch data to be registered to the closest (in time) image which then allowed a temperature valued to be assigned to the noon-time position of the catch record. Note that since the images are composited and filtered, the assigned values are not precise estimates of the temperature at the reported catch position or time (neither is the catch position for that matter as discussed before). However, they do represent a value that can be interpreted as being a value filtered in time (over 15 days) and space (to the nearest pixel).

6.2. Southern Oscillation Index

Time-series of monthly values of the normalised Southern Oscillation Index (SOI) were obtained from the archive at the NOAA Climate Prediction Center. The index is based on the standardised Tahiti-Darwin sea-level pressure difference. Anomalies are computed as departures from the 1950 - 1980 base period. To compute the index, departures of the monthly sealevels from the mean over the base period are calculated. These departures are then normalised, or standardised, by their respective standard deviations (computed over all months). The standard deviation of the difference in standardised sealevel pressures is used to normalise the difference in standardised sealevel pressures between the two sites.

6.3. Bathymetry

Bathymetric data for the analyses were obtained from the ETOPO5 dataset. This is a 5 minute grided field of elevations and ocean depths, produced in 1986 by the National Geographic Data Center, using a variety of sources. Past experience with the data suggests that it may be inaccurate for shelf waters. This is not a particular problem for our analyses which are mainly for waters offshore of the shelf-break.

As with the SST images, the locations of the catch records were positioned onto the bathymetric data layer to determine a relevant depth for each record.

The GEBCO (General Bathymetric Chart of the Oceans) contour line for the 200m isobath was also used to compute the distance of catch locations from the shelf-break.

7. General Distributions and Trends

In this section we examine the distribution of fishing effort (here effort is taken to correspond to catch records or number of fishing operations; this should reflect the number of hooks set as number of hooks/set should be similar) spatially and by season.

7.1. Effort Distribution

The extent and intensity of fishing effort in the region (Figure 7-1) shows a number of characteristic features:

1. The highest concentration of effort located in the continental slope region of the south-eastern sector and extending slightly north-eastward.

2. This region of intense effort is very narrow and somewhat restricted in comparison to the expansive areas of effort to the west and the far north east.

3. A remarkable rectangular region of effort located just to the west of the intensely-fished zone. Apparent isolated points of high effort within this region are due to the reporting of location to the nearest integer latitude and longitude.

4. The eastern region off Tasmania is limited in its northward extent to about 40^0S and is disconnected from the north-eastern region.

5. The north-eastern region (north of 40^0S) shows some effort in the area supposedly closed to the Japanese longliners (the closed area is distinguished by the sharp linear boundaries) - these maybe records from the Joint Vessels. Highest effort in this region are allocated just outside of the closed zone.

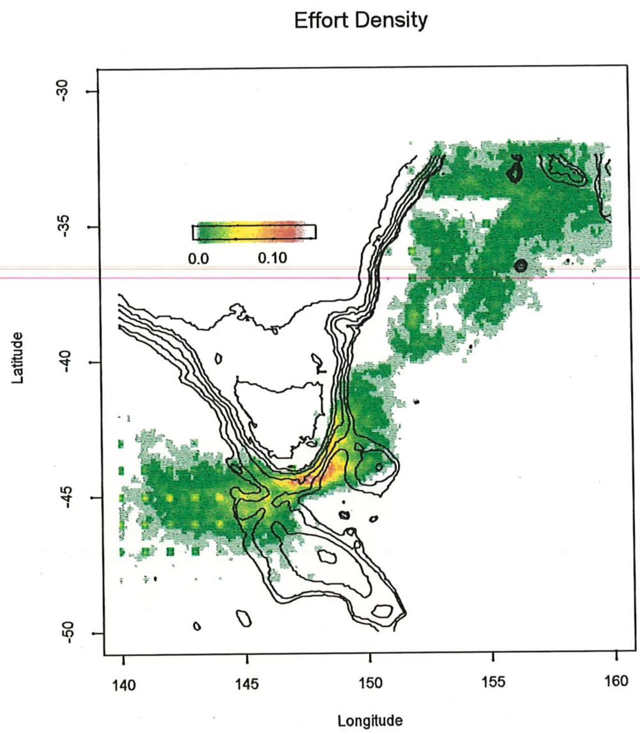


Figure 7-1 Two-dimensional density plot of the distribution of effort (as binned records of log reports) overlaid with contours of topography (at 0, 200, 1000, 2000, 3000 & 3500m) obtained by contouring the *ETOPO5* dataset compiled by the National Geographic Data Center. The bin size is 0.1 degrees in latitude and in longitude. David Scott's *ASH2* binning algorithm (available from the STATLIB archive site) was used with a 2x2 smoothing parameter. The maximum in the density plot is scaled by 1000 to facilitate plotting.

The disjoint nature of the effort distribution superimposed with the isolated hot-spots due to rounding off in the log reports of position poses particularly difficult problems for analyses which require spatially contiguous data. This is a particular problem for later analyses where attempts are made to correlate the catch statistics with satellite-derived sea-surface temperature (SST) data.

7.2. Monthly Variation in Successful Effort

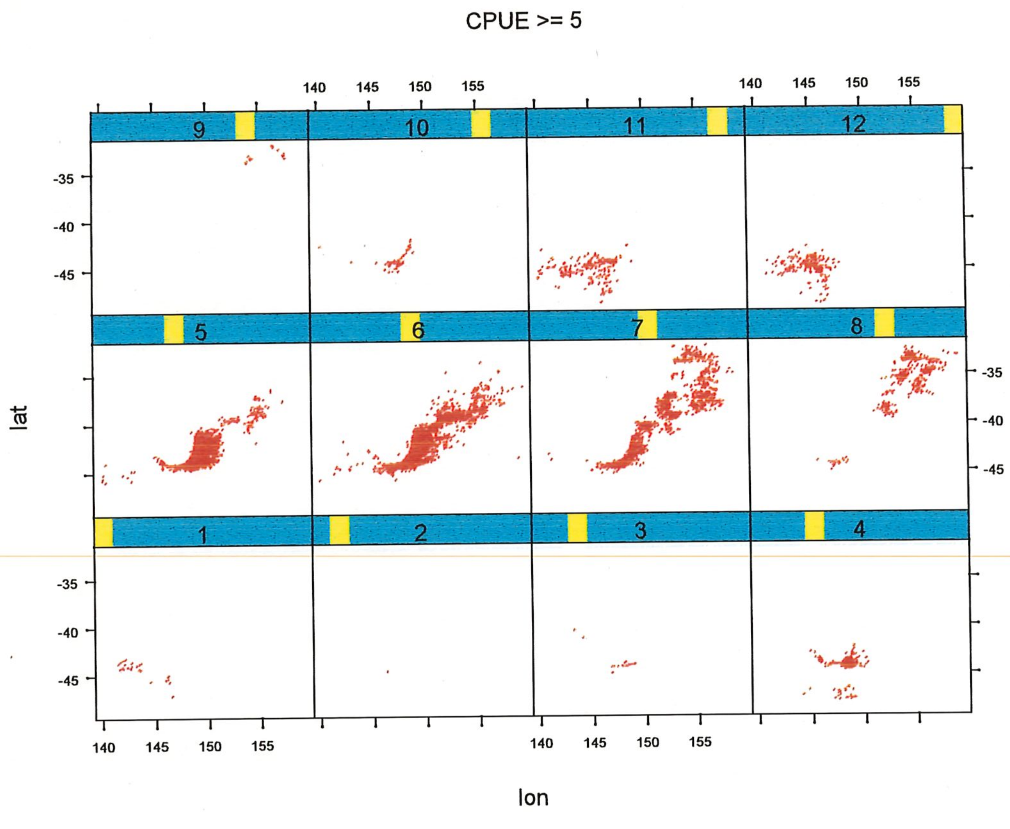
The plot of monthly locations of sets where catches of SBT were made (Figure 7-2) shows the two main fishing seasons. These are mainly November-December (and some in January) for the south and south-western region, and from May to August for the winter fishing season. The winter fishing season progresses from the southern end spreading out in a diffused fan-shaped pattern up to the northern limit of Tasmania and then progressing north-eastward along the NSW coast. The lack of reversibility in the distributions (ie that the northward propagation of the winter fishery is not reciprocated by a southward contraction) could imply:

1. That during winter and summer, SBT are migrating out of the Tasmanian fishing zone rather than reversing back.

2. That the reverse migration, if there were such migrations, is not a feeding migration and the fish are moving quickly back over their migration path.

The winter fishery is much more extensive and intensely fished than the summer fishery which shows a more dispersed and locally-confined distribution of catch rates.

The records for the far north-eastern section shows numerous listings of zero catch rates indicating that the substantial effort in that region is not purely devoted to SBT and that other species, presumably yellowfin tuna, may be targeted with SBT as a by-catch, or in addition to SBT.



• Figure 7-2 "Trellis" plot of the distributions, by month (month index indicated at the top header of each plot; l=January...), for locations reporting catch rates (number of SBT caught/1000 hooks) greater than or equal to 5. The order of presentation of the months is bottom-up starting from the bottom row, scanning from the left to right and proceeding up to the next row. Other "Trellis" plots in this report use this scanning scheme.

8. Trends and Distribution by Weight

Yearly variations in the average weight of SBT caught (Figure 8-1) indicate a sharp decline in the average winter weight from 1989 up to 1995. A similar decline occurs in the summer weight trend but is less evident. The summer weight shows an increase in weight in the 80's prior to the decline; a corresponding trend is also apparent in the winter pattern from 1985 to 1988. In both seasons, from 1991 to 1993 there appears to be a slight increase in the median weight. In the winter distribution from 1990 to 1994 there are a number of high outliers indicating that the distribution is not Normal, in contrast to the distribution prior to this period. This may be a reflection of a dual mode character in the weight distribution possibly caused by the increase in the young fish escaping from the WA and SA surface fisheries during the latter half of the 80's and early 90's (eg Caton & Williams, 1996, Figure 1).

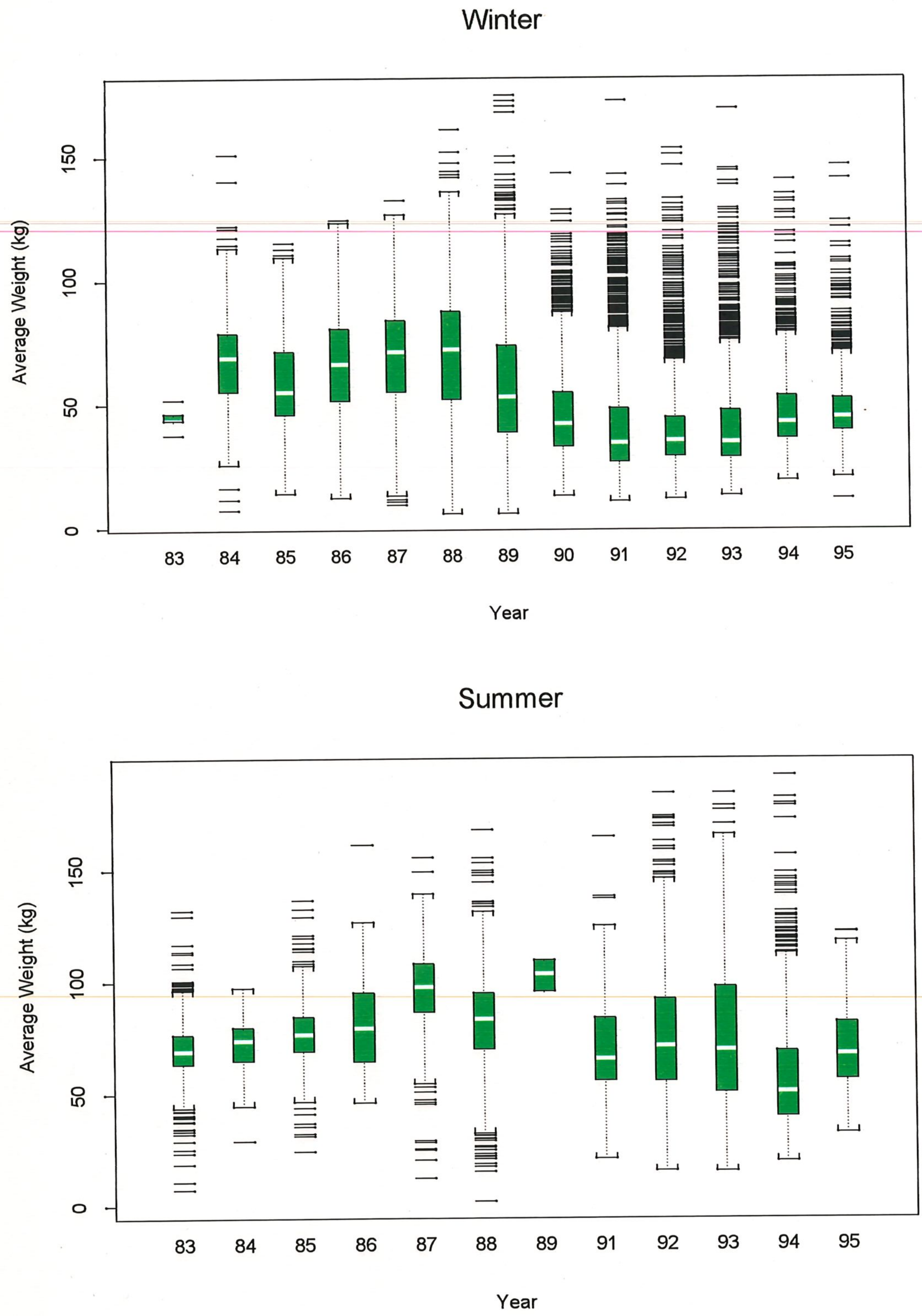
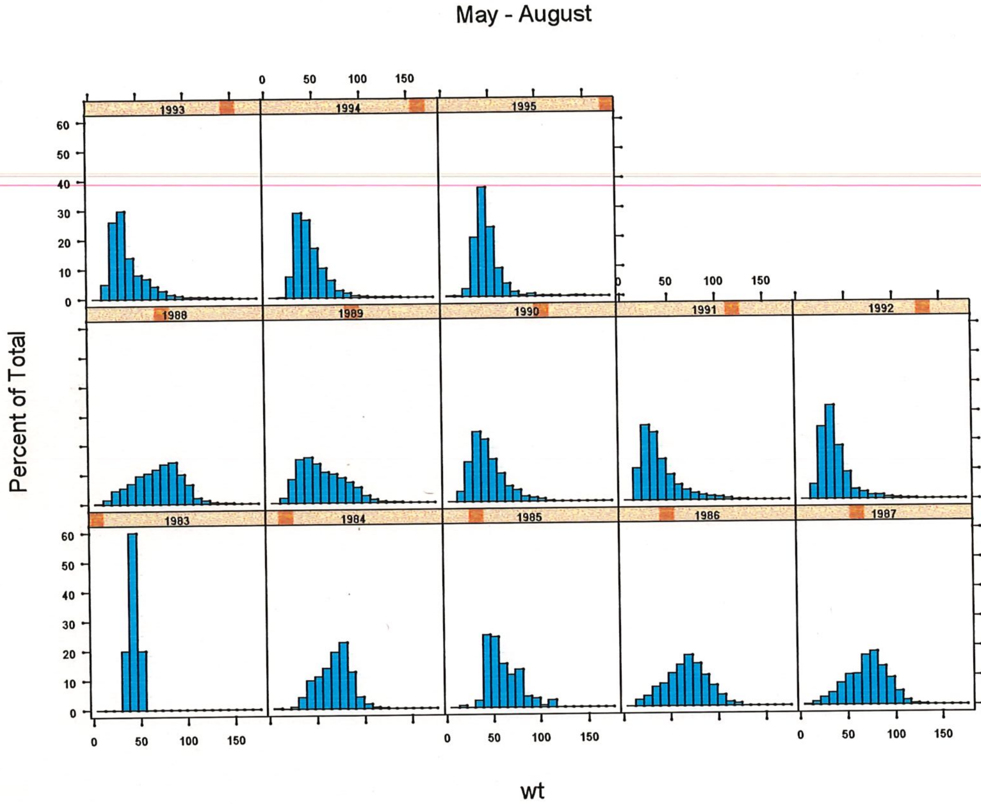


Figure 8-1 Box-Whiskers plot showing yearly variation of the average weight of SBT (using only records where weight and number of SBT caught were recorded) for winter (top panel) and summer (bottom panel). In each plot, the extent of the box corresponds to the *interquartile distance* (difference between first and third quartiles). The horizontal line within the box is the median and the *whiskers* (dotted line enclosed within the square brackets) indicate the maximum of the extreme ranges of the data or 1.5 times the interquartile distance from the centre. Data values outside the extent of the whiskers, indicated by individual horizontal lines, are taken to represent outliers (if the distribution is assumed to be Guassian)



• Figure 8-2 "Trellis" plot of the yearly variation in the histogram distribution of the weight of SBT caught in the winter months from May to August.

Histogram distribution of the weight of fish (average weight per set) caught in the winter fishery each year (Figure 8-2) show that up to 1988 there was a range of small and large (>80 kg) fish being caught. From 1989 onward, the catch of larger fish has diminished - surprisingly quickly relative to the other weight classes. The last few years of the study period give no significant indication of an increase in large fish as measured by their relative contribution to the catch histogram. One possible explanation is that this relative decrease in the large fish may simply reflect the increase escapement of young fish from the western surface fisheries noted above. To resolve this question, a wider study than that being conducted in this project of the downstream influences of the surface fishery needs to be considered.

