Fisheries Biology and Assessment of the Blue Swimmer Crab (*Portunus pelagicus*) in Queensland

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NON TECHNICAL SUMMARY

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OBJECTIVES:

1. To determine key biological parameters (growth, mortality) of blue swimmer crabs in Queensland.
2. To determine the impact (if any) of environmental variables on blue swimmer crab catch.
3. To produce models which describe the impacts of alternative management strategies.

NON TECHNICAL SUMMARY:

OUTCOMES ACVIEVED

Management recommendations presented in this report including a reduction in the minimum legal size, a change in the method of measuring the minimum legal size as well as modifications to gear are currently under consideration by CrabMAC in Queensland. Information provided also supports recent changes to possession limits of blue swimmer crabs by trawl fishers.

The blue swimmer crab is a valuable resource in several Australian states. In Queensland it is fished commercially using pots and also taken as a by-product of prawn and scallop trawling. Recreational fishers also harvest blue swimmer crabs using pots and tangle nets. Traditionally the commercial pot fishery mainly operated in Moreton Bay but in the last 10 years the fishery has expanded rapidly into offshore waters with a five-fold increase in catch in these areas in the last 5 years. The commercial catch in 2001 was almost 700 tonnes of which less than 100 tonnes was a by-product of trawling.

A number of problems were identified with the current commercial logbook system including a probable underestimation of effective effort and a lack of precision in catch records due to problems with the recording of different grades of crabs (ie "tippers" and "markets"). These problems can be overcome by management changes that ensure that there are not alternative measurements that effectively allow different sized blue swimmer crabs to be harvested. A greater emphasis on the recording of pot lifts rather than pot numbers in the logbook would also assist in providing more accurate estimates of fishing effort. Different weight conversion factors also need to be applied in different regions due to regional differences in the size structure of the catch.

Recent management changes limiting the by-product of blue swimmer crabs by trawlers has significantly decreased the proportion of the total crab harvest taken by that sector. There are no major sustainability concerns with the taking of blue swimmer crabs by the trawl method with the current differential in catch limits inside (100 crabs) and outside Moreton Bay (500 crabs) being broadly supported by available historic catch and biological information. Despite this there are greater risks with trawl caught compared to pot caught crabs. This is due to both the selectivity of trawl gear that retains smaller crabs than the pot fishery and also the higher discard mortality of trawl caught crabs.

Temperature was not a major determinate of short term catch rates in the pot fishery but longer term environmental and catch data series are required before definitive statements can be made about the overall effect of the environment on the strength of a particular crabbing season. None of the environmental factors studied appeared to have a significant effect on the density of planktonic blue swimmer crab megalopae in Deception Bay.

The biology of the blue swimmer crab did not differ dramatically throughout the range of the species investigated in Queensland. Reproductive season, spawning and insemination rates did not differ among regions. Despite spawning activity throughout the year it is the spring spawning peak that is providing the bulk of recruits to the fishery. Levels of parasitism by *Sacculina granifera* and *Ameson sp* have also not changed in the last 15 years. The growth rate of crabs >120mm remain difficult to determine and it is this phase of the life cycle which is critical if the yield from the fishery is to be maximized. Estimates of total mortality of blue swimmer crabs suggested that exploitation rates were significantly higher in Moreton Bay than elsewhere in the fishery. These high rates of exploitation may have resulted in a reduction in the size of male blue swimmer crabs in Moreton Bay. Monitoring the size of male crabs in the recently exploited offshore areas will provide further evidence of an effect of exploitation on the size of crabs.

Ghost fishing of lost pots is a minor issue in the fishery with about 6000 pots lost each year of which about half remain in the environment. Crabs continue to be attracted and trapped in these pots even when the bait is exhausted and no dead fish bycatch is attracting crabs into the pots. The quantity of fish bycatch in pots varies among the different regions of the fishery. Bycatch of fish is significantly greater in pots made of trawl mesh that the traditional wire pots with larger mesh size. As the fishery generally takes place in shallow water (<50m), death of discarded fish by barotrauma is not a major problem. In addition, best practice sorting practices can result in discarded bycatch species being returned to the water within one minute of being removed from the pot. Turtle entanglement in ropes attached to pots is a problem in some areas and can be minimized by a greater emphasis on setting pots on trotlines rather than on individual buoyed ropes. Weighting ropes also reduces turtle interactions.

A number of fishery independent surveys were used to gather information on the relative abundance of adults and juveniles and also to collect growth information. They were also used to determine the best way to monitor blue swimmer crab stocks. A mixture of fishery independent and dependent methods is advised.

A number of models indicate that yield in the fishery can be increased by a reduction in the current minimum legal size of blue swimmer crabs. Available information indicates a very high probability of a significant increase in yield for a decrease in the minimum legal size to 14 cm. There are also strong reasons for changing the method of measurement of crabs to the base of the spine (similar to that used in South Australia). There is also no biological reason why female blue swimmer crabs cannot be sustainably harvested although marketing and compliance concerns may limit the possibility of such a change.

KEYWORDS: Blue swimmer crab, fishery, assessment

1. BACKGROUND

This report addresses areas of research on blue swimmer crabs (*Portunus pelagicus*) that were identified in a national research strategy. It includes both national and state specific research objectives that have been addressed by Queensland based researchers over the last 3 years. A Queensland based recreational component of the project has previously been completed in 1999.

The blue swimmer crab *Portunus pelagicus* is fished in all Australian states other than Victoria and Tasmania. The Australian commercial fishery currently produces more than 1500 tonnes per annum (Kumar, 1997). There may be the potential to considerably increase this figure given that only males are exploited in Queensland, and in Western Australia and South Australia the fishery is not believed to be fully exploited and is still undergoing development and expansion. Management measures vary considerably from state to state and involve different size limits, gear restrictions and some states have measures to protect females. There has been no detailed assessment on the status of any of Queensland's blue crab resources in the past 10 years.

An industry workshop on blue swimmer crabs conducted in South Australia (Kumar, 1997) highlighted the need for a national approach to research and management of the blue swimmer crab fisheries. Over 30 managers, industry representatives and researchers attended this workshop from all Australian states that have a blue swimmer crab fishery. As a result of the workshop a national research strategy was produced. This strategy identified a number of high priority areas for collaborative research and also areas where specific state issues needed to be addressed.

National priorities were identified as :-

An Australia wide analysis of the stock structure of blue swimmer crabs,
National assessment of the recreational catch,
Investigations into density dependent growth and mortality
Studies dealing with settlement processes.
Coordinated assessment of the stock(s).

These priorities were agreed to by all researchers, managers and industry representatives from across Australia.

The need for a co-ordinated approach to providing management advice via the production of models for evaluation of management strategies, which have application across all blue swimmer crab fisheries was also stressed. This can only be achieved by the collection of information on growth, mortality and movement within each state. Previous studies have shown considerable variation in biological parameters throughout the species' range (see Kailola *et al*., 1993).