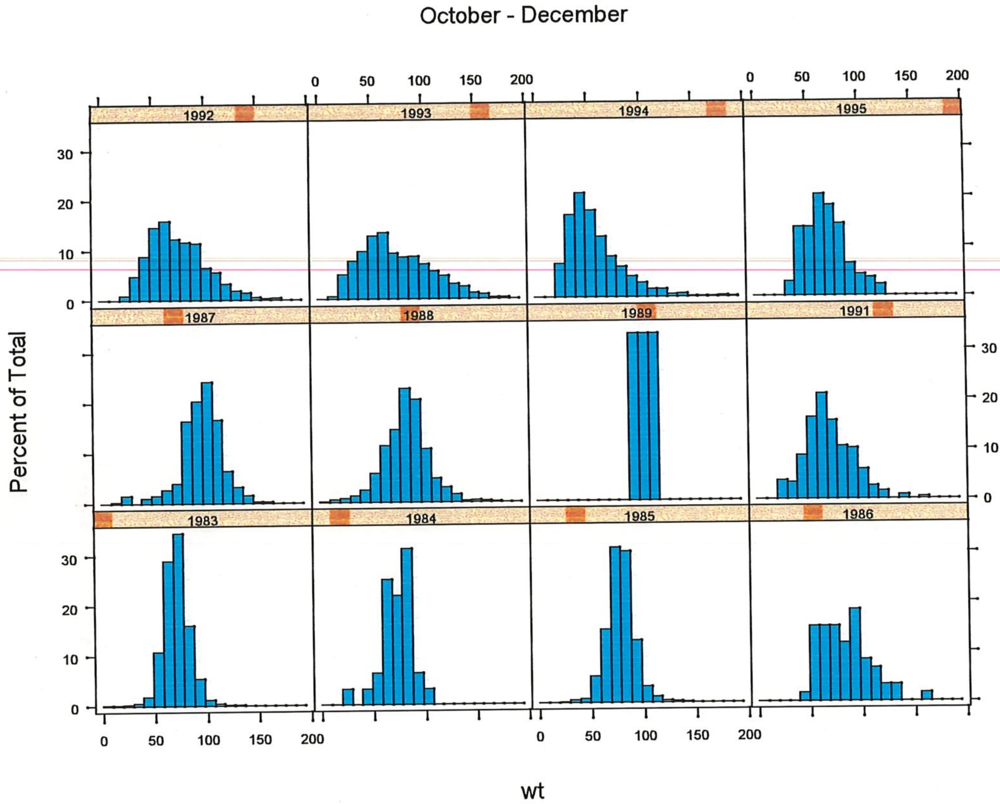
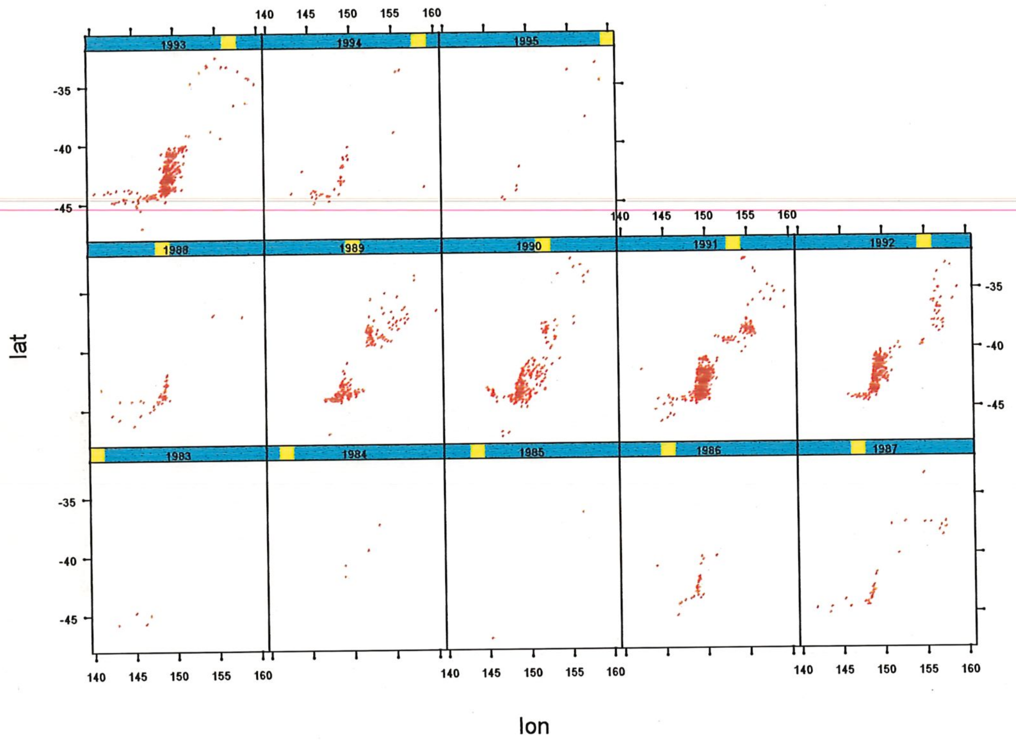


Figure 8-3 "Trellis" plot of the yearly variation in the histogram distribution of the weight of SBT caught in the spring/summer months from October to December.

The yearly variation in the weight of SBT caught for the spring/summer fishery (Figure 8-3) also shows a relative decline in the contribution of larger fish to the total catch from 1991 onwards, which could also be interpreted as a relative increase in the contribution of smaller fish to the catch. The dataset for 1989 is based on a few records. Note also that the distribution for 1995 needs to be interpreted with caution as it may not be complete.

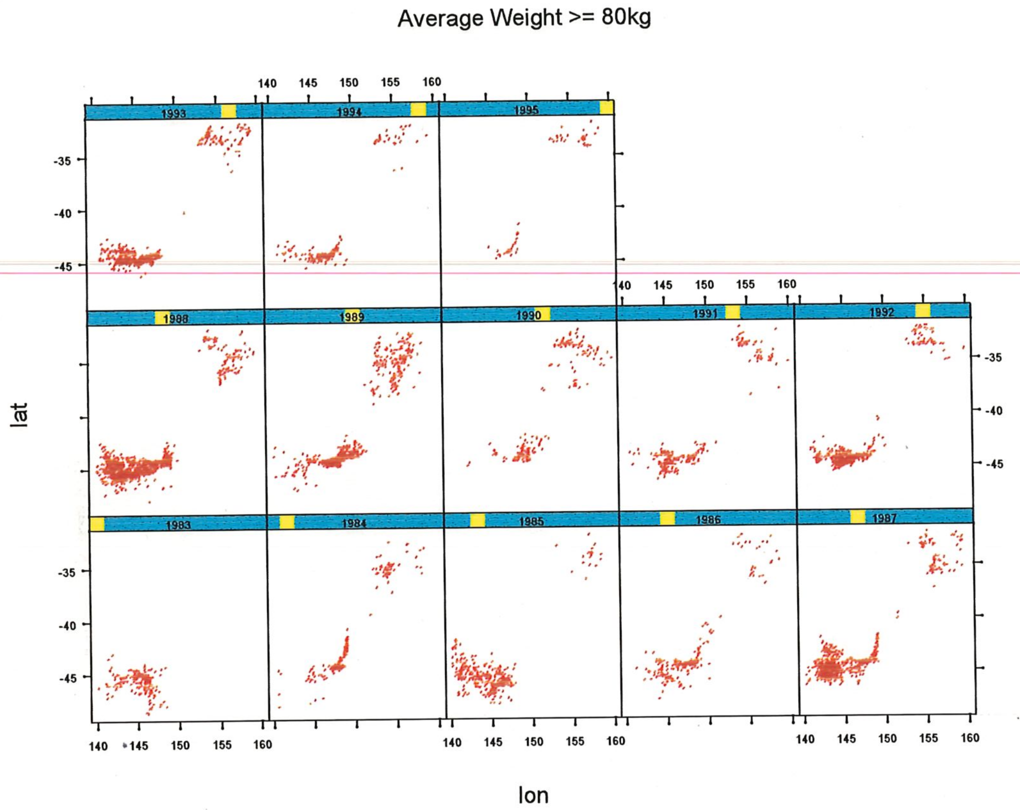
Both the spring/summer and winter distributions clearly point to a change in the composition of weight of fish caught; the principal aspect of this change being the relative decline in the catch of larger fish. To investigate the spatial component of this change, plots of the spatial distribution by weight of SBT were prepared.

Average Weight <= 25kg



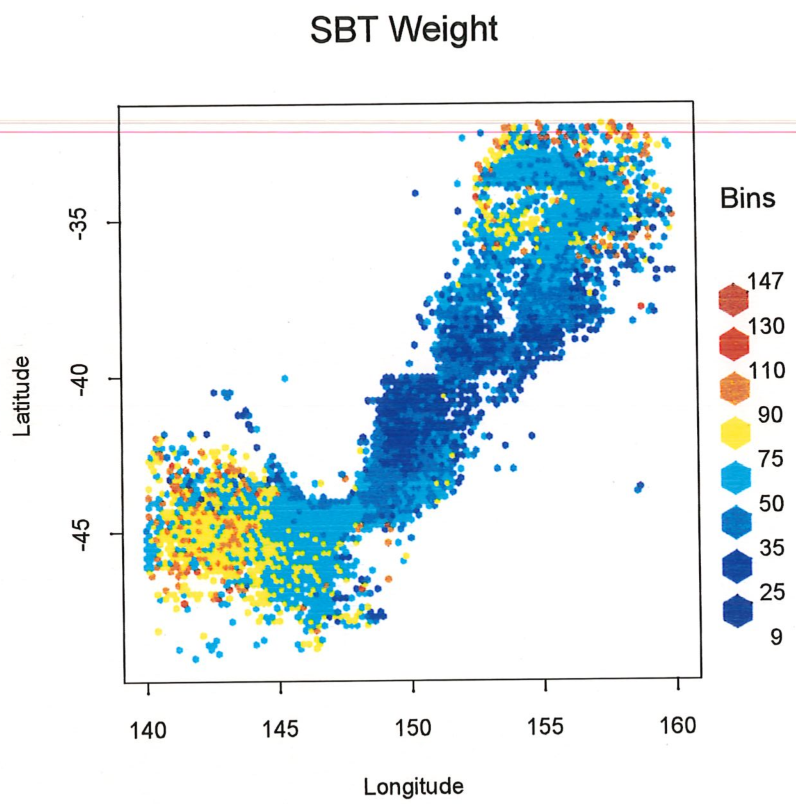
• Figure 8-4 "Trellis" graph showing the spatial variation, by year, of locations where the average catch weight was 25kg or less.

The distribution of small fish (defined here as being less than or equal to 25kg) shown in Figure 8-4, suggests that whilst small fish are found throughout the sector from south of Tasmania up to NSW, the distribution since 1989 shows a much more widespread and intense distribution of small fish particularly noticeable for the areas off south-eastern Tasmania. Here again, these changes may be a downstream consequence of the changing operations in the western surface fisheries noted previously. The distribution for 1994 and 1995 are less intense and in keeping with the lower intensity distributions of the 80's. In contrast, the distribution of large fish (defined as being of average weight of 80kg or more) (Figure 8-5) shows a distribution that is largely restricted to two main regions: the region from south-west to south-eastern Tasmanian and the area off NSW.. Trends are difficult to discern but there is a suggestion that since 1989, the intensity of aggregations off NSW has been in continual decline - in contrast to the trend for the small fish.



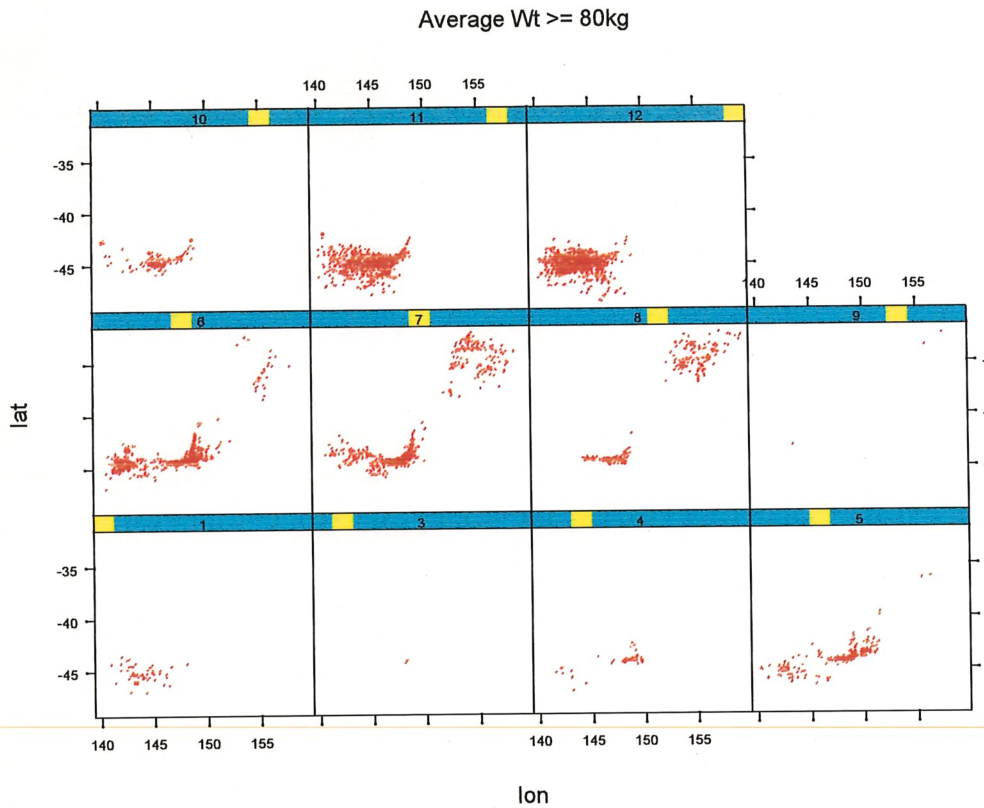
• Figure 8-5 "Trellis" graph showing the spatial variation, by year, of locations where the average catch weight was 80kg or more.

Given that the spatial pattern (as opposed to the temporal pattern) of distribution of SBT by weight class was relatively coherent between years, but that the intensity varied, a composite image of the spatial distribution by weight was prepared (Figure 8-6). This shows a gradation of large fish in the south-western sector to small fish off eastern Tasmania. The gradation then shows a remarkable reverse trend proceeding north to large fish being caught at the northern edge of the study area and the extreme offshore areas of northern end of the study region. The distribution of the smallest size fish class are less obvious. Within the Joint Venture exclusion zone to Japanese longliners, there is a intriguing cluster of large fish (centred at about 35°S). The separation of the weight classes in space is remarkable. The intermediate weight fish (25-50kg) show the classic pattern of migration from the south-west up to about 35°S with a noticeable "stream" off the shelf-edge region of south-western Tasmania. The larger fish (>50kg) show a disjunction at about 147.5°E, with two northward streams, one along the shelf edge of south-east Tasmania and the other in the offshore edge of this region These two streams bound an area of smaller fish (35-50kg). SBT of 75kg or larger are located in a distinctive pattern which would appear to be associated with the north-western tip of the South Tasman Rise (see Figure 7-1). The largest weight class examined is clustered even further west with no evidence of a continuous distribution across the southern sector.



• Figure 8-6 Spatial distribution of the weight (kg) of SBT caught. Records were binned into 0.1x0.1 degree spatial bins from which the median value for each bin was computed. The legend indicates the weight bins used for shading.

To further investigate the nature of the seeming anomalously large fish off northern NSW, trends of the distribution of large fish (80kg+) by month (Figure 8-7) show the appearance of large fish in the two fishing seasons. The summer distribution (Oct-Jan span, but mainly Nov-Dec) shows the expected distribution pattern off southern Tasmania and to the south west. The winter pattern also shows the expected pattern off south-eastern Tasmania but this is accompanied by the "anomalous" pattern appearing off NSW. Looking more closely at the development of the winter pattern, there is a hint of an appearance in April which expands to a maximum extent in June in the south and south-eastern sector. Off NSW however, the main pattern develops later, from June to August, suggesting that the SBT off NSW may have in fact migrated from the distribution off south-east Tasmania. The lack of continuity in the distribution, around Bass Strait, may be attributed to the reduced fishing activity and the presence of the exclusion zone, or alternately it may be due to a rapid migration by SBT to the NSW grounds. Two other possible explanations should also be borne in mind for the NSW distribution: One is a possible unforseen problem with the data (but we have checked that only valid SBT records were used for the analysis); the second possible explanation is that the SBT are in fact northern bluefin tuna. For the moment we can only assume that the observations are indeed legitimate and we will proceed to analyse the information accordingly.

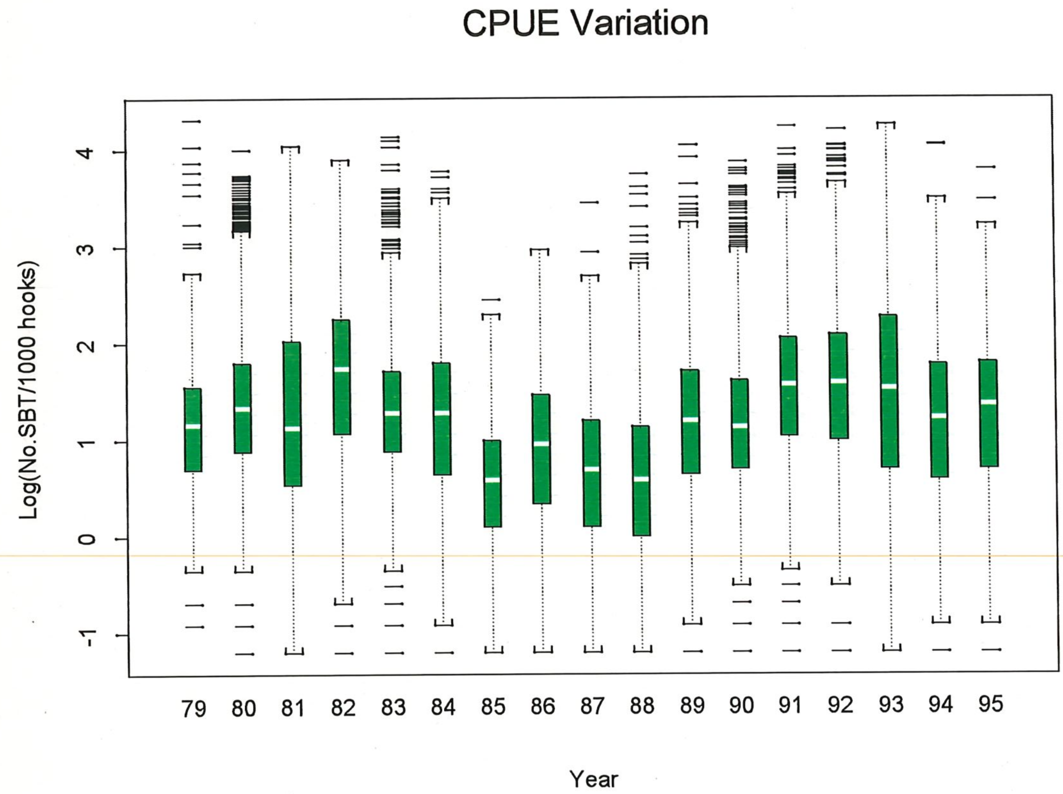


• Figure 8-7 Distribution of large fish (80kg+) by month (noted in header for each plot) as determined by catch locations. Note that there were no suitable catch records for February.

One other aspect of the large SBT distribution (Figure 8-7) worth noting is that the progression of the summer pattern off southern Tasmania supports the notion that the migration phase is an east-to-west one - as opposed to the pattern of migration of younger SBT down the south-west coast of Tasmania and thence north-eastward off eastern Tasmania. We leave the discussion of the hypotheses for the distribution of large SBT to a later section but suffice to note here that it raises a fundamental question about the conventional wisdom on temperature constraints (more precisely *sea-surface temperature)* on the distribution of SBT.

9 Trends in CPUE

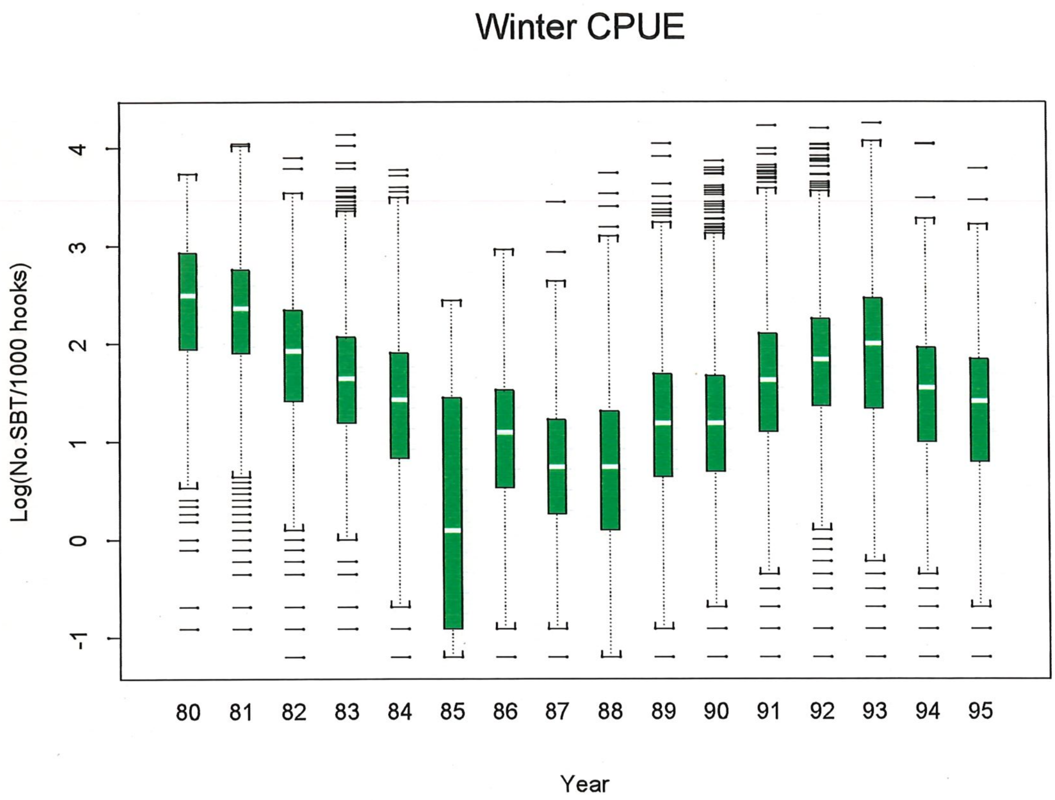
Yearly variations in the logarithm of CPUE (the logarithm approximately normalises the skewed distribution of catch rates) (Figure 9-1) show a seemingly regular cycle of variation which peaks in 1981 and 1993 with a trough in the mid-80's. Given the previous observations of trends in the weight of catch, the yearly variation of CPUE by weight (Figure 9-3) shows that the variation in the different weight classes are not all consistent. All classes examined show a decline in recent years with the exception of the 50-75kg class which show an increase. The smallest and largest classes have the largest relative variability.