Within the Queensland context, the blue swimmer crab fishery has changed dramatically in the last decade. Both the development of the spanner crab fishery and the increased capture of blue swimmer crabs as a by-catch of prawn trawling operations have generated changes in exploitation patterns. The increased profitability of the spanner crab fishery has meant a shift in fishing effort from the blue swimmer trap fishery into the spanner trap fishery. At the same time changes in market demand and fishing behaviour has seen the trawl component increase. Since the implementation of the CFISH commercial logbook system in 1988 the recorded trawl catch of blue swimmer crabs has doubled whilst there has been a 30% reduction in the trap catch. There has also been some expansion and development into new areas that have only previously been lightly fished. The reported commercial catch in Queensland in 1997 was about 450 tonnes with a GVP of $3 million. The magnitude and value of the recreational catch is at present unknown but it is likely that the recreational catch is similar in magnitude to that of the commercial sector given the popularity of crabbing to recreational fishers. A recent phone survey of recreational fishers throughout Queensland highlighted blue swimmer crabs as one of the top 3 targeted species in a number of geographic regions (Cormack, 1997).

A report on trend and condition of fisheries resources in Queensland (Williams 1997) highlighted both the dependence of blue swimmer crabs on inshore habitat, and current uncertainties about population trends as indicated by changes in catch rates. The value of the resource, from both an economic and social perspective, lends weight to arguments that its status be evaluated.

2. NEED

Queensland's fishery for blue swimmer crabs is managed conservatively. Fishers are allowed to take only males, and the size limit (15 cm carapace width) is set at above 85% of L infinity (theoretical maximum size). South Australia, Western Australia and New South Wales currently market female crabs. There is considerable contrast available between management regimes and therefore scope to consider the possible economic gains and biological risks associated with these alternative strategies.

Stock assessment leading to the development of optimal management strategies was one of the key objectives of the National Blue Swimmer Crab Research Strategy. Therefore current information on growth, mortality, movement and size structure of the catch in Queensland (both commercial trap and trawl sectors, and the recreational sector) needs to be collected and incorporated into yield models and more comprehensive population models which allow the risks and gains of alternative management strategies to be evaluated.

The only significant research into the Queensland blue swimmer crab fishery that has been conducted since 1987 (See Reference List) has been the analysis of daily commercial catch and effort logbook records (CFISH). However, there have been concerns about the accuracy of the CFISH crab data. There have also been major changes in the fishery, including reported increases in trawl catches and a decline in both catch and CPUE in the trap fishery. The fishery has also expanded into new areas that were not covered in previous research and is fact the fishery is still expanding.

Subsequent to the commencement of the project the issue of setting trawl by-product limits for blue swimmer crabs became apparent. Interim limits had been set but there was a need to address the question of whether there was any evidence to suggest that heavy fishing pressure imposed by the trawl industry was having a detrimental effect on the blue swimmer crab resource. While this did not form part of the original objectives of the research it was important to address this issue, as it was the most topical management issue facing this fishery.

Megalopa collectors have proved successful for collecting portunid megalopa in North America (Lipcius *et al.* 1990, Olmi *et al.* 1995) and are a routinely used method of fishery independent survey in the US blue crab (*Callinectes sapidus*) and other crab fisheries that have similar life histories to our blue swimmer crab. Similar methods are used to predict year class strength of the western rock lobster and other fisheries in Australia. There is a need to undertake pilot work to develop and trial collectors for quantitatively collecting blue swimmer crab megalopae. If blue swimmer crab megalopae can be collected on artificial collectors then these techniques may have application in a fisheries context, as they are in other crab fisheries around the world.

3. OBJECTIVES

1. To determine key biological parameters (growth, mortality) of blue swimmer crabs in Queensland.
2. To determine the impact (if any) of environmental variables on blue swimmer crab catch.
3. To produce models which describe the impacts of alternative management strategies.

4. HISTORY OF THE BLUE SWIMMER CRAB FISHERY IN QUEENSLAND

In Queensland the blue swimmer crab fishery dates back to the early 1800's. In the early 1820's a convict known as "Bribie" made crab and fish traps and bartered his catch with the officers of the Brisbane penal settlement. However, during the 1800's blue swimmer crabs were only very lightly fished, with people preferring the larger and more popular mud crab (*Scylla serrata*). As mud crabs became scarcer and more expensive, the popularity of blue swimmer crabs increased. The fishery then gradually developed into the 20th century but little is recorded about catches or the fishery in general, until records began to be kept by the Queensland Fish Board in the 1930's. The annual catch of blue swimmer crabs recorded by the Brisbane Metropolitan Fish Market increased from about 32,000 crabs in 1937 to over 100,000 a decade later. By the early 1960's this number had increased to over 400,000 crabs per year (Figure 4.1) representing an annual catch of approximately 140 tonnes.

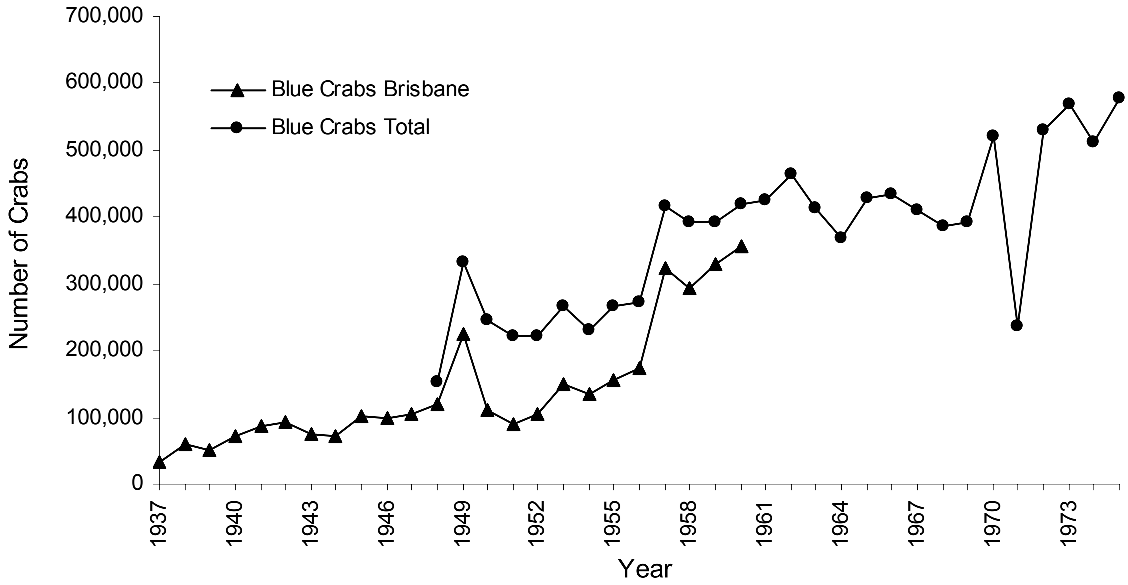


Figure 4.1 Number of blue swimmer crabs marketed through the Queensland Fish Board from 1937 to 1975. The lower graph shows the volume marketed through the Brisbane Metropolitan Markets while the upper line is the total marketed from all agencies throughout the state.

Until the 1940's the majority of the catch was taken using long nets to tangle crabs close to the western shores of Moreton Bay. During the early 1950's large nets were used in the southern part of Moreton Bay and pots, then technically illegal, were used in the north. Thomson (1951) noted that during this time most of the catch was still taken from the waters on the western side of Moreton Bay. Authorities turned a blind eye to the use of pots possibly because of the post-war shortage of cotton for making nets and the fact that pots apparently did little harm. The 1957 Fisheries Act legalised pots, but there was no restriction put on their number, except that pot fishers taking crabs for sale required a license. In December 1976 commercial pot fishermen were restricted to a maximum of 50 pots and this restriction has remained to this day, as has a prohibition on the use of mesh nets. Fish Board records also show a highly variable quantity of crabmeat marketed, particularly during the 1970's when up to 11.5 tonnes of blue swimmer crabmeat was marketed each year. It is believed that a large proportion of this meat was from females and undersized crabs.

Until the 1970's the bulk of the catch was still coming from Moreton Bay. Since the early 1950's the fishery has developed rapidly as a result of increased prawn trawling and recreational fishing activity and more recently due to expansion of fishing activities into offshore waters (outside Moreton Bay). Recreational fishers have traditionally used a tangling apparatus known as a "witches hat" or "dilly" to catch blue swimmer crabs although the last decade or so has seen an increased use of collapsible pots made from a range of different materials in various designs (see Figure 4.2 for the different apparatus used). The wire pots that were common up until the late 1980's are gradually being replaced in both the commercial and recreational fisheries by more collapsible apparatus made from various plastics.

The first two pots (illustrated above) are those commonly used by commercial fishers. The metal wire pot (above left) has been used for the last few decades particularly in Moreton Bay. The size and shape of the pots vary (some are even rectangular) but most have two entrance funnels and are cylindrical in shape. There is more variation in size and design of the collapsible pot constructed from steel and trawl mesh. The design pictured above right is that commonly used in Moreton Bay, but larger and heavier pots are used in offshore waters. Many commercial fishers these days also use pots similar to those used in Western Australia. These pots tend to be larger and with an entrance around almost the entire pot.

The apparatus illustrated left is a "dilly" or "witches hat". This works by entangling crabs in the mesh once they are attracted to the bait. Dillies are usually lifted every hour while the commercial pots are generally left overnight before they are cleared.

Figure 4.2 Some of the common non-trawl apparatus used to catch blue swimmer crabs in Queensland waters.

There is limited information about the contribution of the recreational fishery to the total catch. During 1985/86, Potter *et al*. (1994) found that over 20% of the crabs that were returned from a research tagging exercise were caught by recreational fishers, confirming the importance of the recreational catch. In some areas the return rate from recreational crabbers exceeded that of the commercial sector. In a recent survey conducted by the then Queensland Fisheries Management Authority, blue swimmer crabs were highlighted as one of the state's most targeted recreational species in some areas (Higgs 2001). Although the survey did not discriminate accurately between different species in some areas, the state-wide recreational harvest of blue swimmer crabs was estimated at over 150 tonnes. Recently, there has been considerable expansion of commercial fishing effort into offshore waters where crabs tend to be larger and catch rates higher than the traditional fishing grounds in Moreton Bay. As mentioned earlier, fishing gear has also changed dramatically in the last decade with the traditional wire pots being replaced by collapsible pots that consist of a metal frame covered by trawl mesh (and other materials) which enables pots to be stacked on board relatively small vessels.

In summary, the fishery has experienced the typical pattern where areas closer to port are exploited first, with expansion into more remote locations as catch rates decline and technology improves. The early fishery was restricted to western Moreton Bay. During the 1960's to 1980's effort moved further offshore to the northern banks and Amity Banks area with some exploration in offshore waters outside Moreton Bay. Nowadays, there is considerable effort in offshore waters and the more remote regions of Hervey Bay. The trawl by-product component has likewise changed dramatically, although the data on this is a little more difficult to interpret (see later sections).

5. ANALYSIS OF COMMERCIAL CATCH AND EFFORT LOGBOOK DATA

Data Acquisition and Transformation

Compulsory logbook data have been collected from commercial fishers in Queensland since 1988. These data, which were collected by the Queensland Fisheries Management Authority (QFMA) (now the Queensland Fisheries Service QFS), are contained in the CFISH database. Data are stored in two large tables, one contains the "Mixed Fishery" data that includes data from fishers who fish in the net, line and pot fisheries. The second (Trawl Fishery) has all the catch and effort data of trawl fishers in Queensland. Only a very small proportion of records in the mixed database (<1%) recorded catches of blue swimmer crabs by methods other than potting and so throughout the remainder of this document where the "Mixed" fishery is discussed it is assumed that this is essentially data from the pot fishery.

For the analyses that follow all blue swimmer crab data were extracted from the CFISH database in raw form. Cursory examination of the data revealed several flaws related to the recording methods of fishermen, logbook design as well as database administrative changes. These problems, and the ways in which they have been addressed, are discussed in the following sections.

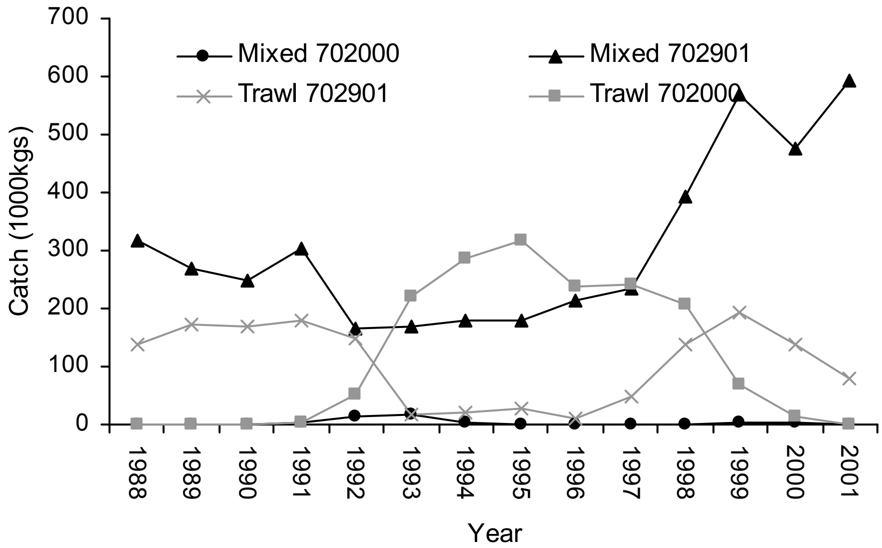


Figure 5.1 Historical changes in the recording of crab species in the CFISH mixed fishery and trawl fishery database. Code 702901 = Blue swimmer crab, Code 702000 = unspecified crabs

Species discrimination

Due to historical changes in the log book recording practises and data entry of certain crab species, two species codes were used for the CFISH analyses: 702901 (Blue swimmer crabs) and 702000 (Unspecified crabs). These changes in the database were made primarily due to recording discrepancies in the trawl database. The trawl catch changed from being predominantly recorded as blue swimmer crabs to predominantly unspecified crabs in 1992-3. This trend was changed again in 1997-98 with the two codes being used almost equally (Figure 5.1).

These coding changes resulted in the possible inclusion of small numbers of other crabs species in the database, but if unspecified crabs (code 702000) were excluded a great deal of the trawled blue swimmer crab catch would have been omitted from the analyses. The species other than blue swimmer crabs that may be included in the analysis include coral crabs *Charybdis feriatus*, three spot crabs *Portunus sanguinolentus* and rock crabs *Charybdis natator*. Commercial catches of these species are probably insignificant when compared with the total blue swimmer crab catch, although *P sanguinolentus* are seasonally very important in some areas (particularly outside Moreton Bay). The difficulty in discriminating between crab species is a major cause of imprecision and inaccuracy in estimating commercial crab catch from the CFISH data.