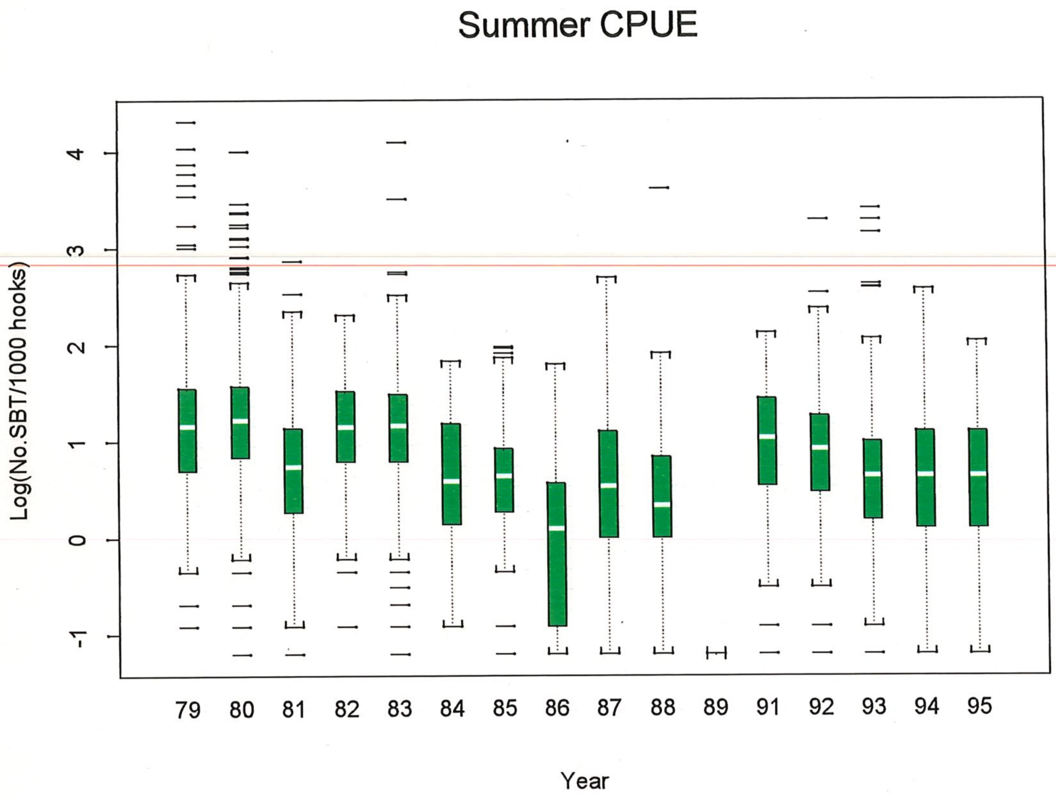


• Figure 9-1 Box-and-Whisker plots showing yearly variation in the log of catch rate (defined as the number of SBT caught per 1000 hooks).

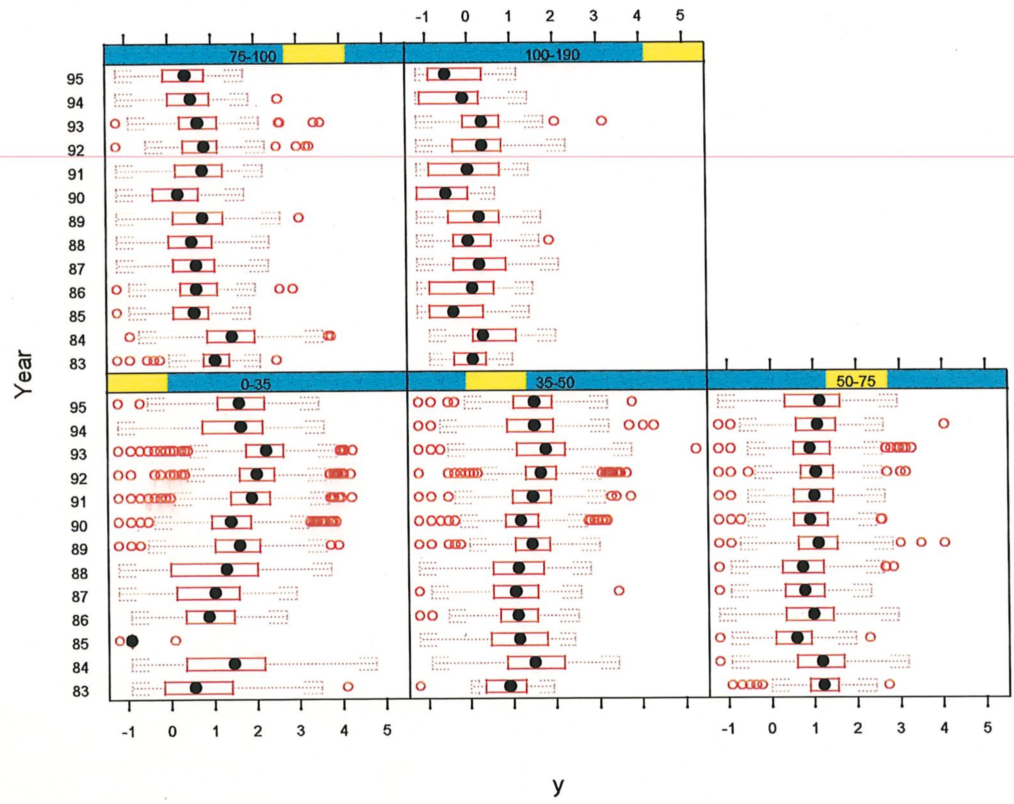
The winter trend of CPUE (Figure 9-2) shows a marked decline during the 80's, up to about 1988 followed by an increase up to 1993 and then a further decline thereafter. The summer trend (Figure 9-2) is somewhat erratic but there appears to be a decline in the 80's, a peak in the early 90's followed by a decline to a steady level in the latter years analysed. The winter trend does not support the notion of an inverse correlation with catch trends in the western surface fisheries.

Whilst the trend in the first half of the 90's does appear to relate to the surface fisheries trends in an inverse manner (see Caton & Williams 1996, Figure 1), the trends in the 80's are of the same sense. Thus the suggestion that the trends are mainly a consequence of the downstream effects of the surface fisheries is not entirely valid.



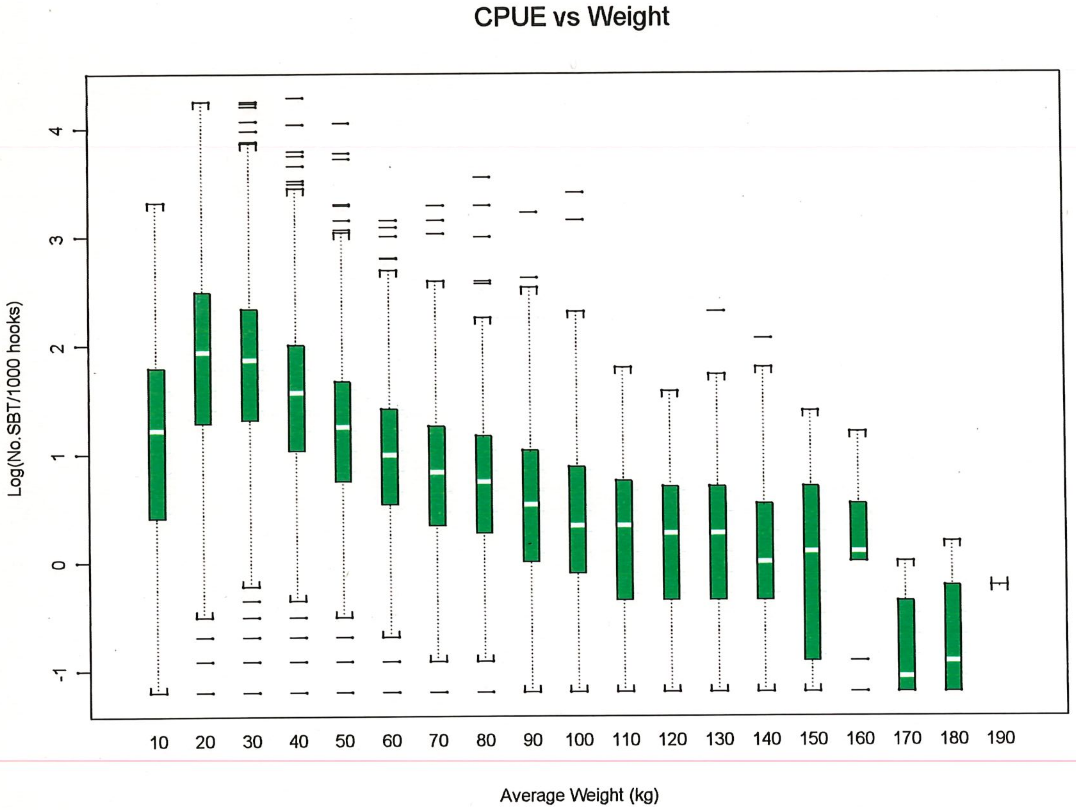


• Figure 9-2 Box-and-Whisker plots showing yearly variation in the log of catch rate (defined as the number of SBT caught per 1000 hooks) for winter (upper panel) and summer (lower panel).



• Figure 9-3 Box-and-Whisker plots (oriented vertically) showing the variation in the logarithm of catch rates according to the weight of SBT. Weight classes (shown in the header for each individual plot) were chosen with ranges of 0-40kg, 40-60kg, 60-80kg, 80-100kg and 100-190kg.

Trends in catch rates (CPUE) ,over all years, appear to be function of the weight class (Figure 9-4). This may partly explain the observation of general reduction in weight during the late 80's and first half of the 90's (Figure 9-1) being accompanied by increases in CPUE (relative to the mid-80's).



• Figure 9-4 Variation of catch rates (logarithm of the number of SBT caught per 1000 hooks) as a function of the average weight of the catch.

To summarise the results of this section, there are clear patterns of spatial clustering and distribution associated with weight of SBT and season. The temporal pattern suggests relative decline in the average weight (size) of SBT caught, accompanied by a relative increase in the number of smaller fish - this may be due to the relative increase in abundance of SBT for smaller sized fish. However there does not seem to be a clear general spatial pattern associated with this temporal trend. The spatial distribution by weight class (ie Figure 8-6) show remarkable clusters of larger fish at the two extremities of the study region with gradations of weight proceeding into the middle of the area. Streams of larger fish are noticed along the shelf-break and outer offshore regions. Yearly trends in CPUE show an overall cyclical variation beginning in 1980 with the winter fishery showing a marked decline in the 80's followed by a small and unsustained recovery. The trends in the summer fishery are less clear but appear to indicated a decline in the 80's and a recovery in the early 90's which has declined to an equilibrium in the latter years. When examined with respect to the weight of SBT, the overall trend is not obvious in the different weight classes. The 50-75kg size category is the only one to show recent increases but all the other classes show a declining trend. Overall, the trends do not support the notion of an inverse relation between the catches in the surface fishery relative to those off Tasmania - not for the whole period examined.

In the next section we examine the trends and distribution for 3 different regions representing the zonation suggested by the results of this section. For this next analysis the environmental variables of temperature and bathymetry are examined for a subset from the data for the later years.

10. Environmental Effects

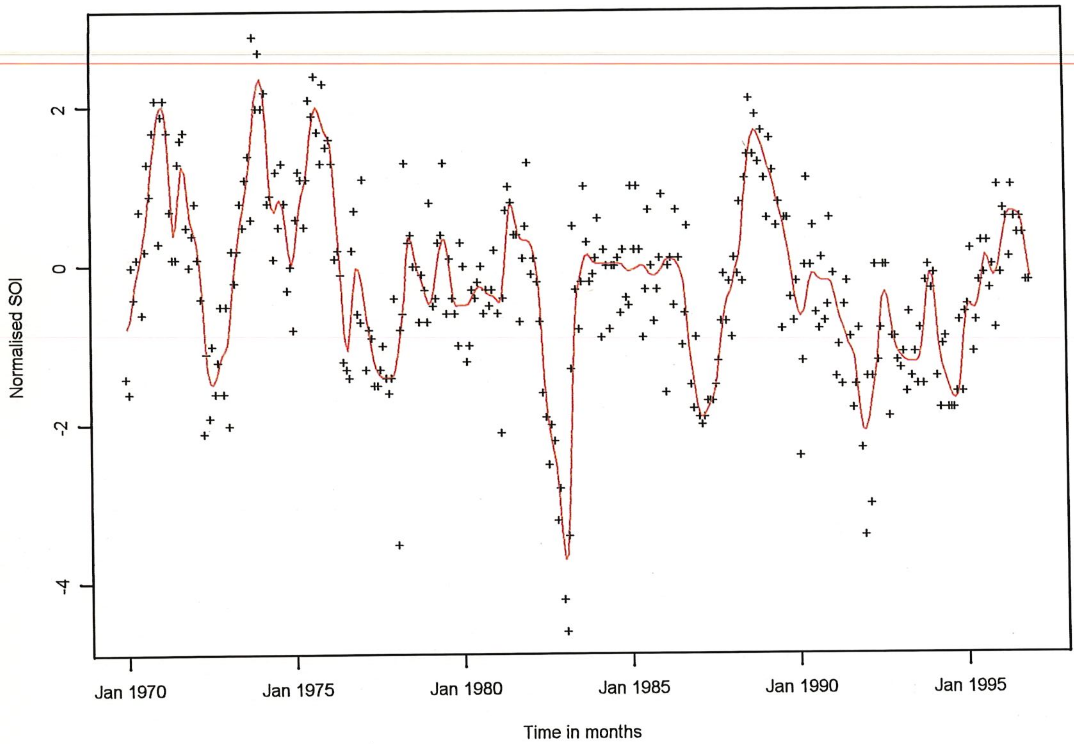
In this section we first examine the use of the Southern Oscillation Index as an indicator of general climatic variability effects on CPUE. We next examine the possible influences of spatial and temporal variations in temperature, with weight as a factor. Moon phase and bathymetric influences are also examined.

10.1. Southern Oscillation Index

The Southern Oscillation Index (SOI) characterises massive coupled changes in atmosphere-ocean circulations in the Pacific tropics. Alterations in the relative extent of warm waters in the western tropical Pacific and the cooler upwelling waters of the eastern tropical Pacific lead to corresponding shifts in atmospheric and rainfall distribution patterns. These atmospheric changes in turn induce oceanic circulation changes resulting in a seemingly chaotic oscillation referred to as the El Nino/Southern Oscillation (ENSO) cycle. Warm phases of the cycle (negative SOI, El-Nino conditions) occur during periods of enhanced eastward drift of the warm pool of western tropical waters. This pool is also partly the "headwaters" which feeds the East Australian Current system. Correspondingly, cool phases of the cycle (positive SOI,) occur when the warm pool contracts westward exposing a more extensive eastern Pacific region of cooler upwelling waters.

The effects along the eastern Australian coast during the different phases are based on the expected effects on the East Australian Current system. During warm phases (-SOI), reduced supply of EAC waters can be expected to lead to cooler conditions and vice-versa for the cool phase (+SOI). Thus the index itself can be thought of being an indicator for expected temperature changes along the Australian eastern seaboard. This however is a highly simplistic view of the expected effects. For a fuller examination of ENSO-related effects we refer the reader to the recent compilation by Allan et al, 1996.

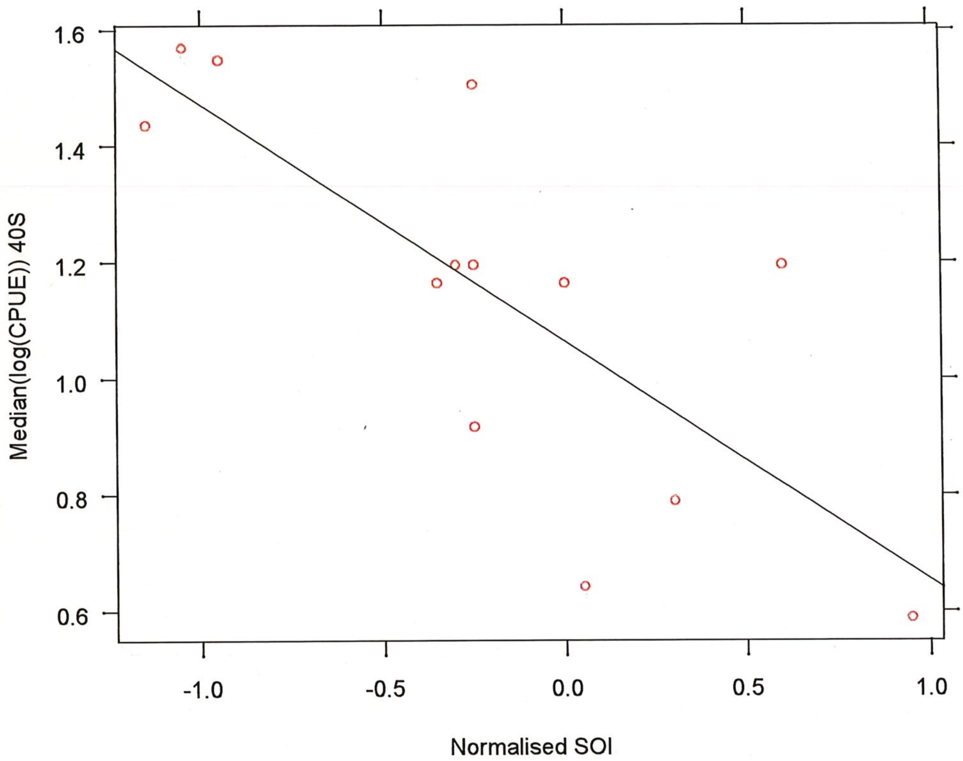
Time-series of the SOI index since 1970 (Figure 10-1) shows the rather chaotic behaviour of the variability with dramatic oscillations in the 1970's. Of note are the high SOI indices for what were warm years for eastern Australia (1970, 1973 & 1976) observed by Rochford. Most cycles associated with the main peaks and troughs last a few years. The time-series since 1980 highlights the dramatic El-Ninos of 82-83, 86-87 and more recently 91-92. The most intense La-Nina event of recent times was the 88-89 episode which saw the collapse of krill production and jack mackerel off eastern Tasmania. Overall, the period since 1990 has been one of prolonged El-Nino conditions which reversed to La-Nina conditions only recently (1996).