Catch weight and catch numbers

The way in which fishers record the quantity of their daily catch in the logbooks also varied. Approximately 90% of the records are in kilograms, 10% of the records in numbers and less than 1% with both kilograms and numbers recorded. It was not possible to attempt any comparison between these different units, so a conversion factor was used. Two common fields were created, a common weight field calculated from the records in the catch numbers field, and a common numbers field calculated from the records in the catch weight field. Conversion factors were used to calculate weights and numbers where only one measure was recorded. These factors were based on the average size and weight of the retained blue swimmer crab catch in each of the three areas used in the analysis (see Table 5.2) as determined from observer trips with commercial fishers in the these main fishing areas. Conversion factors were:- 3 crabs per kilogram for Hervey Bay, 3.2 crabs per kilogram for Bribie to Fraser Island, 3.5 crabs per kilogram for Moreton Bay and 3.2 crabs per kilogram for elsewhere in the state. It is recognised that these conversion factors will significantly impact the resultant data, but differences in recording and fishing practises as well as significant differences in the size structure of the catch necessitated these adjustments (See Chapter 9 for a discussion of differences in size structure of the commercial catch among areas).

Irregular recording of total pot lifts

Vessel skippers are required to record a measure of their total daily fishing effort. The level of precision in effort recording is obviously very different between the trawl and pot fisheries because of the dissimilar fishing methods. In the trawl fishery blue swimmer crabs are primarily caught incidentally and marketed as a by-product therefore each unit of effort was assumed to be a boat day. A boat day for the trawl fishery was defined as any fishing day on which a catch of blue swimmer crabs or unspecified crabs, in weight or numbers, greater than 0 was recorded. No attempt was made to increase the precision of effort to a trawl/hour (or other more precise estimate) due to the incidental nature of most of the catch and the possibility of including large amounts of effort that was incapable of catching crabs. In the pot fishery where each pot directly targets blue swimmer crabs, the more precise effective unit of fishing effort is the pot lift and this has been used as well as the fishing day in some of the analyses that follow.

Vessels operating in the commercial pot fishery are required to record the number of pots that are used during each day of fishing. In addition to the number of pots used, it is required that the total number of pots lifted that day is recorded (as sometimes pots may be lifted more than once per day). It is clear that this second value gives the most accurate estimate of fishing effort. Problems occur with interpretation and recording practises of individual fishers to the “pot lift”. When a fisherman records the use of 50 pots and lifts them once a day the appropriate record in the “pot lifts” is also 50 but some fishers record only one or two pot lifts. This then gives only 1 or 2 effective pot lifts when actually all pots were probably lifted. As with the catch weight and catch numbers problem, recording methods varied widely between fishers. Decision rules were formulated in an attempt to decrease the effect of the pot lift discrepancies and other database irregularities. The application of these rules is shown in Table 5.1.

These rules always caused an increase in the adjusted versus the unadjusted effort that was usually between 1% and 8% per annum but adjustments made in 1993 and 1994 resulted in over a 20% increase in pot fishing effort. Extensive checking of the data failed to find any inconsistencies in the data caused resulting from mis-reporting or other abnormalities. It was mainly caused by problems with the recording of the number of lifts by fishers.

Table 5.1 Decision rules used to adjust CFISH data for inconsistencies in recording pot effort information.

Total pot lifts	Pot numbers	Catch numbers	Action
0	>0		Insert pot numbers value into total pot lifts
<5	>20	>10 crabs	Insert (pot numbers x total pot lifts) into total pot lifts
>5	>20	N/A	Leave unchanged
>5	<20	N/A	Leave unchanged
<5	<20	N/A	Leave unchanged
0	0		Exclude record from CPUE calculations

Suspicious records

Outliers and suspiciously high records were also removed from the calculations related to the mixed fishery. A record was deemed unreliable and removed from the analysis if it had any of the following features:-

- Greater than 300 pot lifts were recorded in any one day,
- More than 2000 crabs were caught in one day,
- Null or 0 values in both catch weight and catch number fields,
- Null or 0 values in both pot numbers and total pot lifts field,
- Duplicate records (One duplicate was removed)

These decision rules were not used in the trawl fishery, as there is no data on the potential maximum number of crabs caught per day. The application of these rules in the mixed fishery database resulted in the effective elimination of between 1.5% and 2% of the reported mixed fishery effort and 0.9% and 3.5% of the catch in any given year.

Multiple records for one day

Records were converted to ensure that each Vessel Sequence Number (VSN) could have only 1 record per fishing method, per day. This was necessary when calculating the average catch per boat day of different fishing sectors. Fishing latitude, longitude, catch, pot numbers and total pot lifts were averaged by each VSN, day and fishing method.

No grid location references

Where null values were encountered in the fishing ground field, average latitude and longitude were used to calculate the corresponding 30 nm by 30 nm CFISH grid.

Spatial and temporal trends

For the purposes of the results and discussion that follow, the fishery has been broken into two fishery components (trawl and mixed) and three regions. The regions are based on the major centres of catch and effort by both the trawl and mixed (predominantly pot) fisheries. In addition to these three major regions, the whole Queensland fishery will be analysed in order to determine any statewide trends. The boundaries of these three regions are summarised in Table 5.2 and the grids that are used in fishers logbooks are shown in Figure 5.2.

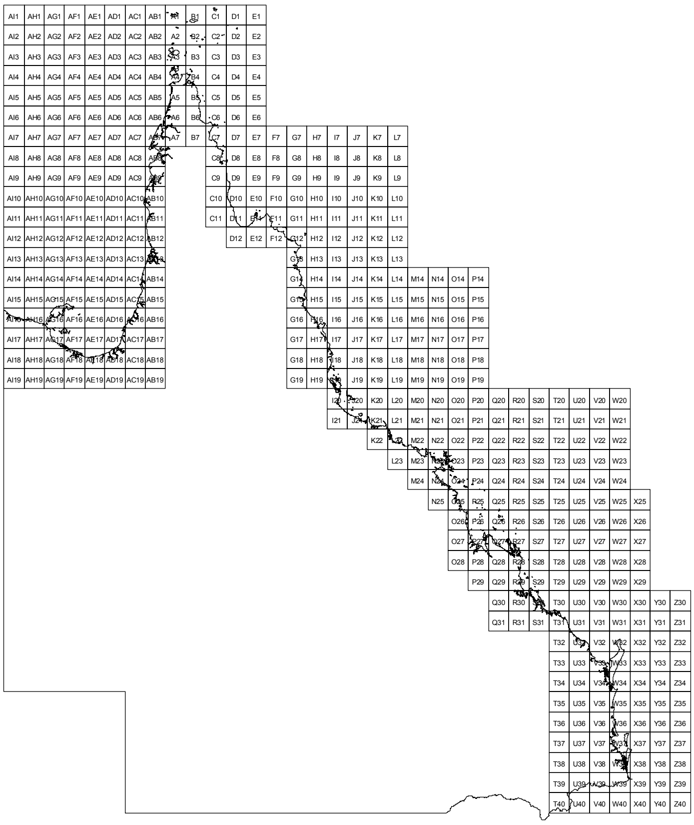


Figure 5.2 Grids (30nm x 30nm) used in commercial logbooks for geographic positioning of catch and effort records (see also Table 5.2).

Table 5.2 Summary of major regions used in the commercial logbook analysis.