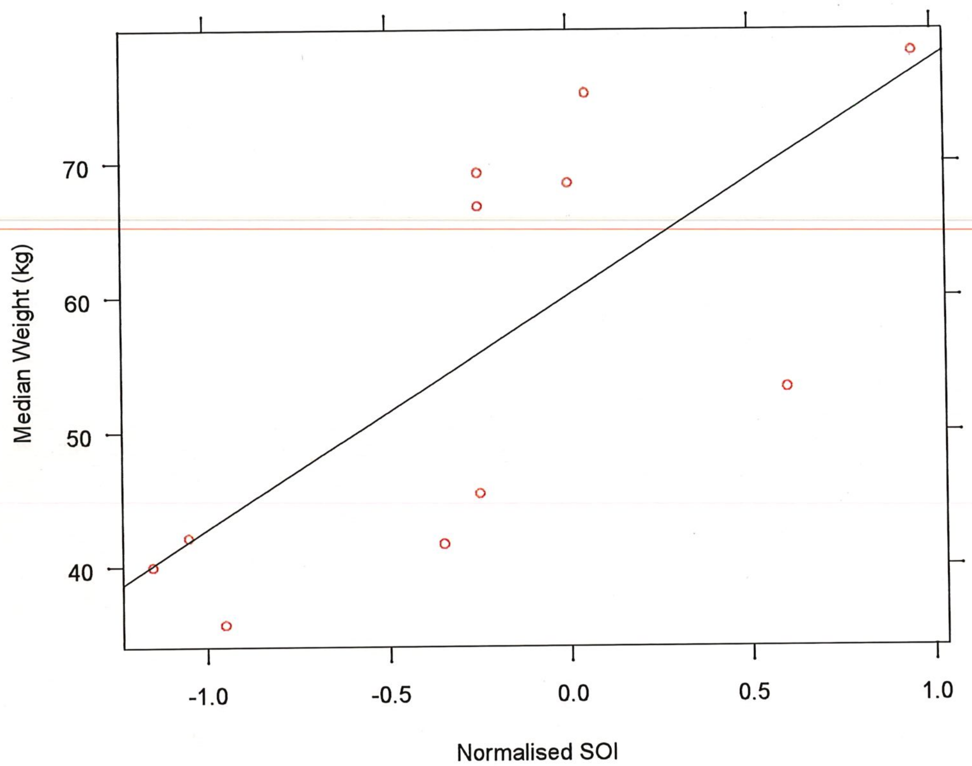
• Figure 10-1 Time-series of the normalised Southern Oscillation Index (SOI) based on the standardised Tahiti-Darwin sea-level pressure index computed by the NOAA Climate Prediction Center. Anomalies are computed as departures from the 1950 - 1980 base period. Actual values denoted with a "+" and the fitted line is a smoothed loess curve.

Given that climate variability impacts as reflected in the SOI variation are expected to be long-term effects, we chose to analyse the potential relation of CPUE and SOI variability over a yearly timescale, where median values of the variables (log(CPUE) and SOI) over a calendar year were related. Initial analyses also indicated that the correlation patterns were not significant unless some restrictions were made on the dataset. First, the region had to be limited to that south of 40^0S and secondly, years of extremely low SOI indices (82, 87 and 94) did not have correspondingly extreme variation in CPUE. Thus, the points corresponding to these three years were eliminated as outliers.

Within the spatial and SOI range of data analysed, the correlation was highly significant (Pr(F) = 0.0025, Figure 10-2) with the trend line indicating higher catch rates during negative SOI periods. In a similar vein, the variation of weight of SBT was also analysed (Figure 10-3) and found to be significant (Pr(F) = 0.01). This indicates that negative SOI periods correspond to periods when smaller SBT are more prevalent, and by the previous analysis, when CPUE rates are higher. Thus, the essential result of the SOI analysis is that period of negative SOI correspond to the appearance of smaller more abundant SBT whilst periods of positive SOI are those of large and less abundant SBT. The reduction in catch rates for high SOI periods is consistent with the observations of Rochford of catch reductions in the warm years of the 70's.



• Figure 10-2 Scatterplot and correlation between the yearly median of CPUE (logarithm of the number of SBT caught per 1000 hooks) and the median of the normalised Southern Oscillation Index (SOI) for the period 1980-1995. For the CPUE values only the data south of 40^{0}S was used (to eliminate possible confounding effects from the interaction with the yellow-fin tuna fishery north of this boundary and to concentrate the analysis on the core region of interest). We have also eliminated the points corresponding to extreme values of SOI larger than -1.25 (3 values occurring at 1982, 1987 and 1994). The fitted line is the linear regression.



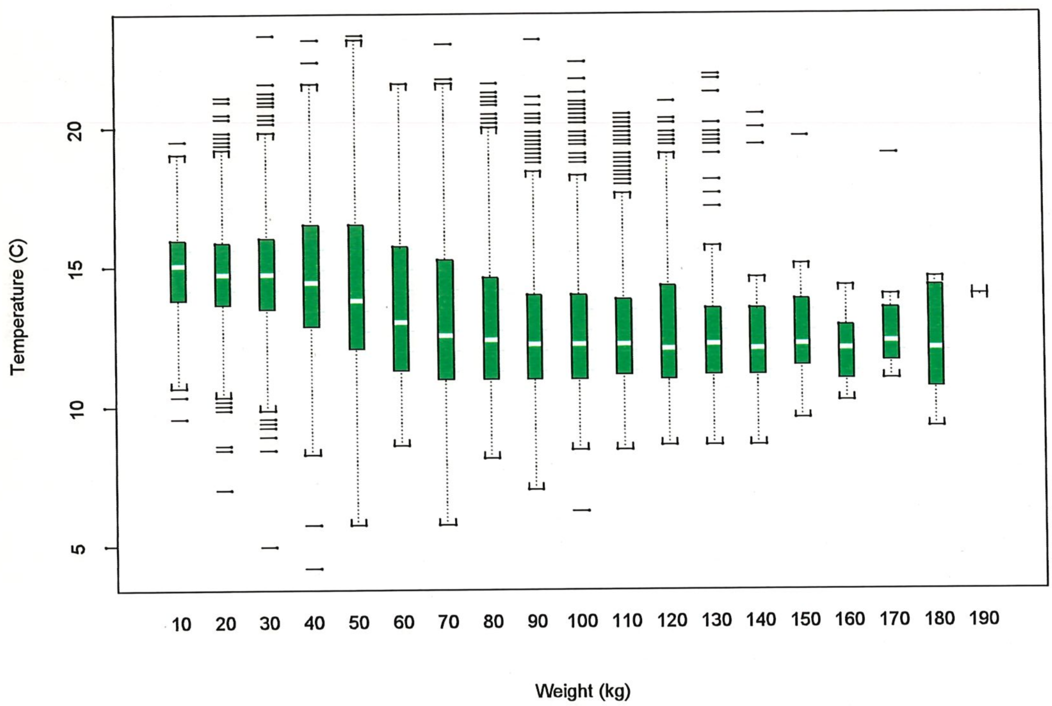
• Figure 10-3 Scatterplot and regression of weight of SBT and normalised SOI using median values of variables for each year. Spatial and SOI restrictions are as per Figure 10-2.

There is a possibility that coincidental changes in the fisheries, outside the area of analysis, could be causing these correlations. These can only be resolved by a much wider analysis than we have conducted which considers at the very least the downstream effects of the western surface fisheries; as remarked previously, the effect, if any, is not a purely inverse relation.

10.2. Temperature

Satellite SST images were composited using the histogram filtering technique of Rathbone and Parslow (1997) with a filter period of 15 days for the compositing and with composite images being produced every 5 days (ie one image produced every 5 days but each uses a 15 day compositing period). Unfortunately due to problems of data formats and storage media, the series used was only available for the period from December 1989 to December 1995. Thus, for the analyses which use temperature, we concentrate primarily on the data from January 1990 to December 1995.

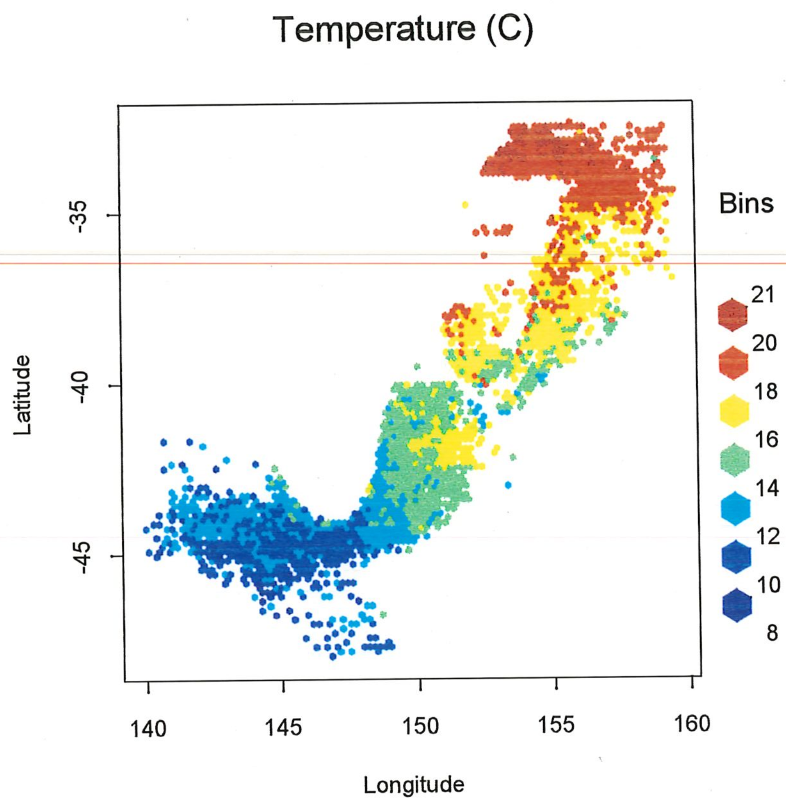
Estimates of temperature corresponding to each logbook record were obtained by extracting the temperature from the satellite data using the image closest in time to the time of the log record and at the pixel of the recorded lat/lon location. Note that with the observation of discretisation errors in the log records (Figure 7-1), the extracted temperature will not be appropriate for those records. Thus the analyses undertaken here are designed to examine relatively general trends and correlations.



• Figure 10-4 Box-and-Whiskers plot of the distribution of temperature with weight of SBT. Note that the data used for this analysis was from January 1990 to December 1995 as these were the years for which SST data were available.

The variation of the temperature of capture of SBT in relation to weight (Figure 10-4) shows a trend of decreasing temperatures with weight. Note that for the larger fish, whilst the spatial pattern (Figure 8-6) may suggest a bimodal temperature distribution, the larger fish in the north are caught in the winter fishery whereas the larger fish in the south are caught in the summer fishery. Thus, their temperature preference are narrower than that suggested by their latitudinal range. The other factor to keep in mind also is that the section in this analysis only uses the subset from 1990 to 1995 and hence the range of temperature seen in Figure 10-4 is narrower than that over the whole time-series (if temperature data were available over the whole record). The nominal range within which SBT are caught shows relatively narrow ranges for both the small and large SBT with the 50kg class having the greatest range. Beyond about 90kg, the variation in median temperature is minimal but the range still appears to decrease. The results may ***seem*** to suggest that fish of intermediate weight conduct more extensive migrations across the different water masses off Tasmania than those at either end of the spectrum - we return to this point in a later section. This in turn suggests that the search for temperature effects (from an analysis of catch records) may be more effective if targeted at the weight classes with relatively restricted temperature ranges (ie small and large fish) - in keeping with observations of the larger relative temporal variations in CPUE for the smallest and largest classes of SBT noted in Figure 9-3.

The spatial distribution of temperature obtained by collating the temperature at which SBT were captured (Figure 10-5), obtained posthoc by analysis of the SST satellite data as described previously, shows the expected latitudinal gradation. Note however that since the image is a composite over the whole year, features such as the apparent “mixing” of waters in the southern sector are due to the differing water masses between the two fishing seasons (since this region is also the main area for the summer fishery). The gradation and intermingling of water further north (eg north of 40^0S) is associated with the intermingling of SBT of differing weight (Figure 8-6). The cooler waters rising northward along the south-eastern section of the Tasmanian shelf-edge is also noticeable and may be responsible for enabling relatively larger fish to travel up to the area off eastern Bass Strait, noted previously.



• Figure 10-5 Binned and median-filtered temperature obtained from analysis of satellite SST images and using the locations and dates at which fish were caught. The image represents a composite for the period from January 1990 to December 1995. The image represents the spatial distribution of temperature at locations at which SBT were caught.

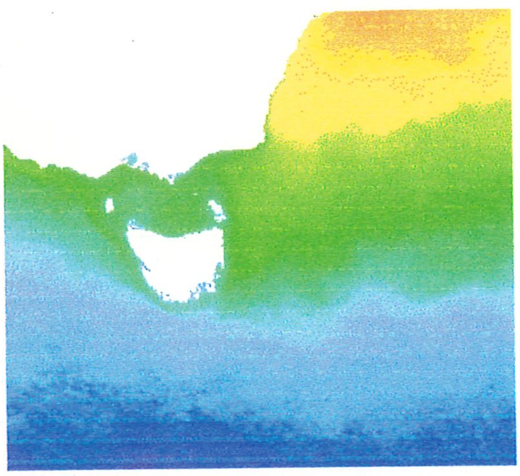


Figure 10-6 Average temperature for June computed for the years 1990-1995

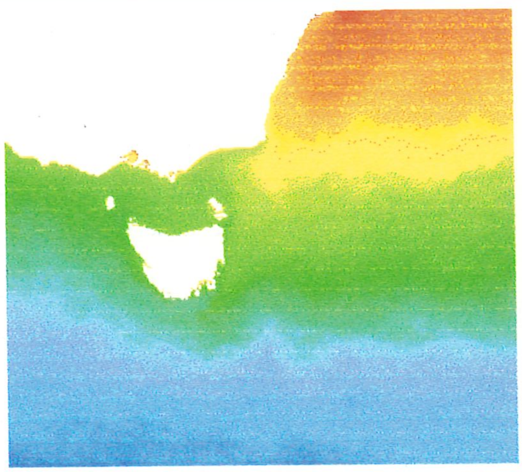
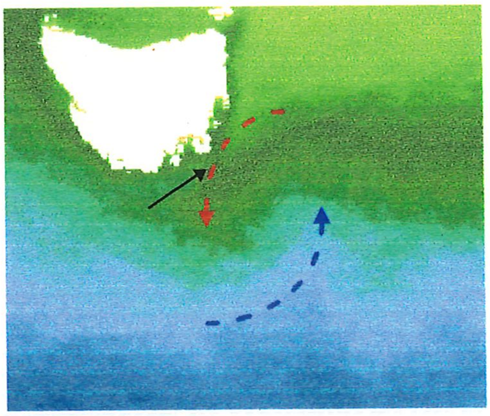


Figure 10-7 Average temperature for December computed for the years 1990-1995.

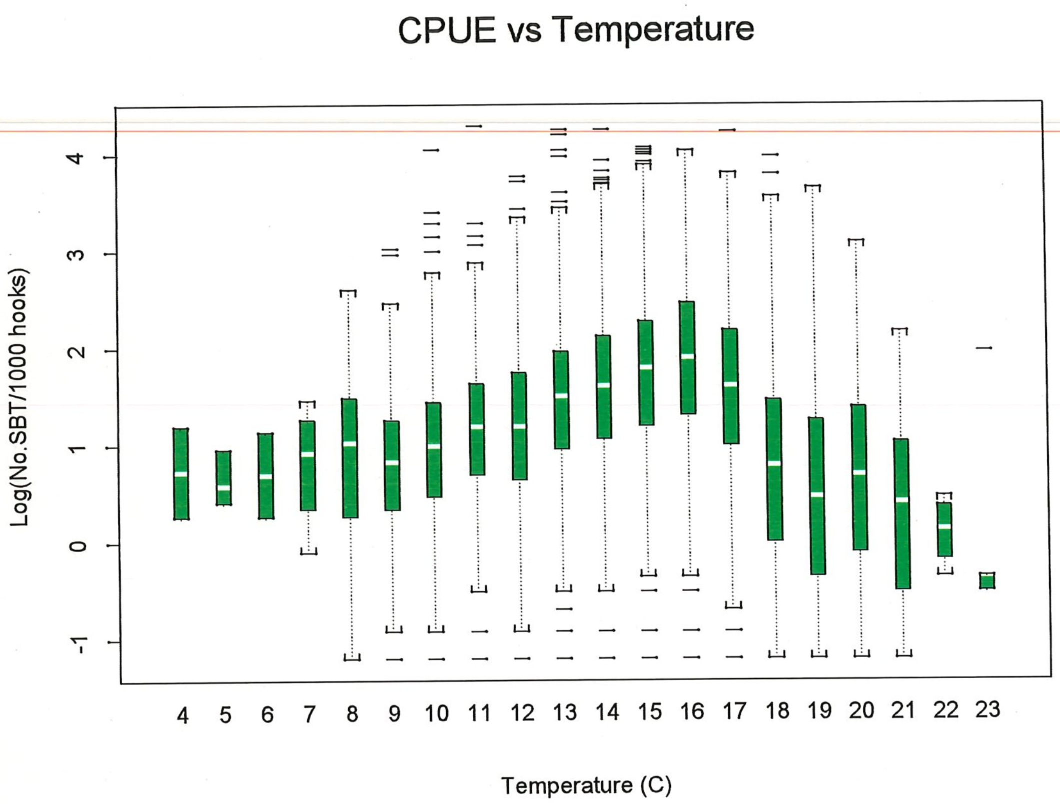
In contrast to the temperature distribution derived from the catch locations, the mean temperature maps derived directly from the satellite imagery (Figure 10-6, Figure 10-7) show smooth variations in temperature across the SBT fishing zone. The wedge-shaped intrusion of warm water penetrating down the eastern coast of Tasmanian is evident in both winter and summer. The shape of the intrusion is in accord with the distribution of the SBT catches off eastern Tasmania. These observations suggest an inferred circulation pattern (Figure 10-8) consisting of a recirculating region off south-eastern Tasmania caused by the interaction of the southward flow of warm water interacting with the, presumed eastward, surface flow of cooler waters. The nature of the recirculating appears to relate to the topographic constraints imposed by the south Tasman Rise and East Cascade Plateau. Associated with the recirculation is a flow of cooler waters north-eastwards along the shelf-break region of south-eastern Tasmania.



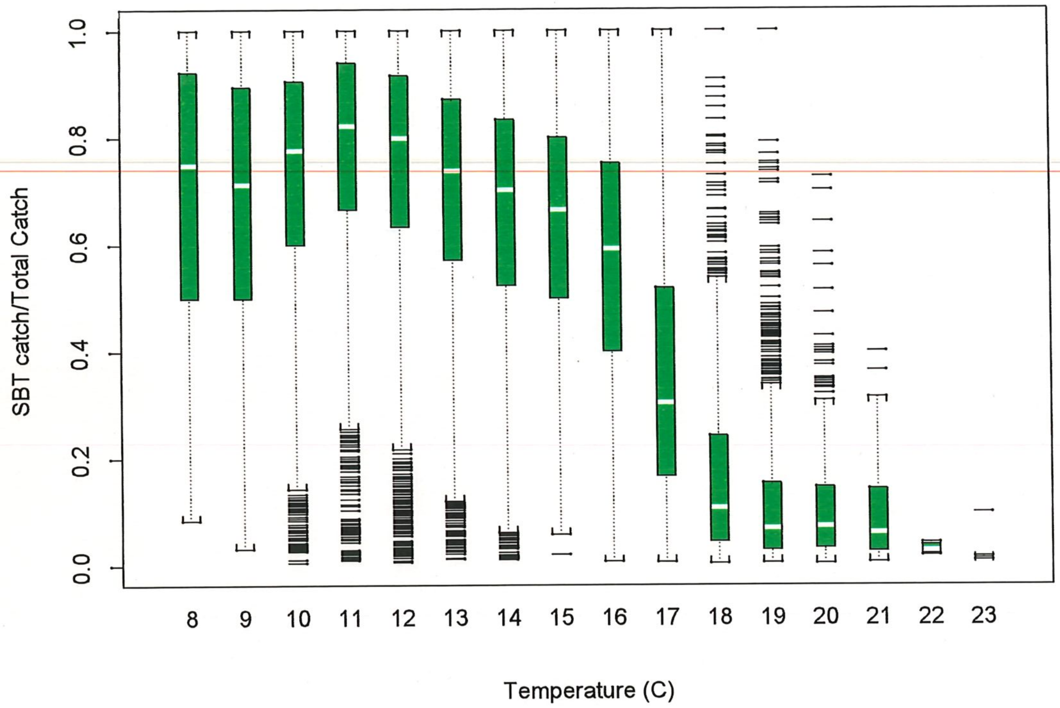
• Figure 10-8 Inferred circulation pattern for June off south-eastern Tasmania consisting of a wedge-shaped southward intrusion of remnant EAC water accompanied by a northward flow of cooler waters. The lighter solid arrow line on the shelf/shelf-edge indicates a hypothesised flow of cooler waters along the shelf-edge which may be associated with the separation of the remnant EAC flow from the shelf-break.

10.2.1. CPUE Variation with Temperature

The peak in CPUE catch rates (Figure 10-9) reflects the temperature range in which the smaller (and presumably more abundant) SBT are caught (Figure 10-4). The other noteworthy feature is that the decline of CPUE with higher temperatures is greater than the decline with lower temperatures - suggesting that warm temperatures are a greater constraint on catch rates than cooler temperatures. Part of the explanation for this trend may be that in the warmer waters, there is a greater chance of hooking other fish species. In comparing the catch rate of SBT and the total catch, by temperature, (Figure 10-10), at temperatures higher than about $16^{0}C$ the median relative catch of SBT (compared to the total number of fish caught) declines from about 80% to around the 10% level.



• Figure 10-9 Variation of log of CPUE (as number of SBT caught per 1000 hooks) versus temperature, plotted as a box-and-whisker plot.



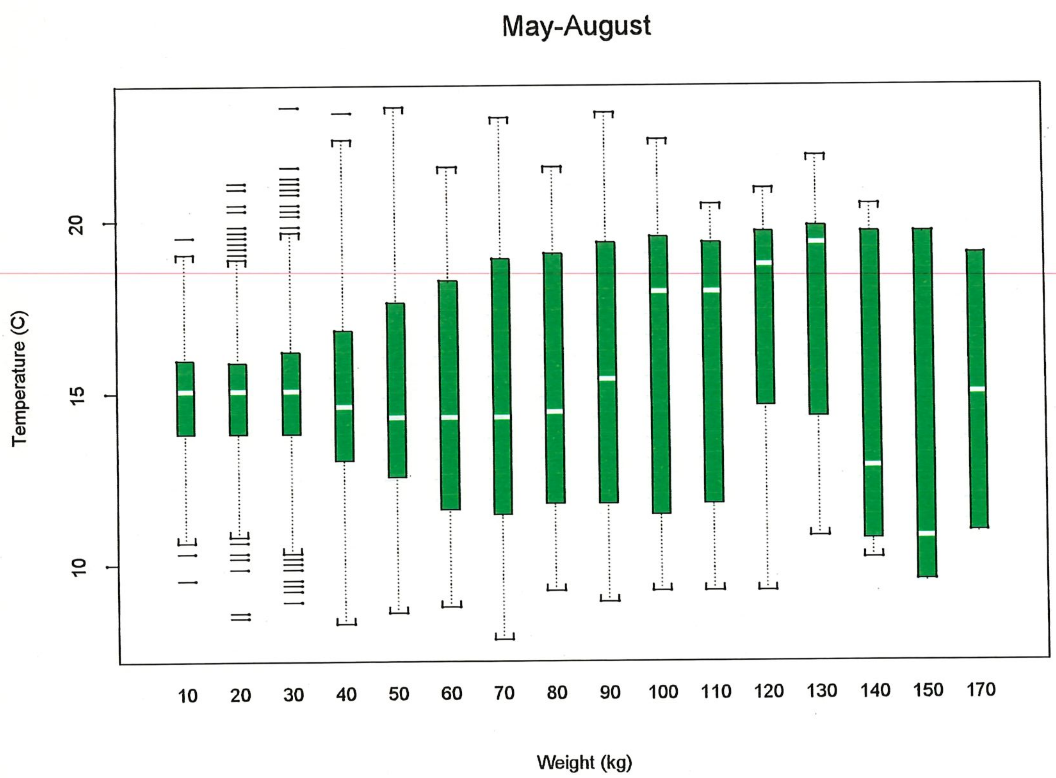
• Figure 10-10 Relative catch rate of SBT to the total catch (for each record according to numbers caught) as a function of temperature for 1990-1995.

Previously, we noted the general trend of decreasing temperatures with increasing average weight of SBT caught (Figure 10-4). This however appeared to be in discord with the observation of catches of large fish off NSW. To provide further insight into this, Figure 10-11 shows the trend of temperature of capture as a function of weight for the winter fishery. This shows the remarkable and seemingly anomalous rise of temperature for the 100-130kg class which presumably are the group responsible for the cluster of large SBT observed off NSW in winter. A slight rise in median temperature is also noted for the 90kg class. The observed temperatures for these "anomalous" group would appear to be too warm for comfort given that such large fish are normally associated with cool/cold waters south of Tasmania.

This anomaly is not unique to this fishery however, large SBT spawn in the oceans north-west of Australia in waters where temperatures are in the high 20's (^{0}C). Spawners in this region are generally in poor condition with most fish being over 160kg in weight (Tim Davis pers.comm). There is also an Indonesian fishery in waters immediately off the south coast of Java where the rapid drop in the continental slope is also associated with intense upwelling of cooler deep water (Wrytki, 1962).

Drawing upon these observations, our inferred hypothesis for the anomaly off NSW is that, firstly, large fish are capable of migrating into warmer waters; we suggest that they achieve this by migrating in the cooler deeper water masses. Secondly, that the area off NSW is a well known area where large vigorous eddies spawned off the EAC stir up deep cooler waters along their frontal edges and especially during interaction with the continental slope. These are also potentially productive areas. We infer that the larger fish migrate up to this region where they rise along the cooler edges to feed. The fact that the frontal edges are narrow and that the position along the longline where such fish are caught is not known accurately, and the fact that our estimate of the temperatures from the satellite are not in congruence with the catch position, or time, prevents us from carrying this hypothesis any further.

We note also that the larger fish are not generally caught in the intermediate zone between NSW and SE Tasmania; we hypothesise that this is due to the weakening of the eddy structures as they proceed south but note also that the occasional strong eddy does penetrate south and is accompanied by greater catches along the frontal edges (Young and Lyne, 1993).



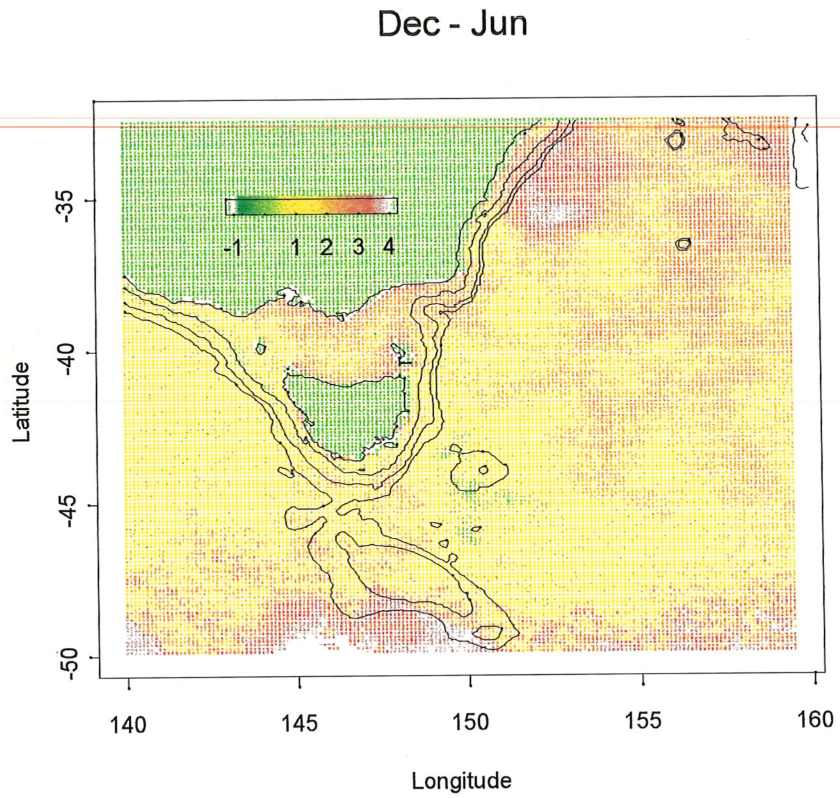
• Figure 10-11 Variation in the temperature of capture of SBT for the period May-August as a function of the weight. Note the skewed higher median temperatures for the weight group 100-130kg.

10.3. Bathymetry

Two aspects of the bathymetry were examined: the water column depth and the distance from the shelf break. Depth was selected to examine the commonly held view that larger SBT inhabit the deeper waters. Distance from the shelf break was selected to examine the hypothesis that the shelf and shelf-break areas may be providing much of the prey species for SBT (Young et al, 1996). Distance from the shelf-break was computed using the GEBCO 200m isobath as representing the shelf-break and computing distances with the ARC/INFO Geographic Information System.

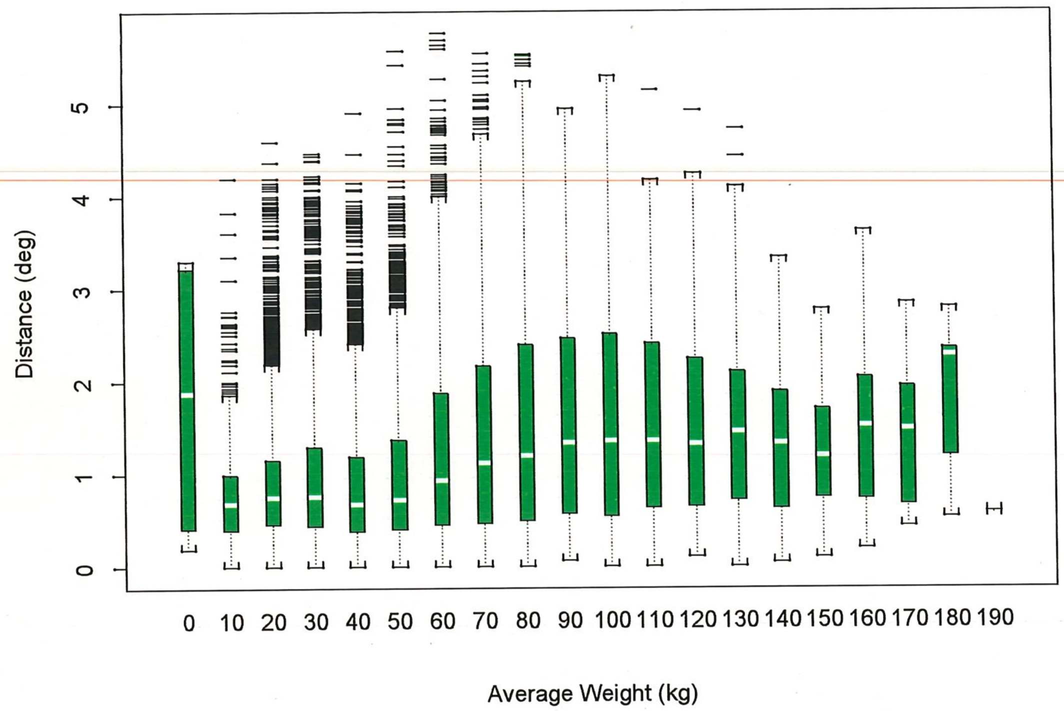
Part of the intimate association between bathymetry and temperature patterns (at least in the area of interest) is apparent in the image of the differences between the SST of December and that for June overlaid with bathymetry information (Figure 10-12). In the absence of dynamic mixing processes and currents, the whole area could be expected to heat up in a pattern that was at least zonally homogeneous. This however is clearly not the case, as the image indicates. In particular, it shows that the areas of greatest temperature change are located in the northern section of the zone and the far southern strip of the image. The heating west of Tasmania is generally less compared with the Tasman Sea. A filament of water that undergoes relatively small temperature changes is noted along the shelf-break of western Tasmania and curling around the southern shelf up to about Storm Bay on the south-eastern coast. Another extensive area of relatively minimal change occurs off south-eastern Tasmania within which the Cascade Plateau is situated.

The persistent filament off west Tasmania is explainable by the presence of the Zeehan Current which brings with it warm waters in a narrow but swift jet that follows the path indicated in Figure 10-12. However the extensive Cascade Plateau area of minimal change is an intriguing finding. A number of plausible scenarios could be advanced to explain the phenomenon. The one we advance is based on the hypothesis that this region is one that is intensely stirred due to the topographic effects on deep and surface currents flowing along and past Tasmania. Thus the warm waters of the Zeehan Current which flow along the Tasmania west coast and disappear off southern Tasmania are hypothesised to be entrained in this mixing zone (and thus raising the winter temperature). In summer when the Zeehan Current weakens, this area also receives less warm water and thus has a summer-winter difference much like that of the Zeehan Current. This is probably not the only factor responsible and other factors such as upwelling of cooler waters due to the intensity of the stirring (which may have differing strengths in summer-winter) may be operating. The oceanographic processes need to be further examined to advance our understanding in this area. Whatever the case, it is clear that this area possess rather unique characteristics that are conducive to its formation as an SBT feeding ground.



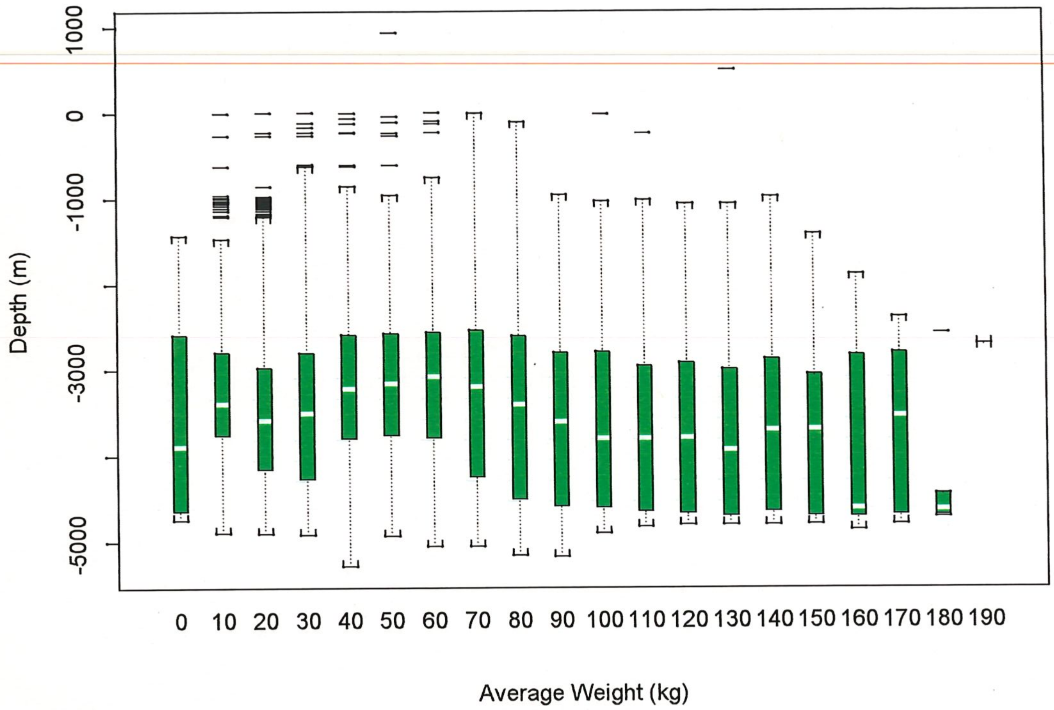
• Figure 10-12 Difference in SST temperature between the months of June and December subsampled to about 3km resolution (see Figure 10-6 & Figure 10-7 for images of each month). Topographic contours at 0m, 200m, 1000m, 2000m and 3000m are overlaid onto the image.

Larger fish do appear to be caught farther from the shelf-break (Figure 10-13), however the distribution for some of the classes (notably the 20-50kg classes) is not normal. In contrast, the distribution with respect to water column depth is not monotonic, rather the 40-70kg classes appear to have median preferences for shallower water. The analysis here is somewhat biased by the exclusion zone.



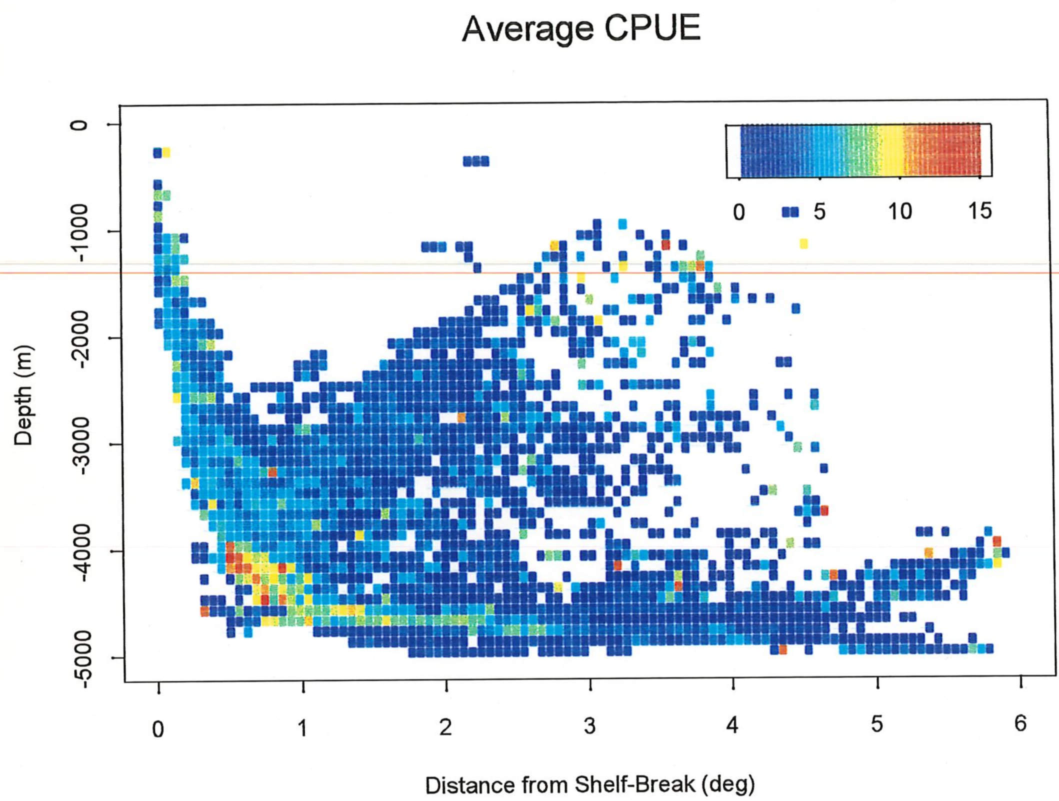
Distance (deg)
0
1
2
3
4
5
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190
Average Weight (kg)

• Figure 10-13 Distance (in equivalent latitude degree units) off the 200m isobath versus the average weight of SBT. Note the substantial number of outliers for the 20-60kg classes. The 0kg class is not relevant to the purposes of the analysis and may be ignored.



• Figure 10-14 Variation in the water column depth versus the average weight of SBT caught.

The variation of CPUE relative to depth and shelf-break distance (Figure 10-15), using all weight classes, shows high catch rates preferentially located along the continental slope. A hotspot aggregation of the highest catch rates is located beyond about the 4000m isobath and at distances less than about 1 degrees from the shelf-edge. Spatial plots of the location of high catch rates for the 50kg and over classes shows a pattern of high catches that mimics fairly closely the pattern of effort density shown in Figure 7-1. Thus, high catches occur along the south-eastern sector of the Tasmanian slope with a slight offshoot of high catches along the southern section of the saddle joining the East Cascade Plateau to the Tasmanian slope.