Region	**Description**	**CFISH Grids***
Moreton Bay	Moreton Bay.	W37, W38, W88.
Bribie to Fraser	The Offshore area between the southern end of Bribie Island and Indian Head on Fraser Island.	W33, W34, W35, W36. X33, X34, X35, X36. Y33, Y34, Y35, Y36. Z33, Z34, Z35, Z36.
Hervey Bay	The Great Sandy Straits to Yeppoon, including the Capricorn and Bunker groups.	R29. S29, S30. T29, T30, T31. U29, U30, U31, U32. V29, V30, V31, V32, V33. W29, W30, W31, W32. X29, X30, X31, X32.

*These are location grids specified in fishers logbooks (See Figure 5.2 for the geographic location of these grids).

Daily effort by commercial pot fishermen

For the period covered by the compulsory logbook, the standard daily effort recorded by most fishermen has been 50 pot lifts (Figure 5.3). This is clearly due to fishers being restricted by regulation to a maximum of 50 pots per vessel since the late 1970's. Apart from the widespread recording of 50 lifts per day, there is evidence that some vessels are using only 20, 30 or 40 pots. These vessels are most likely supplementing their netted catches in the net and crab fisheries or may be using multiple lifts of small numbers of "dillies" (tangle nets) to catch crabs.

There are relatively few records where more than 50 lifts have been recorded per day. These fishers are lifting each pot more than once during the day or are using more than 50 pots. The entries that recorded over 300 pot lifts per day were not included in any catch per unit effort analyses, although these records were very few in number.

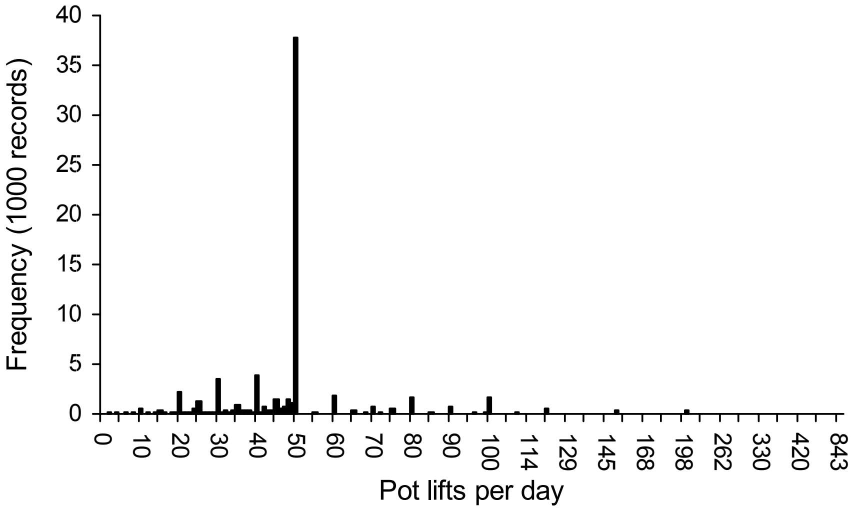


Figure 5.3 Frequency of pot lifts per day recorded in commercial logbooks from 1988 to 1998.

The average reported daily effort in the Moreton Bay pot fishery showed a slight decrease over the 12 year period (Figure 5.4) since the establishment of the logbook program with the highest average daily fishing effort of 57 pot lifts per day occurring in 1990. These data had a very low variance within each year, reflecting the common practise of most fishers for recording 50 pots as the standard unit of effort.

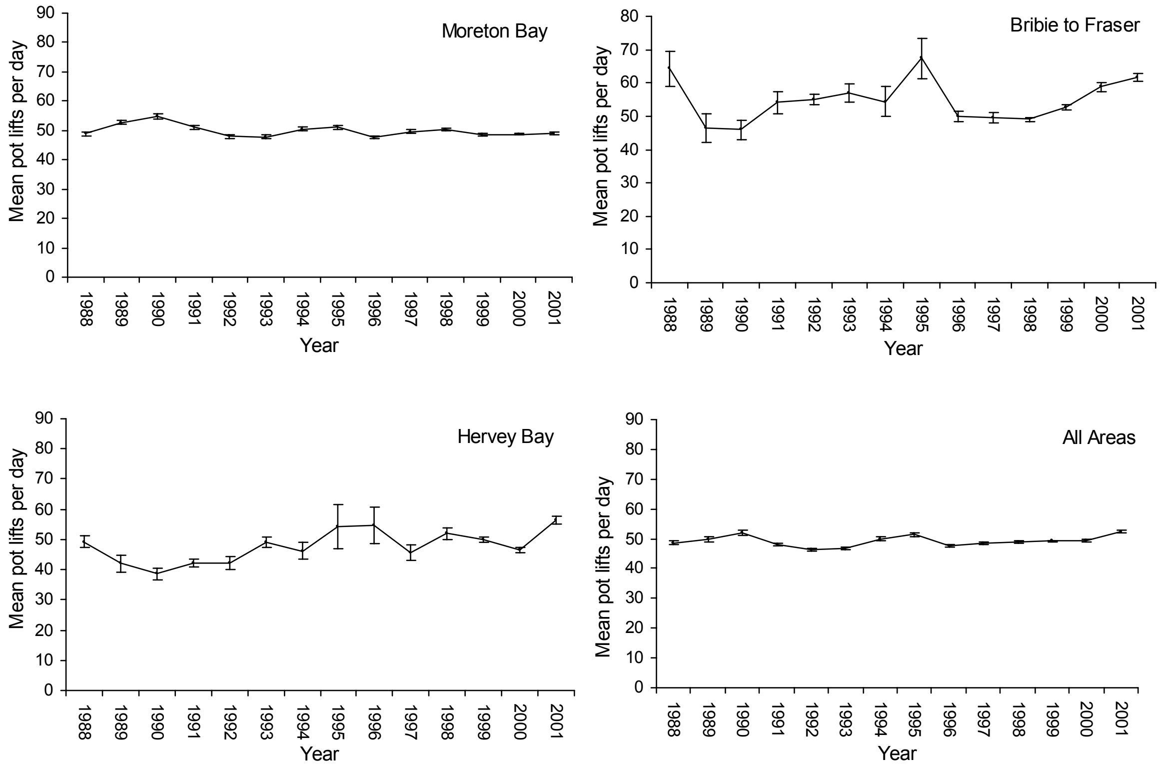


Figure 5.4 Average number of pot lifts per day by individual fishers from a number of areas in Queensland. 95% confidence intervals are shown as vertical bars

Observer trips have shown that it is in fact rare for fishers to use exactly 50 pots, and usually the number of pot lifts is significantly higher than this figure. The impact of these discrepancies is difficult to determine because recording practises vary dramatically among fishermen. The average daily effort in the area from Bribie Island to Fraser showed more variation over the period prior to 1996 with a peak of 67 pot lifts per day recorded in 1995. Caution must be used when considering this value as it was accompanied by a noticeably larger variance than previous years. The increase in average daily effort may have been caused by pulses of effort from a few boats as there were only 30 vessels fishing in this region in 1995. The reduction in variance after 1995 is a reflection of an increase in vessels participating in the fishery. The average daily effort in the Hervey Bay region was also marked by considerable inter-annual variation that declined after 1995 with the participation of more vessels in the pot fishery. The mean daily effort over the State reflected the trend shown in the Moreton Bay region, as this is the region where the majority of pot effort is expended.