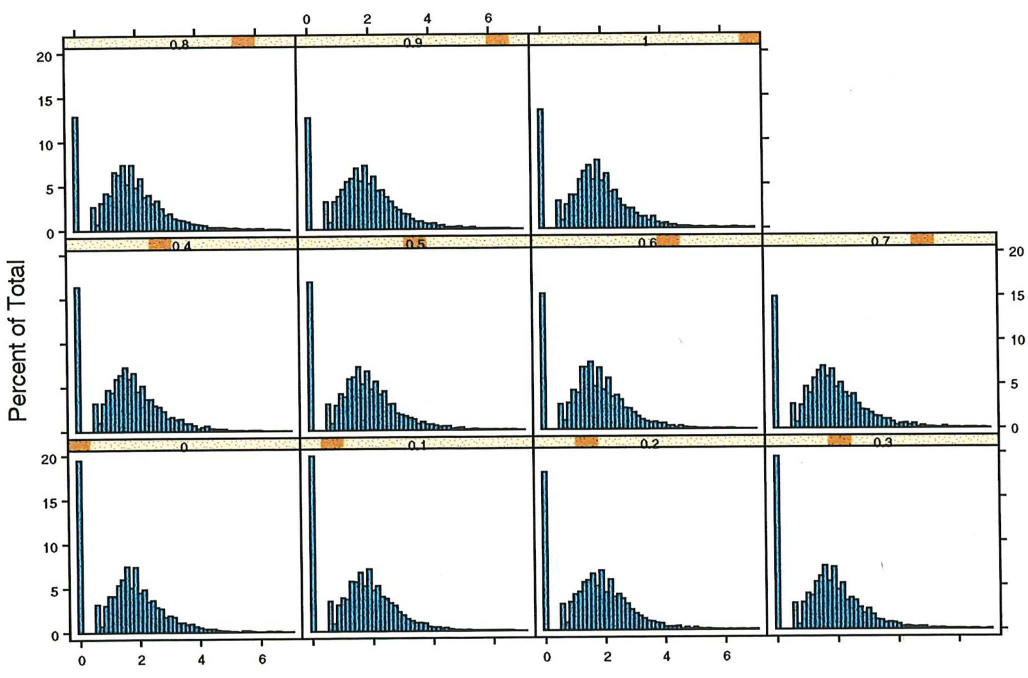


• Figure 10-15 Image plot the variation of CPUE as a function of water column depth and distance from the shelf-break (in units of equivalent latitude degrees).

10.4. Moon Phase

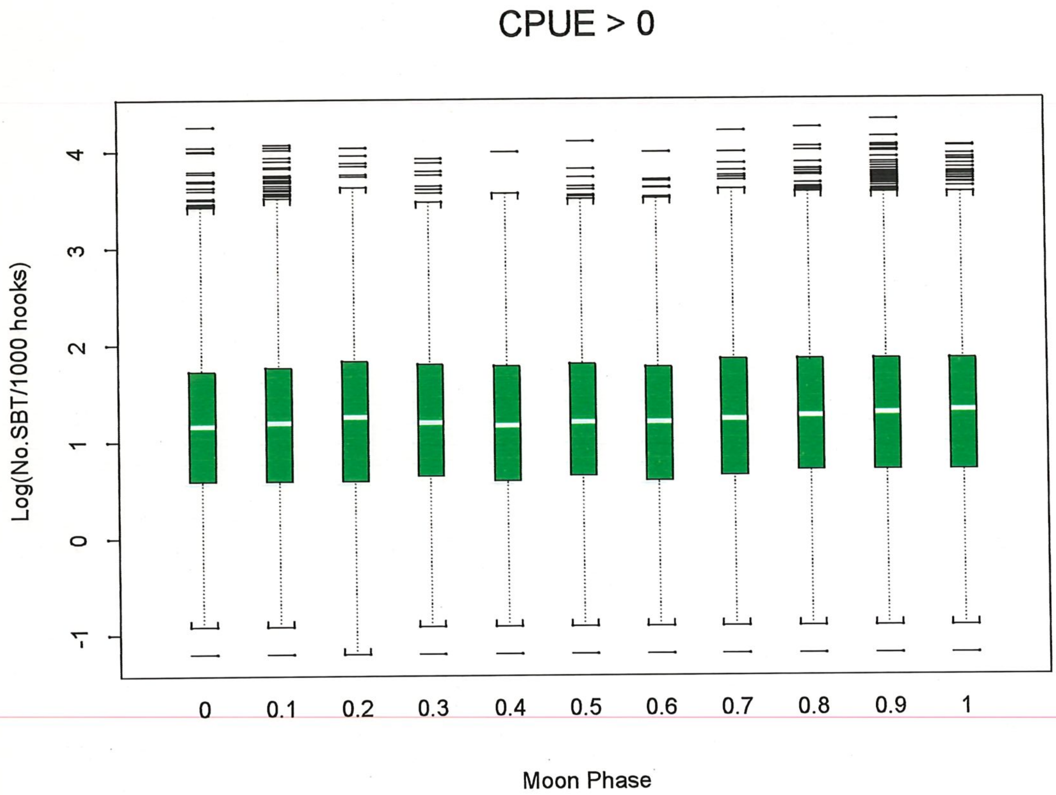
It is well known that moonphase does affect the distribution of nekton and midwater fish and that this in turn may affect the feeding behaviour, and possibly aggregation of pelagic fish. The review of the Observer Report (Section 14) notes that fishing strategies (hook depth, time of set) are varied with moonphase and would suggest that past experiences, or experience elsewhere, that fish behaviour and catchability are linked to moonphase. Moon phase was rated as the second most influential variable in the review of the Observer Report.

In an earlier study Campbell et al (1992) examined catch records, held at the National Research Institute of Far Seas Fisheries, using a Generalised Linear Model which considered the log of CPUE (presumed for area 7) as a function of moonphase (waxing and waning phases treated the same), year and month. After removing the year and month effects, an almost linear increase of about 30% was found between the new moon and full moon phases. Our initial examination of trends of log(CPUE) with moonphase revealed no significant statistical differences in the distribution of catch rates with phase (Figure 10-16). To reconcile this with the Campbell et al

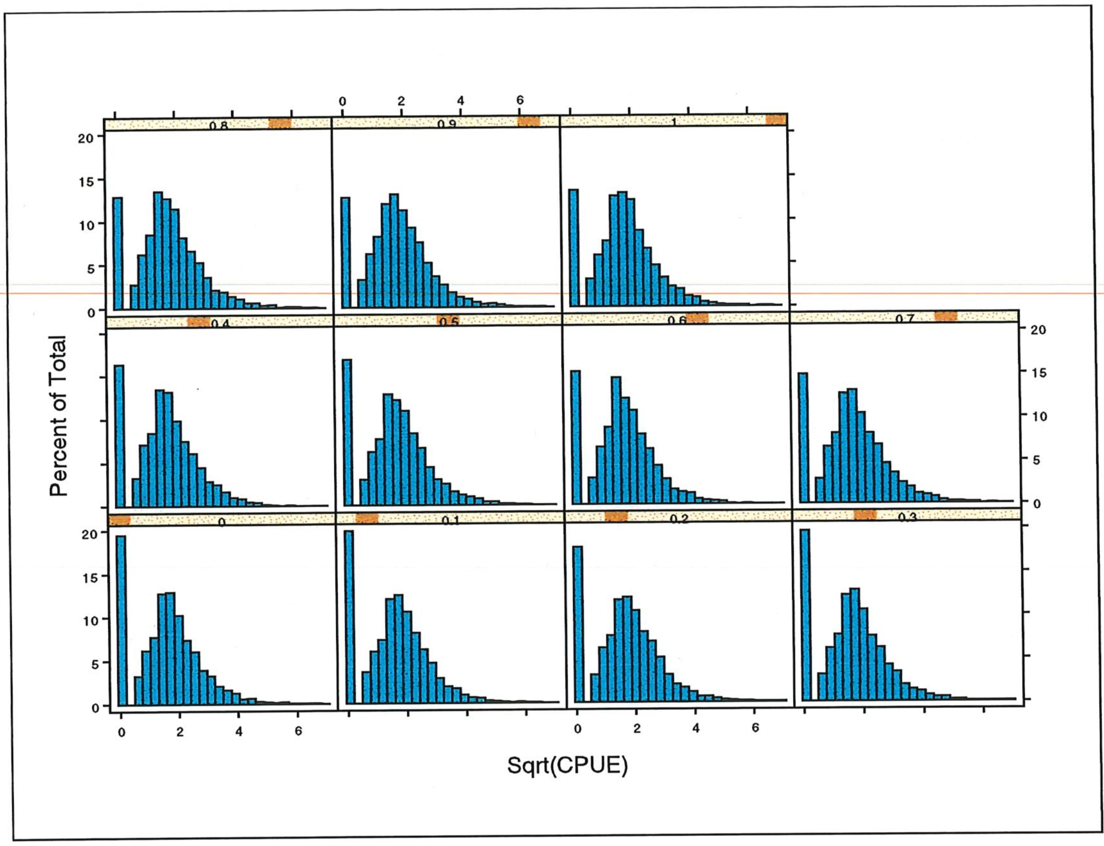


0.8
0.9
1
0.4
0.5
0.6
0.7
0
0.1
0.2
0.3
Percent of Total
Sqrt(CPUE)

(1992) findings, variation of the mean CPUE with moonphase were calculated (Figure 10-17). This shows the trend discovered by Campbell et at (1992) but also shows additional effects of the phasing of the moon (waxing and waning). Best mean catches occur in the waxing phase beyond about the first quarter with highest catch rates occurring towards the new moon. There is a distinct decline in catches on the waning phase relative to the same point in the waxing phase. In the latter half of the waning phase, catch rates are at their lowest up to the new moon phase.

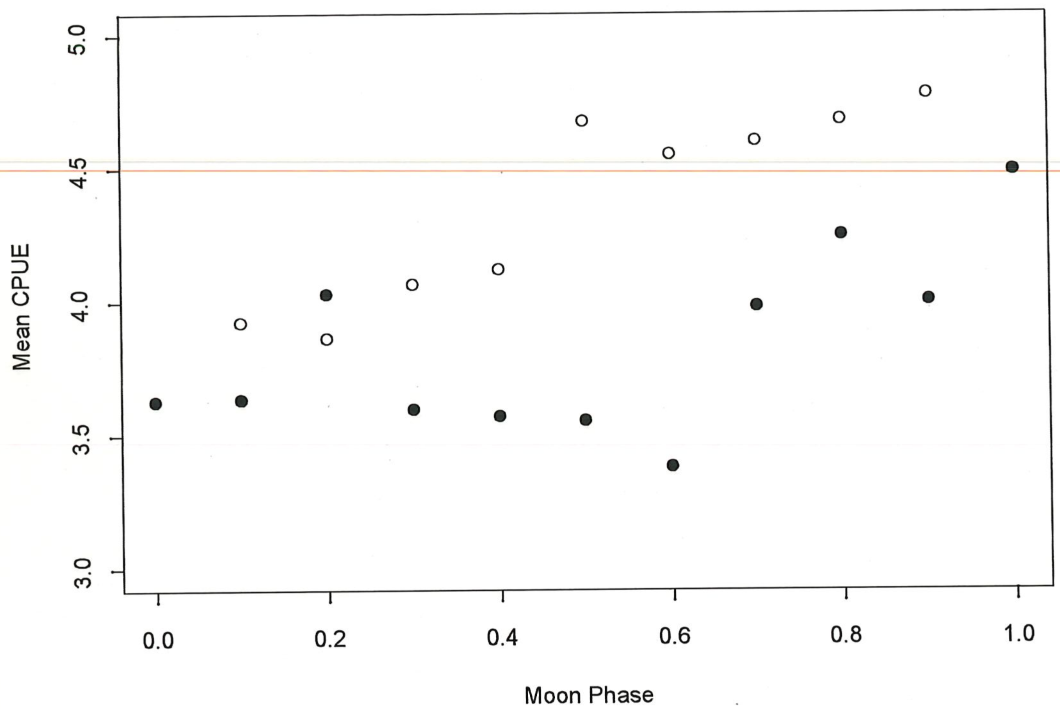


• Figure 10-16 Variation of the log of CPUE with moonphase (0=newmoon, 1=fullmoon) for records where nonzero catches were recorded.



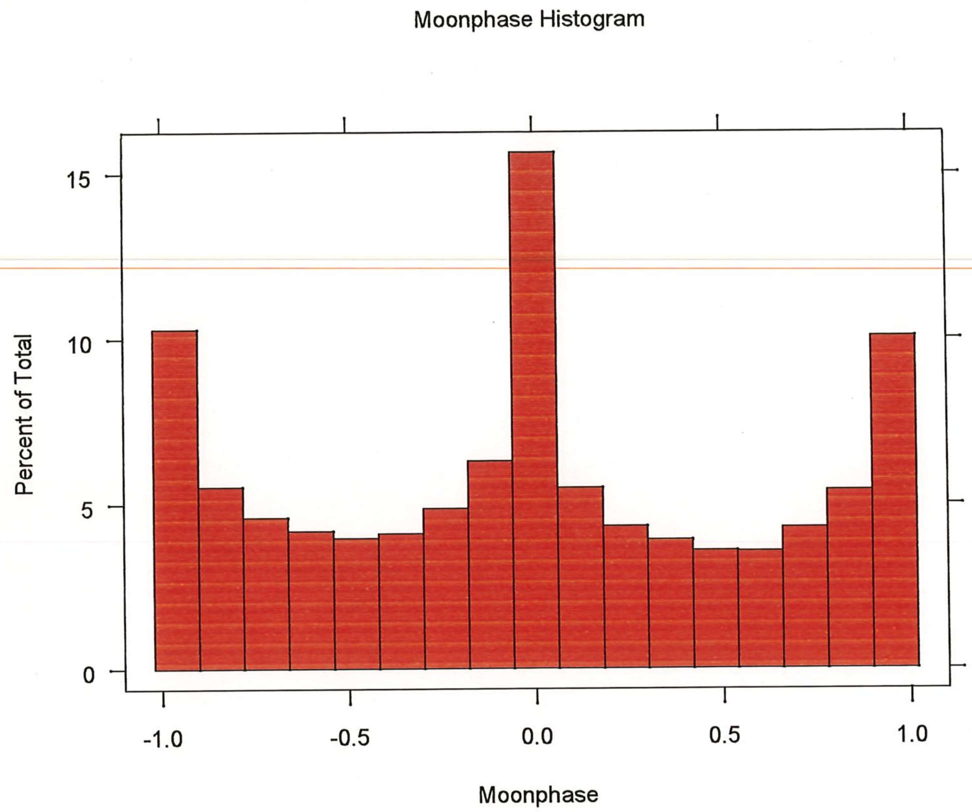
• Figure 9-17 Trellis plot of the histogram of the square-root of CPUE, including zero catches (upper panel) and not including zero catches (lower panel), as a function of the moonphase (0=new moon, 1=full moon).

To reconcile our results with the Campbell et al (1992) findings, variation of the mean CPUE with moonphase were calculated (Figure 9-18). This shows the trend discovered by Campbell et at (1992) but also shows additional effects of the phasing of the moon (waxing and waning). Best mean catches occur in the waxing phase beyond about the first quarter with highest catch rates occurring towards the new moon. There is a distinct decline in catches on the waning phase relative to the same point in the waxing phase. In the latter half of the waning phase, catch rates are at their lowest up to the new moon phase.



• Figure 10-17 Variation of the mean value of CPUE as a function of the waxing and waning phases of the moon. 0=new moon, 1=full moon, open symbols=waxing phase and filled symbols=waning phase.

The distribution of effort with moonphase (Figure 10-18) shows a distinct targeting of effort with respect to moonphase. There is greater concentration of effort centred near the new moon and full moon phases. The intensified effort near the new moon is somewhat puzzling given the evidence that relative catch rates are at their lowest levels during that period. An inspection of average weights of the catches with moonphase indicates increases during the full moon phase with the smallest weights at new moon. Thus, the new moon effort would not appear to be related to catchability of larger fish. We leave this puzzle unsolved for now and can find no explanation related to catch rates or size of fish caught.



• Figure 10-18 Variation of effort with respect to moonphase displayed as a histogram (0=new moon, 1=full moon).

The implications of the moonphase analyses and results is that much of the variability inherent in such statistics as mean catch rates is occurring in the distribution of outliers; during full moon phases there are more of these outliers. This increase is not explained by the increased effort since similar increases of effort occur at the new moon phase but without the increase in outliers (or mean values of catch rates). We interpret these results to imply that during full moon there is some aggregation and increase in the density of feeding by larger fish. Since these high catch rates are outliers they do not reflect catches made by the bulk of the fishery which are by-and-large independent of moonphase. These increased catch outliers bias such statistics as the mean. The observed increases are also small given the scale of the catch rates experienced by the fishery but it does indicate that in certain areas/circumstances substantial feeding aggregations, and hence enhanced catch rates, of SBT are occurring during phases of the full moon, particularly the waxing phase.

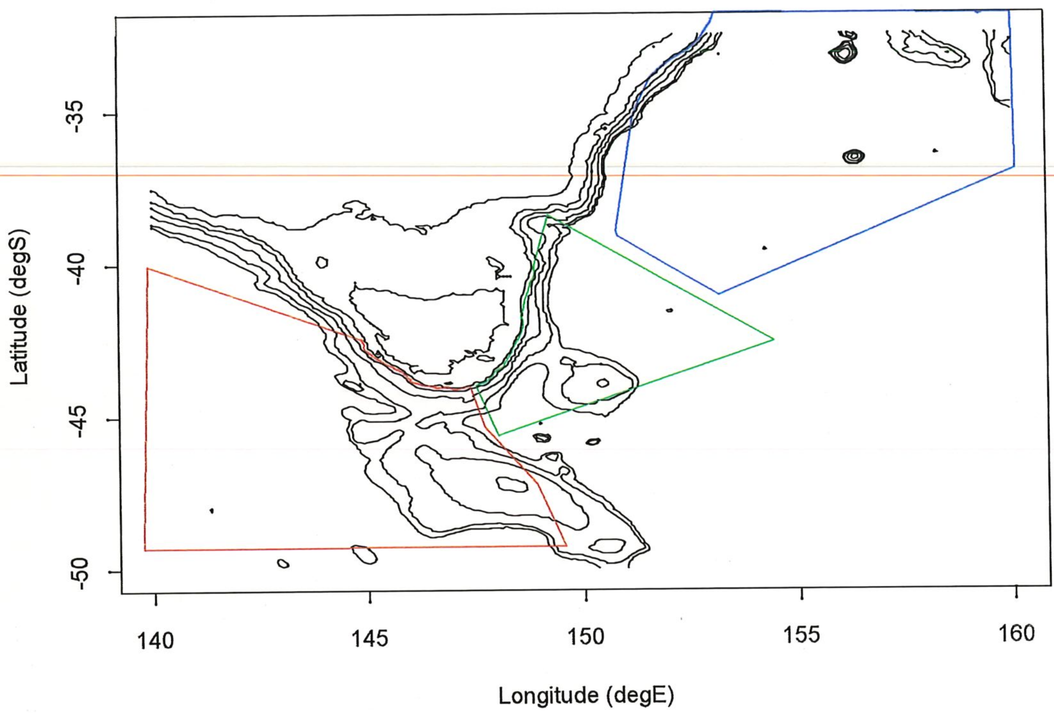
11. Regional Environmental Correlations

In this section, the variation of CPUE is analysed by partitioning the fishing zone under consideration into three distinct regions. These regions were identified by the previous analyses as having elements of CPUE variability that were distinct in some respect. The chosen regions comprised (Figure 11-1):

Region 1: Southern Tasmanian Region - comprising the region of the summer fishery (and hence larger SBT) west of the SE corner of Tasmania.

Region 2: Eastern Tasmanian Region - comprising the main fishing grounds for the winter fishery extending in a north-eastward fan-shaped pattern from the SE corner of Tasmania up to about the latitude of the northern limit of Tasmania.

Region 3: South-East Australian Region - extends northward from the northern limit of Region 2 and includes the area east of Bass Strait up to the northern limit of the study zone (32°S).