Changes in annual total catch and effort in the commercial pot fishery

Annual catch and effort in the Moreton Bay region varied significantly over the period from 1988 to 2001. (Figure 5.5) There was a decrease in effort from 1989 to 1992, followed by a net increase until 1997. These changes in effort did not parallel the changes in catch, with increasing catches from 1990 to 1991 despite the decrease in effort. The most marked changes occurred after 1997. In 1991/2 a dramatic drop in both catch and effort reduced the annual catch from 231 to 111 tonnes, with effort also decreasing from 240,000 to 170,000 pot lifts per year. The 1997-98 season saw an increase in total catch accompanied by a slight decrease in effort, with the annual catch increasing from 172 to 226 tonnes. Over the period from 1998 to 2001 the catch from the offshore region of Bribie Island to Fraser Island increased from less than 25 tonnes to almost 200 tonnes with the effort also increasing dramatically. The change in catch for this region was closely correlated with the increase in fishing effort over those years suggesting that the stock was perhaps previously under-utilised. The largest change in catch and effort occurred from 1997 to 1999 where the catch increased by 208% with only a 95% increase in effort.

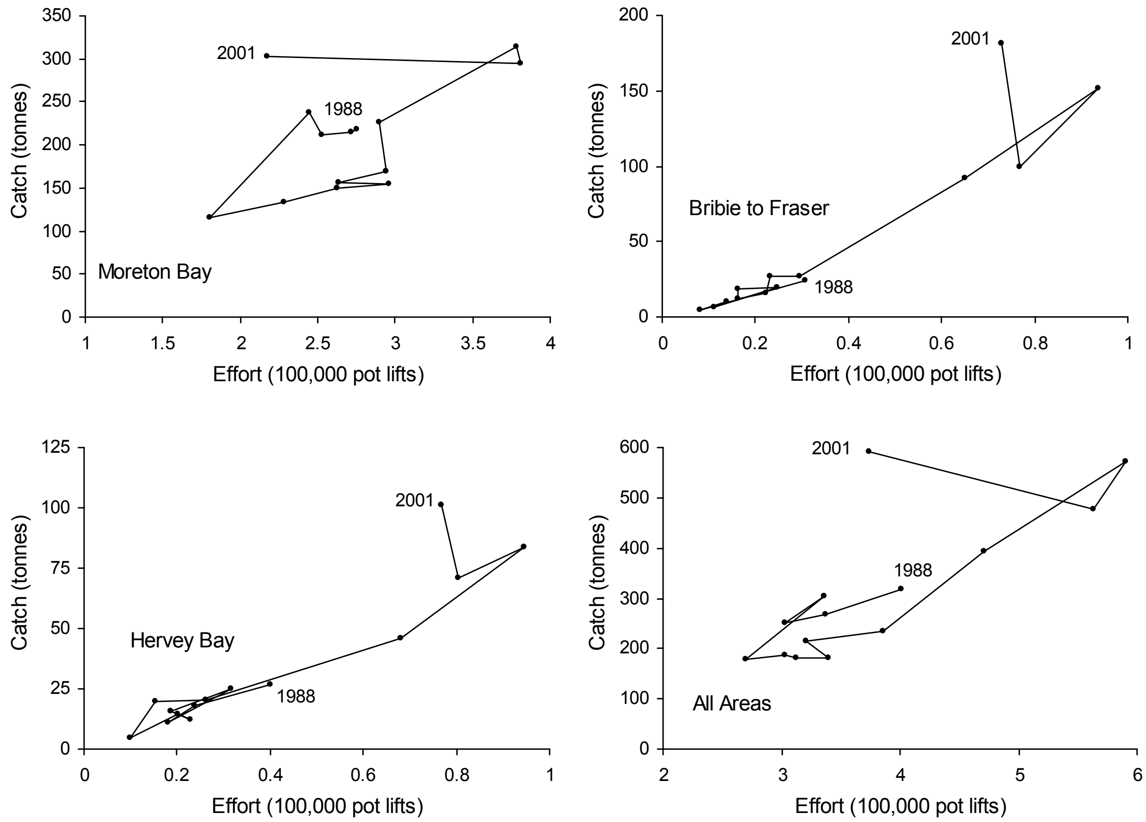


Figure 5.5 Annual changes in total pot catch and effort of blue swimmer crabs in various areas in Queensland.

The Hervey Bay pot fishery closely reflected the trends in the Bribie Island to Fraser Island region. It was also marked by a relatively stable catch and effort followed by a dramatic increase in 1998. The overall catch in 1999 was by far the largest of the decade with a 64% increase in catch accompanied by a 17% increase in effort on the previous year. At the time of this analysis the full data for 2001 were not all available so conclusions about the 2001 season are questionable for all these analyses. What is clear from these plots is that the areas outside Moreton Bay appear to be not yet fully exploited since they were more capable of sustaining increases in effort whilst maintaining proportional increases in catch (i.e. maintaining a high CPUE). While Moreton Bay has also recently shown increases in CPUE the proportional increase is much less than in offshore areas. A complicating factor in the interpretation of these data is that they only represent changes in the pot fishery. Since 1998 there has been a dramatic shift in the share of the commercial catch between pot and trawl fisheries (see Figure 5.6) which has implications for the interpretation of biomass dynamics models that use these data (see later Discussion).

Change in annual catch in the commercial trawl and pot fisheries

Considerable conflict exists between both recreational and commercial pot fishers and trawl fishers over the proportion of the resource taken by each sector. The annual catches of the commercial pot and trawl fisheries in Moreton Bay and elsewhere are shown in Figure 5.6. The pot fishery in Moreton Bay landed a significantly larger annual catch than the trawl fishery throughout the period. As mentioned earlier the pot fishery suffered a major decline in annual catch between 1991 and 1992, possibly caused by an exodus of pot fishers into the spanner crab fishery. However, this decline was followed by a steadily increasing catch from 1992 to the present. The blue swimmer crab catch from the trawl fishery increased to its highest level in 1989. However, after this time the annual trawl catch was variable but showed a general decline in Moreton Bay. This decline in annual catch occurred despite a quite steady level of fishing effort within the region. By comparison the Bribie to Fraser region shows an increase in annual catch for both fisheries with the trawl catch higher than the commercial pot catch from 1989 to 1997. The difference between the two catches over this period was generally between 5 and 20 tonnes. The trawl catch and effort for the Bribie to Fraser region increased steadily until 1998 when it started to decline. The annual trawl effort grew from 765 boat days in 1988 to a peak of 2829 boat days in 1997.