• Figure 11-1 Demarcation of regions used to partition the SBT catch data and environmental information for analysis, overlaid onto contours of the bathymetry derived from the ETOPO5 dataset. The regions are referred to as region 1, 2 or 3 proceeding sequentially from the southern to the northern region.

For each of these regions, the environmental statistics used in the analysis were derived from the SST image dataset. Statistics were computed for each region for two "seasons" and by year. The chosen seasons were winter, from May to August (inclusive), and summer from October to December (inclusive).

Whilst CPUE statistics for these seasons were computed using data for the months listed, statistics from the SST dataset for these season were computed using a representative image from mid-June (representing the winter season) and a representative image from mid-December (representing the summer season). Statistics computed for CPUE comprised the median and variance (for each combination of year, season and region), after taking the log-transformation of CPUE. Statistics computed for the SST image data (factors as per CPUE) comprised the mean, variance and median temperature and various statistics of the spatial correlation structure which we describe in the next section. The reasoning behind the attempt to quantify the spatial correlation structure were previous observations (eg Young and Lyne, 1993, see also section 4) that catches of SBT and other tunas tend to be concentrated around frontal regions and eddy structures, at least for the regions offshore of the shelf-break.

11.1. Spatial Statistics of SST

We chose the two dimensional spatial correlation structure as the basis for computing the spatial statistics. In one dimension, the spatial autocorrelation measures the correlation between spatial locations separated by various spatial distances, in much the same way that a time-series autocorrelation measures the correlation between observations separated by various time lags. In two dimensions, the spatial separation distances can be taken along various radial trajectories (as in compass directions) thereby giving rise to a spatial correlation structure that depends on both spatial separation and radial direction.

Given this two-dimensional structure (one for each year, season and region combination), statistics chosen to quantify the distribution comprised:

- The sum of the autocorrelation coefficients within a spatial window of 50 units width (approximately 200km) centred over the origin of the spatial correlation structure. This statistic, measured the overall correlation, a large value implying that the spatial structure was relatively homogeneous, or smoothly varying, whereas a small value implying greater randomness of structure.

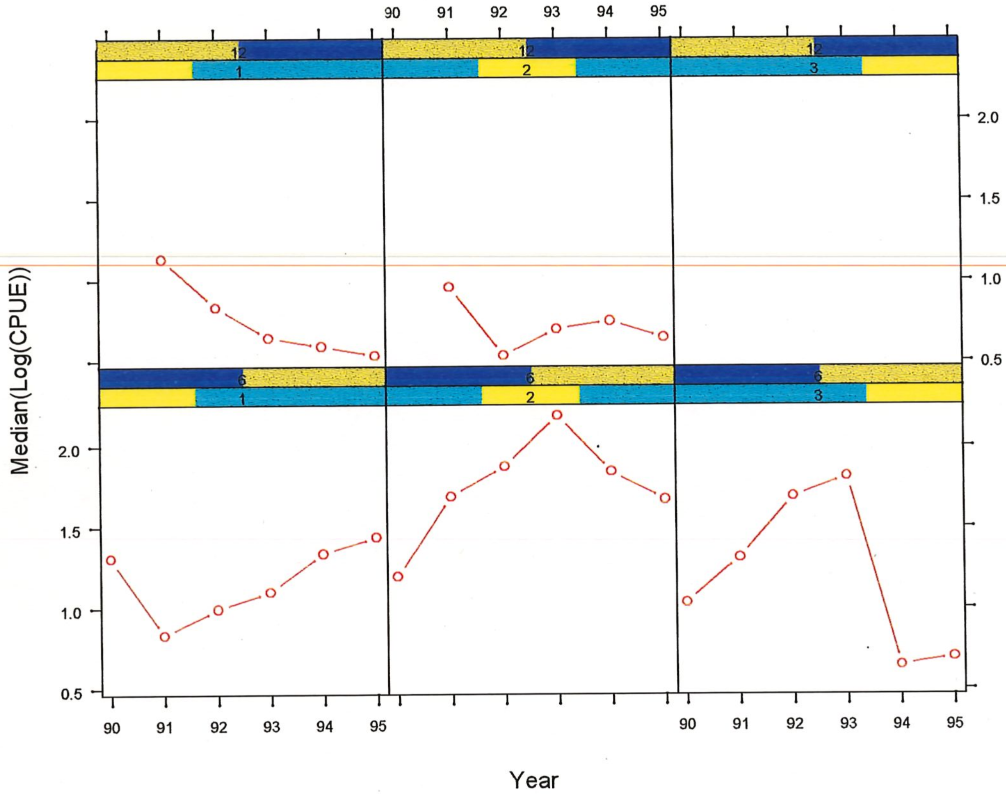
- The principal angle of the correlation structure computed as the angle about which the rotational "moment of inertia" is minimised. In essence, this statistic was used to indicate the direction in which the greatest extent in correlation occurred. Thus with an elliptical SST field, this statistic will pick out the principal axis of the ellipse (axis along which the ellipse is most extended).

- A structural "circularity" index. This was computed by calculating the rotational "moment of inertia" (as in the second statistic above) for a set of angles. We chose 72 angles spanning the range from 0 to 180 degrees (only one half of the 360 degree range needed to be computed because of the symmetry of the spatial correlation structure). The inertia values for each angle was then scaled by the maximum value and the resulting values were averaged. For a perfectly circular structure, the values for each angle would be the same and hence when averaged over all angles would be equal to 1.0. Departures from this ideal were used as a measure of the distortion to the SST field.

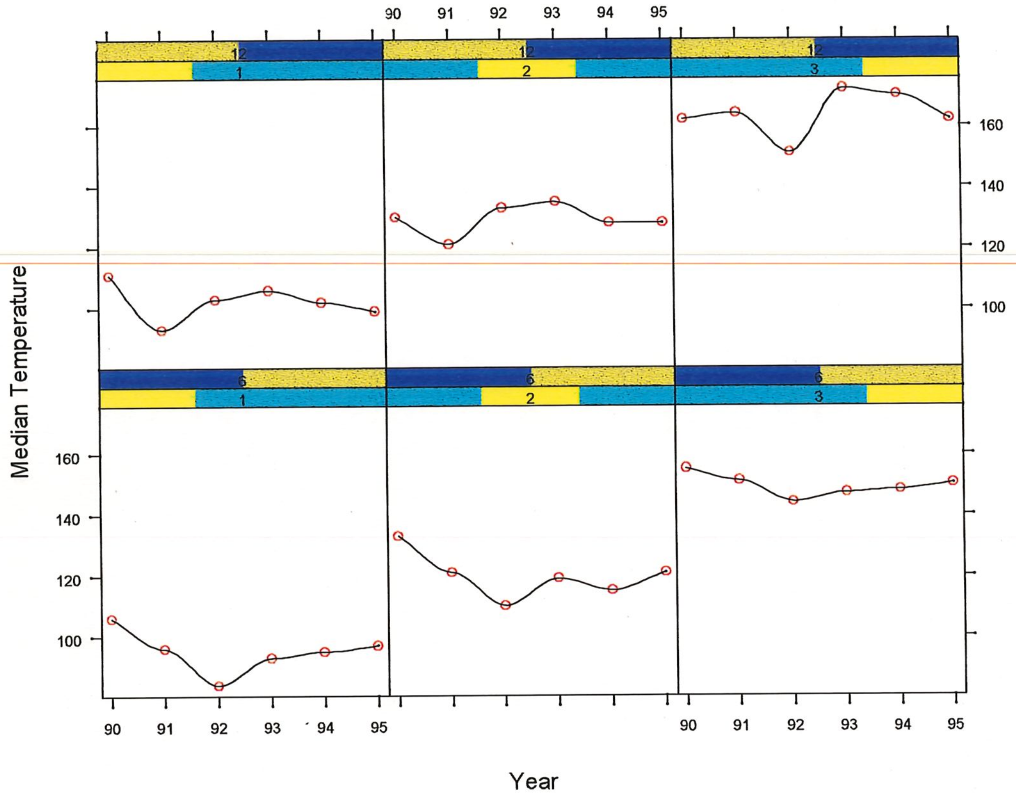
Thus in summary, the 3 chosen statistics measured the overall correlation, the principal directional orientation and the circularity of the spatial structure of the SST field.

11.2. Correlation Analysis

The correlation analyses attempted to relate the log-transformed CPUE (mean and variance), computed for each year, season and region combination (see for example Figure 11-2) to environmental variables comprising the median temperature and the three spatial structure statistics. For the CPUE calculations, we used SBT of 25kg or less as this size class was expected to respond more sensitively to temperature changes (as observed in a previous section). A general analysis of variance was not possible given the limited number of observations and the extensive list of possible factors. Instead, the chosen procedure was to examine the numerous scatterplots of CPUE variables against the dependent variables, as well as plots of dependent variables against each other. Analyses of variance and linear models were also examined between each of the CPUE statistics against each of the dependent variables (median temperature and the 3 spatial statistics), and between the dependent variables themselves. We noted that whilst CPUE statistics appeared to be not significant when all regions were combined, in some instances only using regions 1 and 2 (in combination, or separately) resulted in higher correlations.



• Figure 11-2 Trellis plot of the variation in the median of the log-transformed CPUE, for SBT of 25kg or less, by year for the summer/winter seasons (identified by 6=winter and 12=summer headings on the top header of each plot) and for each of the 3 regions (identified by 1, 2 or 3 in the lower header for each plot.



• Figure 11-3 Trellis plot of variation in median temperature by year for the summer/winter seasons (identified by 6=winter and 12=summer headings on the top header of each plot) and for each of the 3 regions (identified by 1, 2 or 3 in the lower header for each plot).

The statistically significant relationships that emerged from these analyses were:

Variance of CPUE versus *median temperature* (negative relation with Pr(F) = 0.004) using regions 1 and 2 only (Figure 11-4).

Variance of CPUE versus *principal correlation angle* (positive relation with Pr(F) = 0.03) using regions 1 and 2 only (Figure 11-5).

Amongst the dependent variables themselves, the significant correlations were:

Median temperature versus *principal correlation angle* (Pr(F) < 0.003), for all regions and for regions 1 and 2 together (Figure 11-6).

Sum of correlation versus *principal correlation angle* (Pr(F) = 0.01), for regions 1 and 2 together only.

Circularity index versus *principal correlation angle* (Pr(F) = 0.013), for regions 1 and 2 together only.

Circularity index versus *sum of correlation* (Pr(F) < 0.00012), for all regions and for regions 1 and 2 together.

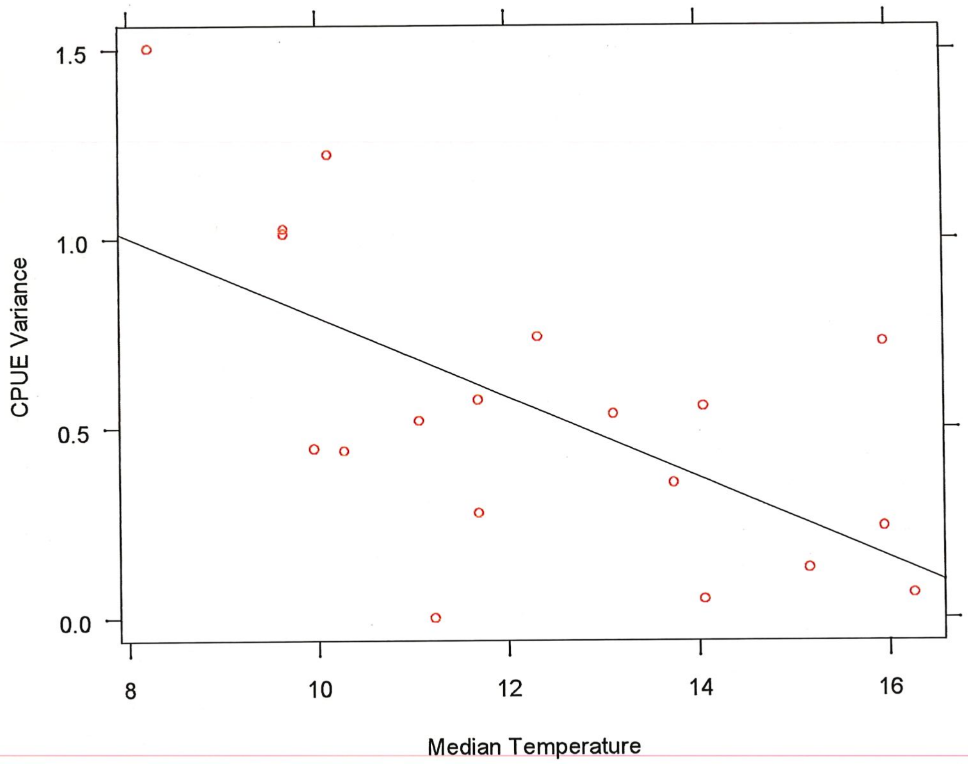


Figure 11-4 Variation of CPUE variance (defined for each year, season and region combination) with median temperature indicated by the scatterplot and a linear regression line. Data for this plot is limited to regions 1 and 2 (region 1 is the southern area off Tasmania and region 2 is the area off eastern Tasmania).

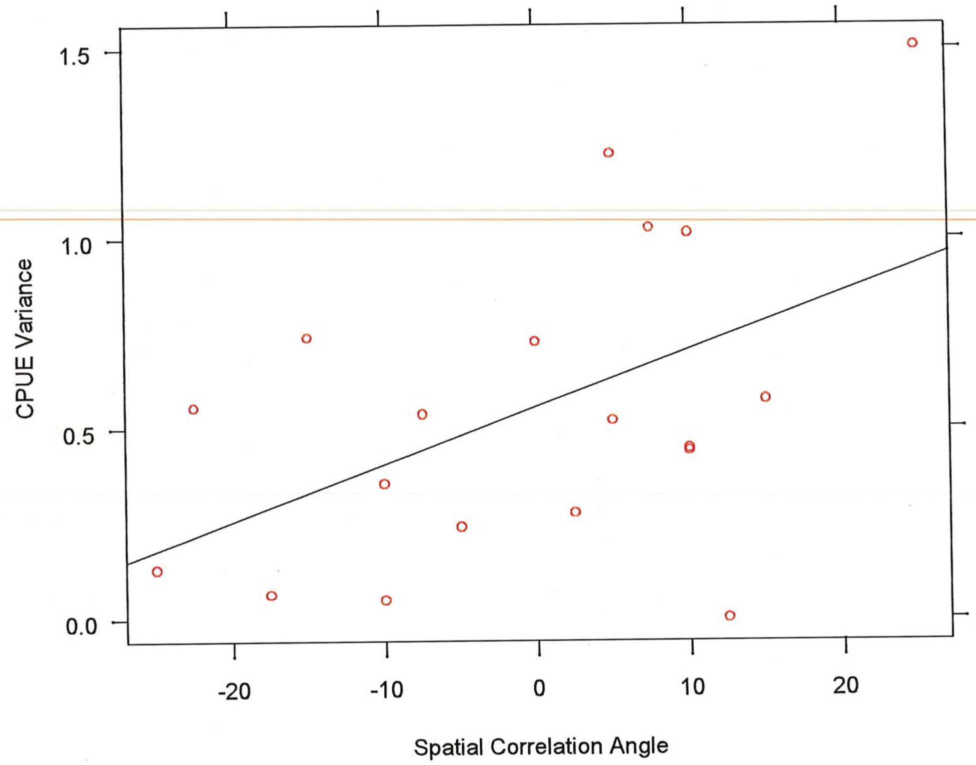


Figure 11-5 Variation of CPUE variance (defined for each year, season and region combination) with the angle of the principal axis of the spatial correlation structure. A scatterplot and a linear regression line are indicated. Data for this plot is limited to regions 1 and 2 (region 1 is the southern area off Tasmania and region 2 is the area off eastern Tasmania).

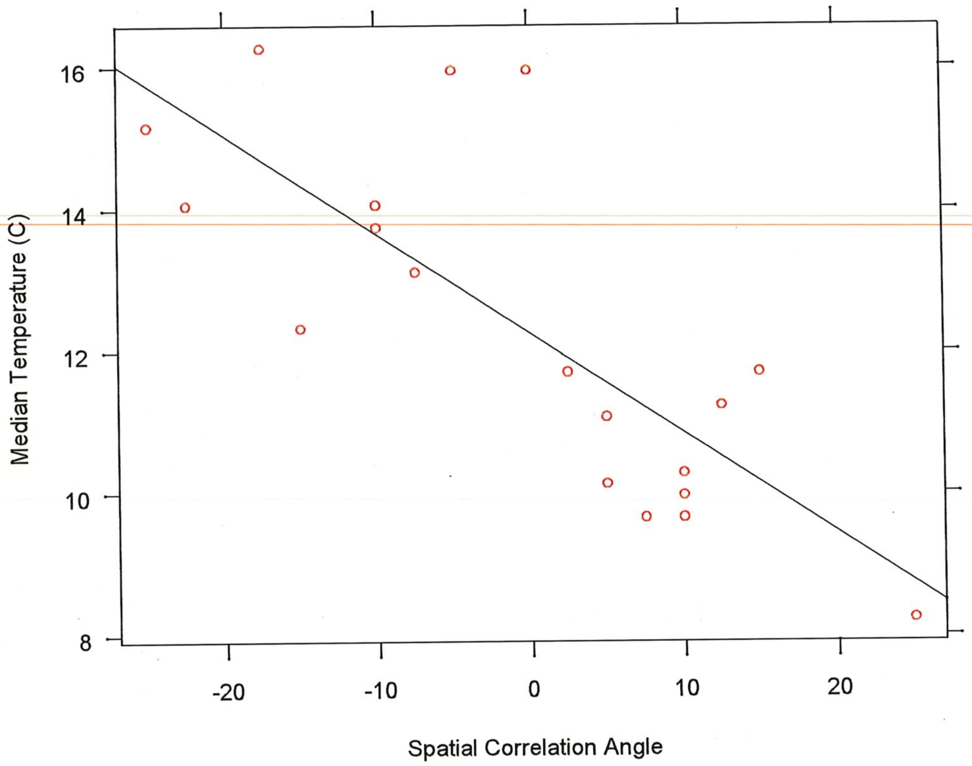


Figure 11-6 Variation of median temperature with the angle of the principal axis of the spatial correlation structure. A scatterplot and a linear regression line are indicated. Data for this plot is limited to regions 1 and 2 (region 1 is the southern area off Tasmania and region 2 is the area off eastern Tasmania).

The salient points to note about the results of the analyses, *keeping in mind that this applies only to the SBT weight class less than 25 kg*, are:

1. *CPUE by itself is not significantly related to each of the environmental variables (taken in turn). This does not necessarily mean that a combination of the environmental variables in concert was not significant but that the paucity of observations did not make such a general analysis feasible.*

2. *Variance in CPUE was significantly related to each of median temperature and the principal correlation angle but only for regions 1 and 2 taken together. The correlation was not significant if region 3 was included. These two environmental variables are also significantly correlated between themselves.*

3. *Significant correlation exists between some of the environmental variables so that these variables are not independent measures of the environment.*

11.3. Interpretation of Correlation Analysis

If we first look at the correlation between the significant environmental variables: median temperature and the principal correlation angle, the results suggest that the spatial structure, as measured by the principal angle of correlation, is influenced by the extent of warm, or cold, water masses in the regions. Presumably, the spatial structure of warm water influx into the fishing zone from the East Australian Current determines the strength of the wedged-shaped intrusion seen in the satellite images (Figure 10-6, Figure 10-7). The other significant correlations between the environmental variables also suggest that the extent of warm/cold water masses (as measured by the median temperature) are also linked to significant changes in the coherence of the spatial structure (sum of correlation and circularity index).

The lack of significant correlation with CPUE, as opposed to the variance of CPUE, indicates that the relative success, or otherwise, of catch rates are more *consistently* related to some environmental factors. This in turn suggests the corollary inference that variations of CPUE, at least for the years analysed (1990-1995) are influenced by factors other than those environmental factors used, or by other intrinsic variations in the SBT class (<25kg) occurring outside the fishing zone analysed, or at larger scales (eg SOI-related changes noted previously).

12. Summary

The temporal and spatial trends of CPUE off SE Australian are interpreted in this project with a view to examining the influences of environmental effects. A review of past studies indicates unanimous consensus that pelagic fish have a preferred, generally age-dependent, range of temperature. For SBT, past studies of catch rates show that within the preferred temperature range, aggregations are likely to be associated with meanders, frontal systems and upwellings. In addition in regions of topographic protrusions, aggregations are likely when these protrusions intercept seasonal migrations of the major frontal systems. Off SE Australia, the major frontal system associated with SBT catches is the Sub-Tropical Convergence Zone, a broad band of mixed waters extending from southern NSW to well south of Tasmania (eg Clementson et al). A review of the Observer Reports also indicated temperature as the top ranked indicator with moon phase the next highest ranked indicator.

Off SE Australia, the preferred temperature ranges decreases proceeding from the north east to the south west sectors of the Tasmanian fishing zone. The range of 15.2 - 16.4^{0}C with an optimal value of 15.8^{0}C for the north east sector is not in disagreement with the much earlier observations of Hynd. Decreases of up to 2.6^{0}C are noted for the south west sector relative to the north east.

There are two fishing seasons, a winter and a summer fishery, with larger fish being preferentially caught in the summer fishery off the southern and south-western sections. In both seasons, the temporal evolution of catch rates is unable to discriminate a reversal in the pattern of migration of SBT out of the Tasmanian fishing zone.

Temporal trends indicate a sharp decline in the average weight of SBT caught, relative to other size classes, from 1989 up to 1995 with a slight increase in the median weight from 1991 to 1994; an alternate explanation is that the contribution of juvenile fish increased Up to 1988 there was a range of small and large (>80 kg) fish being caught, however from 1989 onward, the catch of larger fish diminished. The last few years of the study period give no significant indication of the return of large fish as measured by their relative contribution to the catch histogram.

SBT caught for the spring/summer fishery also shows a decline in the contribution of larger fish to the total catch from 1991 onwards. Whilst small fish are found throughout the sector from south of Tasmania up to NSW, the distribution since 1989 shows a much more widespread and intense distribution of small fish particularly noticeable for the areas off south-eastern Tasmania. The distribution for 1994 and 1995 are less intense and in keeping with the lower intensity distributions of the 80's. In contrast, the distribution of large fish shows a distribution that is largely restricted to the region from south-west to south-eastern Tasmanian and the area off NSW.. Trends are difficult to discern but there is a suggestion that since 1989, the intensity of aggregations off NSW has been in continual decline - in contrast to the trend for the small fish. However there does not seem to be a clear general spatial pattern associated with this temporal trend.

Yearly trends in CPUE show an overall cyclical variation beginning in 1980. When examined with respect to the weight of SBT, the cyclical trend is not obvious in the different weight classes. The 50-75kg size category is the only one to shows recent increases but all the other classes show a declining trend. The hypothesis that the trends for the juvenile fish reflect downstream effects of the western surface fishery is not supported by the observed substantial decline in this size class throughout the 80;s when the surface fishery was in decline. None-the-less they may well be a downstream effect which needs to be analysed as part of a wider study.

The spatial distribution by weight class show remarkable clusters of larger fish at the two extremities of the study region with gradations of weight proceeding into the middle of the area. Streams of larger fish are noticed along the shelf-break and outer offshore regions. The observation of catches of large fish off NSW in winter is hypothesised to be due to the increased productivity associated with the deep stirring of cooler waters by energetic eddies which is targeted by the large fish which migrate in the deep cooler waters up to that region.

Statistically, distributions of CPUE do not appear to be enhanced with moonphase although there is greater concentration of effort following the new moon and just before full moon with consequently greater overall catches during these periods of intensified effort. However mean values of CPUE, and average weights, do show a trend with highest catches occurring at the full moon phase, particularly the waxing phase. Whilst these increases are relatively small, they imply that a bias in such statistics as the mean is being introduced by an increase in the outliers of high catch rates during the full moon phase. This is interpreted as being due to an enhanced aggregation of larger fish during the full moon phase.

Yearly catch rates, and average weights, of SBT off eastern and southern Tasmania do appear to relate to the Southern Oscillation Index. Warm phases of SOI, when the index is negative and conditions off eastern Australia are relatively cool, are accompanied by increase catch rates and smaller fish, and vice-versa for the cool phase of SOI.

A variety of measures of the spatial structure of the environment were calculated from the satellite images of SST. Of these, the spatial structure, as measured by the principal angle of correlation, was found to be influenced by the extent of warm, or cold, water masses in the regions. Significant correlation was also noted between the extent of warm/cold water masses (as measured by the median temperature) and the coherence of the spatial structure. The lack of significant correlation between CPUE for small SBT (under 25kg) and the spatial structure variables, as opposed to some significant correlation with the variance of CPUE, indicates that the relative success, or otherwise, of catch rates are more *consistently* related to some environmental factors. The corollary inference is that variations of CPUE, at least for the years analysed (1990-1995) are influenced by factors other than those environmental factors used, or by other intrinsic variations occurring outside the fishing zone analysed.

In conclusion, there are substantial temporal and spatial variations in CPUE as well as the size of SBT. Of these variations, spatial temperature variations in the study zone, in association with bathymetry, appear to influence the general spatial distribution of CPUE and size of SBT. Catch rates and size of SBT off eastern and southern Tasmania are significantly correlated with the Southern Oscillation Index (SOI), opening the possibility of predicting catch rates through forecasts of the SOI index. A wider study examining the downstream effects of the western surface fishery off WA and SA is recommended to examine the impacts of regional variations in fishing activities. There is a noticeable increase in catch rates with full moon, particularly the waxing phase. Overall, the changes in mean catch rates with moonphase are small and reflect a bias by outliers of large catch rates which are inferred as being due to enhanced aggregations during full moon. Observations of large SBT in the northern section of the fishing zone appear to be related to the unique energetic oceanic conditions off southern NSW. However temporal variation in CPUE from 1990-1995 do not appear to be significantly correlated with the chosen environmental factors although the variance of CPUE is correlated to the extent of warm/cold water masses. The consistency of CPUE, rather than CPUE itself, appears to be more strongly influenced by local environmental factors.

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14. Appendix A Review of Observer Reports

Reports prepared by Mr Russell Bradford, CSIRO Division of Marine Research

14.1. Analysis of Observer Reports 19 April to 18 July 1994 (Tasmanian Winter Season)

Due to a change in the format of the observer reports much of the detail regarding the gear has been omitted. For the most part the gear was described as:

"...typical longline equipment. (see *AFZ Observer Program Guide Manual* issued May 1992 for details)."

Similarly, the data sheets detailing the targeting methods used and the relative importance of each method have been omitted from the AFZ Observer Reports. For these reasons the analysis of the reports for the 1994 winter season off eastern Tasmania should be viewed with caution.

A total of 13 observers participated in monitoring the activities of the longline fleet during the 1994 Tasmanian winter season. On average each observer spent 11.8 (± 0.6 d) days on each vessel visited, with 10.7 (±0.6 d) of those days spent fishing. The shortest cruise was of 4 days duration; the longest 18 days.

Gear

The average mainline length (132 ± 4.9 km, n = 5) appears to be slightly longer than that reported in previous years (128.5 km). However, the variation between the minimum and maximum values is much lower with mainline lengths ranging between 120 and 144 km during the 1994 winter season. Some differences were noted for several aspects of the fishing gear and techniques (Table 3). For example, the number of snoods varied between five and seven in previous years compared with the six to nine snoods per basket in 1994. Snood length, the minimum depth fished and the average soak time were less in 1994 than reported during earlier cruises (Table 3). However, the average maximum hook depth was greater in 1994 compared with the previous years (Table 3).

Bait

The bait types most commonly used were: squid (and occasionally squid lures), mackerel (slimy, blue, mackerel scad, Indonesian, silver and jack), pilchard (Japanese, Peruvian) and milkfish. Squid was most commonly used on the first hook (i.e. shallowest hook), with 21 of the observers reporting the use of squid, 5 reporting mackerel and 4 pilchard on the shallow hook. However, the last hook (also shallow) was baited more evenly with squid and mackerel; the ratio being 13 :11.

• Table 14-3 Changes in the gear setup between the 1994 SBT winter season and the previous reports

	1994			pre 1994
	mean	SE	n	mean
Snood length (m)	34.63	1.2	19	36.3
Ave min hook depth (m)	60.1	3.4	28	67.8
Ave max hook depth (m)	132.3	5.0	29	124.5
Ave soak time (h)	3.95	0.2	20	4.5

Indicator Rankings

Sea surface temperature was given as the most important indicator of where to set the lines (Table 4), however, the direction and position of setting within the Tasmanian sector is largely controlled by the space allocated to a particular vessel. As in previous years not all indicators are used by every fishing master. Table 4 lists the relative importance of the each of the indicators. Of note, the category "other" ranked higher in 1994 than previously. The change in the format of the AFMA reports does not include a defined area for the reporting of SBT target indicators; therefore, the number of reports supplying this information has been reduced in the 1994 season.

• Table 14-4 Average rank of SBT target indicators listed in AFMA Observer reports.

Indicator	Averaged Ranking	n
sea surface temperature	1.2	24
"other"	1.9	16
currents and eddies	2.3	6
bottom topography	2.6	8
baitfish	2.9	4
upwelling	3.4	5
moon phase	3.6	5
whales and dolphins	–	0
birdlife	–	0

Included in the observer reports for 1994 was the catch per unit effort (CPUE) observed. The observed CPUE was widely spread, ranging between 134 to 452 kg·1000 hooks. Average CPUE, 275.6 kg·1000 hooks (±16.2), more accurately reflects the true CPUE of a cruise as minimum and maximum CPUE (observed) are affected by the number of days spent fishing/observing. For example the highest observed CPUE (452 kg·1000 hooks) occurred on a four day cruise.

Conclusion

The AFMA observer reports for the 1994 winter season do not change the conclusions derived from the previous reports. In fact, the 1994 reports support and enforce the finding that the previous experience of the fishing master and the collective knowledge of the fleet may be underestimated in the ranking of the indicator categories for the targeting of southern bluefin tuna.

Tasmanian summer season TSS)- 1/11/92 to 31/1/93

Tasmanian winter season (TWS)- 15/5/93 to 31/7/93

14.2. Summary of AFZ Observer Program Cruise Reports: Japanese Style Longline Tuna Fishing in the Australian Fishing Zone. 1 November 1992-31 July 1993. Report: AA93(1). Dated 1st September, 1993

Summary report 1/11/92 to 31/7/93:

Fishing procedure:

Average length of longline 155 km.

Most vessels used tetron line.

Average diameter of longline was 6.9mm

Buoy lines ranged from 10 - 23m averaging 12.2m

In TWS number of different branchlines averaged 2.86 (3.7 for TSS)

Total length of branchlines ranged between 29 - 50m, average 33.5 for TWS (42.5 m for TSS).

No. hooks/branchlines between buoys almost always 6 or 7.

Hook depth ranged between 21 - 230m for TWS (45 - 159 m for TSS)

Most common baits: squid, mackerel, silver mackerel, jack mackerel, sardine/pilchard, milkfish.

Squid most commonly on first and last hooks (shallowest).

Squid lures more prevalent this year with some success noted.

Targeting:

Thermoclines/sea surface temperatures noted as most important

Historical records and communication with other vessels in the area were highly rated.

Combination of bottom topography, upwelling, and baitfish were additional targeting aspects, particularly for TWS.

Hook depth occasionally adjusted prior to full moon.

Hook/bait soakage time was generally a minimum of 4 h.

Setting pattern initially N-S or S-N in a straight line 2 - 3 nm apart.

Line setting commonly at 10 - 11.5 kn; hauling at 2 - 5kn.

Once more room was available to fish (June/July) "L"-shaped setting pattern became more prevalent.

Note was made that when a warm (15°C) frontal boundary passed a longline vessel the catch of SBT dramatically increased up to 2752 kg for the haul; reportedly the largest amount taken for the night in Tasmanian waters.

14.3. Summary of AFS Observer Cruise Reports for the 1991 Tasmanian Tuna Season. AFZ, Area 'G'

Dated: 19 September 1991.

Common hook set-ups varied from 5 to 7 per buoy.

Common bait types: squid, mackerel, pilchard, trevally.

Artificial lures used in some instances.

Vessels appeared to target thermoclines where the sea surface temperature was 15 - 16 °C.

Hook/Bait soakage time was generally a minimum of 4 h.

Setting pattern initially N-S or S-N in a straight line 2 to 3 nm apart.

Setting was at 10 12 nm; hauling at 4 -7 nm.

14.4. AFZ Observer Program Annual Report for the 1990 - 91 Australian Tuna Season, 12 th February, 1992

Report: AA90-91(3)

Five to eight hooks per buoy, often seven.

Common bait types: squid, horse or jack mackerel, mackerel, sardine, pilchards.

Artificial baits were occasionally used with limited success.

Water temperature was used to target thermoclines or cooler upwellings near seamounts.

Fishing master's intentions were to target the area of turbulence created by upwellings along contours.

In Tasmanian waters vessels targeted areas of current convergence; where warm East Coast waters met cooler southern waters often causing sharp thermoclines.

Most common longline material 7-8 mm black (or pink) Kuralon.

Average longline length was 98 km; ranging from 80 - 150 km.

Setting was generally straight although "L"-shaped patterns were relatively frequent.

Setting commenced between 0100 - 0900; soak time usually around 4 h.

14.5. Summary of AFZ Observer Cruise Reports for the 1990-91 East and West Coast Tuna Season, 12th February, 1992

Report: AA90-91(2) - Little about fishing around Tasmania

Line setting commenced around 0100 - 0600 h.

Common hook set-up was 5 -8 hooks per buoy; often 7, deepest hook set at ~ 150m.

Common bait types: squid, horse or jack mackerel, mackerel, sardine, pilchards.

Squid found in stomach contents of tuna more often around a full moon.

Squid was also more often used on the hooks in the shallowest settings.

Sea surface temperature was used to target thermoclines or cooler upwellings near seamounts.

Vessels worked in waters where the surface temperature was 18-26 °C, but mainly 22-24 °C.

Setting pattern was generally straight although "L"-shaped pattern was relatively frequent.

Most common type of material was 7-8mm black (or pink) Kuralon.

Average length of longline was 114 km; ranging between 80-150km.

Line setting conducted at 9-11kn was between 0100 to 0600 h; hook/bait soakage was usually a minimum of 4 h.

14.6. Summary of AFZ Observer Program Cruise Reports: Japanese Style Longline Tuna Fishing in the Australian Fishing Zone

Report: AA92(2a); dated 30th March, 1993.

Vessels fishing in the Tasmanian region generally targeted known fishing grounds.

In the Tasmanian region hooks were set at depths ranging between 70-150m to target SBT.

Six hooks per buoy was the normal pattern.

Setting commenced at 0400-0500 h; hauling at 1600-1730.

Common bait types in the Tasmanian region: squid, jack mackerel, slimy mackerel.

14.7. Consolidation of AFZ Observer SBT Cruise Reports for the 1992 Tasmanian Tuna Season. May-September 1992

Report: AA92(1a).

Fishing commenced on the 15 May 1992

Fishing initially concentrated south east of Maria Is and eastwards of 148.30 (to 150.30).

Vessels operated in groups, one group setting southwards (usually between 0200 - 0900) down to approx. 44.30S and hauling northwards to about 43S (usually between 1300 - 0100). A second group of vessels began operating northwards of 43S, up to approx 42S. Others were hauling northwards up to 41S.

The longline was most commonly made of Tetron, average line diameter was 7 mm (ranging between 5 -8 mm)

Up to four different branchlines were used, however, 3 was the most common.

Total length of branchlines ranged between 21 - 42 m, most commonly 30 -36 m.

Almost always 6 hooks per buoy.

Common bait species: squid, mackerel, horse mackerel, pilchards.

Squid was retained on hooks for a longer period than other bait types.

Artificial squid lures were used instead of real bait in some instances with some success noted by observers.

Thermoclines where the surface temperature was 15-17.5 °C were targeted.

Hook/bait soakage time was generally a minimum of 4 h.

Hook depth was occasionally adjusted prior to a full moon.

Setting pattern was initially N-S or S-N in a straight line 2-3 nm apart.

Line setting was commonly conducted at 9.5 - 11.5 kn; hauling at 3 - 7 kn.

The "L"-shaped setting pattern became more prevalent once there was more room for manoeuvring.

15. Sea-surface temperature data

• Table 15-1 List of sea-surface temperature images used to determine temperature corresponding to catches of SBT. The filename is in the format *yymmdd* where yy is the last two digits of the year, *mm* is the month and *dd* is the day.

891207	891230	900104	900109	900114	900119	900124	900129
900203	900208	900213	900218	900223	900228	900305	900310
900315	900320	900325	900330	900404	900409	900414	900419
900424	900429	900504	900509	900514	900519	900524	900529
900603	900608	900613	900618	900623	900628	900703	900708
900713	900718	900723	900728	900802	900807	900812	900817
900822	900827	900901	900906	900911	900916	900921	900926
901001	901006	901011	901016	901021	901026	901031	901105
901110	901115	901120	901125	901130	901205	901210	901215
901220	901225	901230	910104	910109	910114	910119	910124
910129	910203	910208	910213	910218	910223	910228	910305
910310	910315	910320	910325	910330	910404	910409	910414
910419	910424	910429	910504	910509	910514	910519	910524
910529	910603	910608	910613	910618	910623	910628	910703
910708	910713	910718	910723	910728	910802	910807	910812
910817	910822	910827	910901	910906	910911	910916	910921
910926	911001	911006	911011	911016	911021	911026	911031
911105	911110	911115	911120	911125	911130	911205	911210
911215	911220	911225	911230	920104	920109	920114	920119
920124	920129	920203	920208	920213	920218	920223	920228
920304	920309	920314	920319	920324	920329	920403	920408
920413	920418	920423	920428	920503	920508	920513	920518
920523	920528	920602	920607	920612	920617	920622	920627
920702	920707	920712	920717	920722	920727	920801	920806
920811	920816	920821	920826	920831	920905	920910	920915
920920	920925	920930	921005	921010	921015	921020	921025
921030	921104	921109	921114	921119	921124	921129	921204
921209	921214	921219	921224	921229	930103	930108	930113
930118	930123	930126	930131	930205	930210	930215	930220
930225	930302	930307	930312	930317	930322	930327	930401
930406	930411	930416	930421	930426	930501	930506	930511
930516	930521	930526	930531	930605	930610	930615	930620
930625	930630	930705	930710	930715	930720	930725	930730
930804	930809	930814	930819	930824	930829	930903	930908
930913	930918	930923	930928	931003	931008	931013	931018
931023	931028	931102	931107	931112	931117	931122	931127
931202	931207	931212	931217	931222	931227	940101	940106
940111	940116	940121	940126	940131	940205	940208	940213
940218	940223	940228	940305	940310	940315	940320	940325
940330	940404	940409	940414	940419	940424	940429	940504
940509	940514	940519	940524	940529	940603	940608	940613
940618	940623	940628	940703	940708	940713	940718	940723

940728	940802	940807	940812	940817	940822	940827	940901
940906	940911	940916	940921	940926	941001	941006	941011
941016	941021	941026	941031	941105	941110	941115	941120
941125	941130	941205	941210	941215	941220	941225	941230
950104	950109	950114	950119	950124	950129	950203	950208
950213	950218	950223	950228	950305	950310	950315	950320
950325	950330	950404	950409	950414	950419	950424	950429
950504	950509	950514	950519	950524	950529	950603	950608
950613	950618	950623	950628	950703	950708	950713	950718
950723	950728	950802	950807	950812	950817	950822	950827
950901	950906	950911	950916	950921	950926	951001	951006
951011	951016	951021	951026	951031	951105	951110	951115
951120	951125	951130	951205	951210	951215	951220	951225
951230							