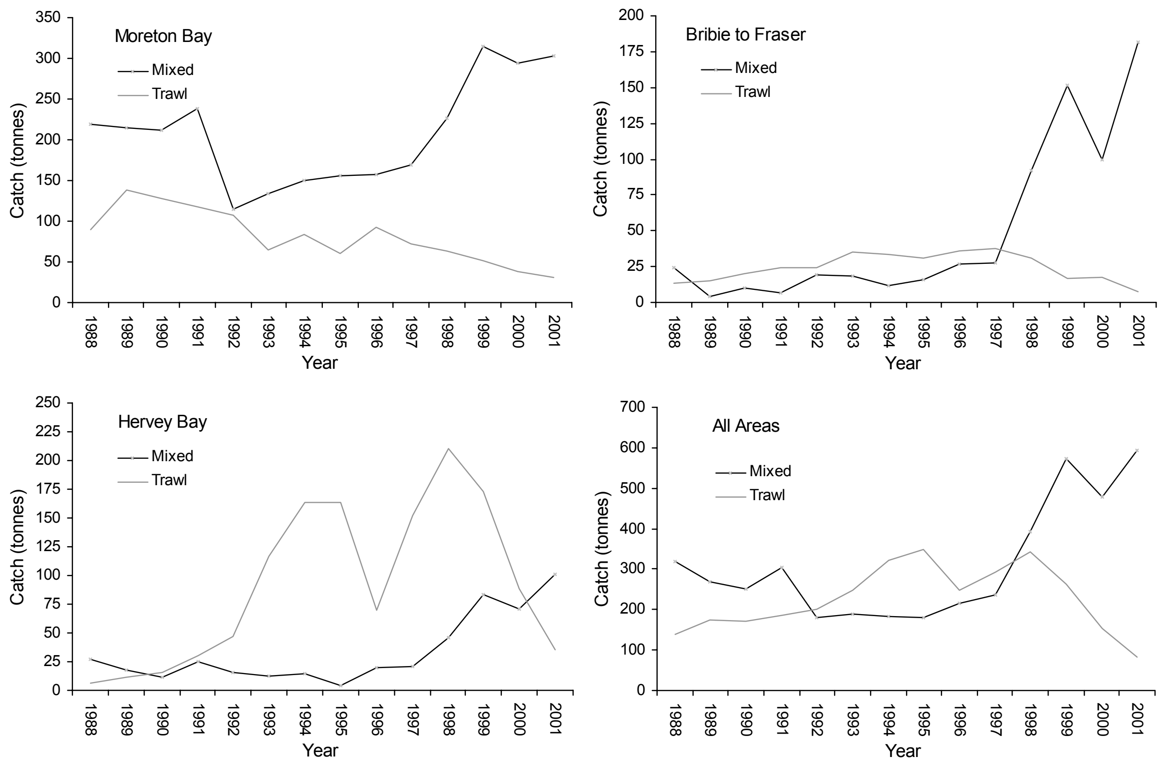


Figure 5.6 Annual catch of blue swimmer crabs in the commercial pot and trawl fisheries in various areas of Queensland.

Trawl catches of blue swimmer crabs in the Hervey Bay region increased substantially during the early 1990's. A dramatic drop followed this period of growth in 1996, followed by another period of increased catches in 1997 and 1998 and another subsequent decline. This decrease in catch was also associated with a decrease in effort, with the fishing effort in 1996 down 33% on the 1995 level. It is interesting to note that this period was marked by fluctuating (and generally lower) scallop catches in this region (Williams 1997). As mentioned earlier blue swimmer crabs are generally caught incidentally when more valuable species are readily available. However, during times when scallop and prawn catches are low, blue swimmer crabs can be heavily targeted by trawlers. The change in catch and effort over this period for the trawl fishery may therefore be partially explained by fluctuations in the abundance of other trawl caught species within this region. The catch in the commercial pot fishery showed a minor decline until 1995, followed by a steady increase in catches up to 1998. Annual pot catches were variable with a low of 4.6 tonnes caught in 1995 and high of 46 tonnes in 1998. The annual trawl catch for the whole of Queensland was clearly influenced by the Hervey Bay region and the commercial pot catch was influenced by the Moreton Bay region. The general trend in the last 4 years has been for the logbook data to show a dramatic increase in the catch share taken by the commercial pot fishery.

Monthly variation in catch and CPUE in the commercial pot fishery

Monthly variation in the commercial pot catch for the Moreton Bay region is shown in Figure 5.7. The catch and CPUE showed consistent seasonal patterns with two annual peaks in October/November and March/April each year, with the second peak generally the higher of the two. The annual peaks in blue swimmer crab catch and CPUE showed a high inter-annual variation, although the seasonal patterns remained relatively constant between years.

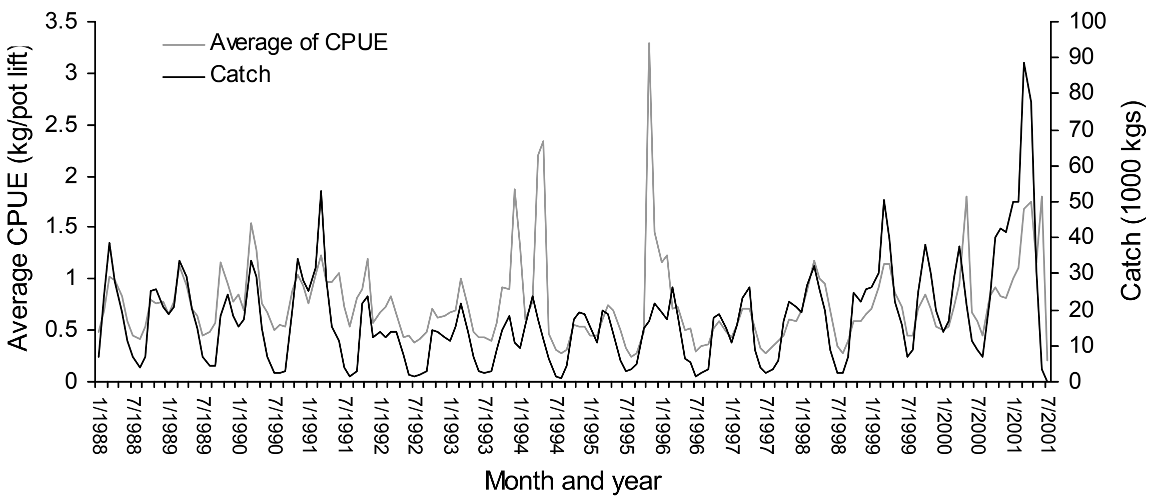


Figure 5.7 Mean monthly CPUE and catch for the pot fishery in the Moreton Bay region.

The period from June to August (winter) had the lowest catches and catch rates each year, with this period showing almost no variation between years apart from increases in the winter catches in recent years. This winter period represents a time of reduced growth and feeding in blue swimmer crabs, presumably reducing the movement of crabs and their attraction to baited pots. It is also believed that moulting is not replacing recruits being removed by the fishery at this time.

The monthly catch pattern for seasons of 1998 to 2001 depart somewhat from average conditions with both 1998/99 and 2000/01 showing less pronounced dips in catches during the summer period. The intervening year (1999/2000) had the highest proportional summer drop in catches reported since the establishment of the logbook program.

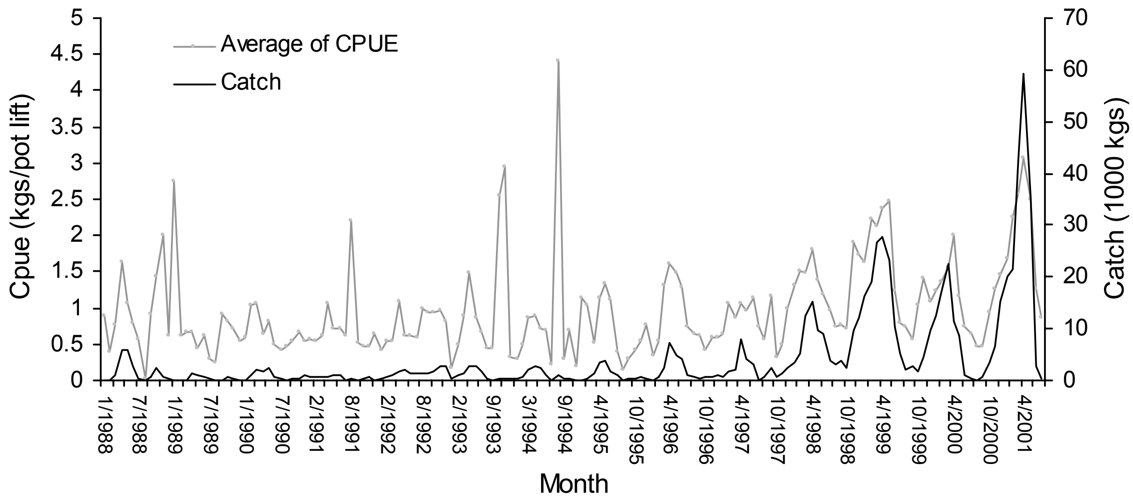


Figure 5.8 Mean monthly CPUE and catch for the pot fishery in the Bribie to Fraser region.

As the area from Bribie Island to Fraser Island was not heavily targeted before 1995, the monthly pattern of catch and effort before this time is unclear (Figure 5.8). In contrast to the Moreton Bay data, this region showed only a single peak in annual catch, usually during April. Catches were relatively small and variable until 1995 when fishing effort increased. Several instances of high CPUE were recorded prior to this time but it would appear that limited fishing effort kept the total catch relatively low. Catches after about 1996 increased significantly without a large decrease in CPUE, indicating that stocks in this region were only lightly exploited prior to that time.

The "twin peak" catch and CPUE periods for the Hervey Bay region occur later in the year than in Moreton Bay (Figure 5.9) and the pattern is not as clear. The first period of increased catches started in November and ended in January, the second started in April and ended in June. The catch and CPUE for the Hervey Bay region showed substantial variability with a large increase in catches in 1997. The Hervey Bay region also showed a significant increase in catch in 1998 with similar CPUE levels to that of previous years.

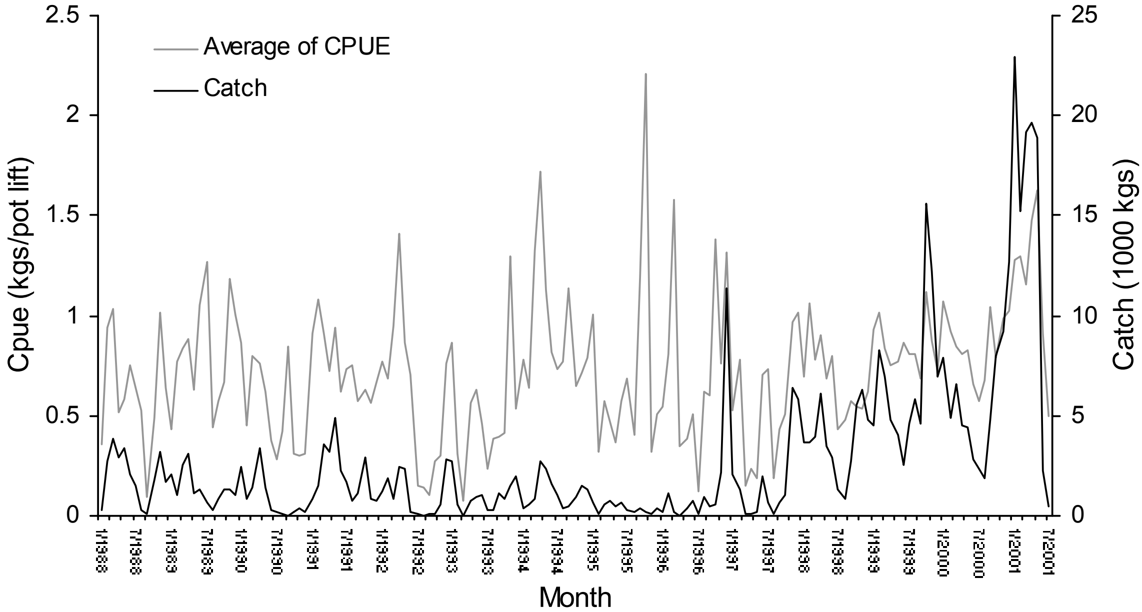


Figure 5.9 Mean monthly CPUE and catch for the commercial pot fishery in the Hervey Bay region.

State-wide changes in catch per boat day in trawl and pot fisheries

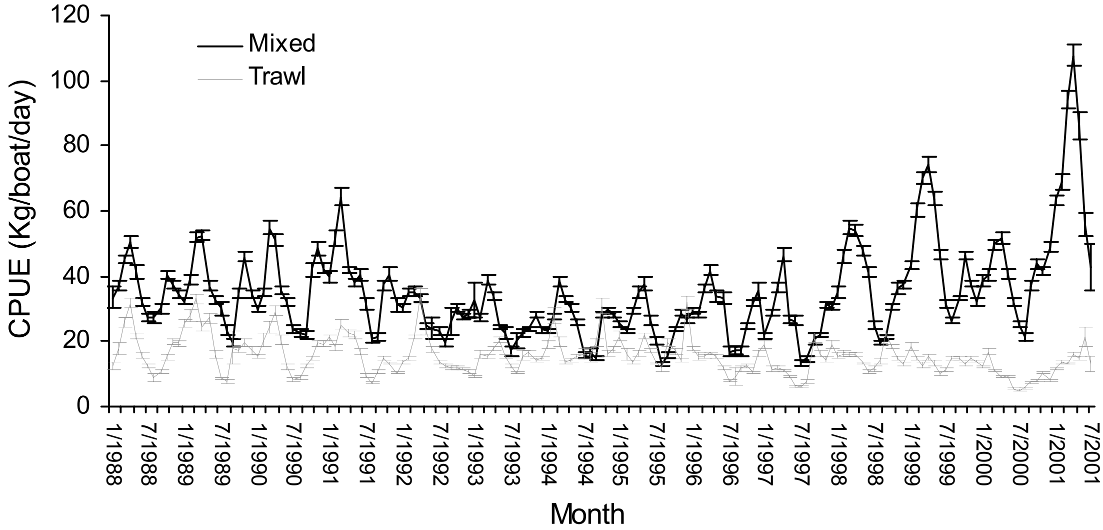


Figure 5.10 Mean catch per boat day for the commercial pot and trawl fisheries by month. Bars represent the 95% confidence interval.

Both pot and trawl fisheries displayed high inter-annual variation in mean daily CPUE, with dual annual peaks only visible in the commercial pot fishery (Figure 5.10). The mean daily CPUE in the commercial pot fishery was significantly higher than the trawl fishery for most of the period, with the trawl CPUE only higher during periods of low pot catch in winter. The overall trends for the logbook data indicate recent increases in CPUEs in the commercial pot fishery, after a decline in the early 1990's. The trawl fishery showed highly variable CPUEs with a possible decline over recent years.

The catch and fishing effort in the commercial pot fishery for the Moreton Bay region varied greatly over the logbook period (Table 5.3). The catch ranged from a minimum of 115 tonnes in 1992 to over 300 tonnes in 2001 (data not complete for this year). There was no significant relationship between fishing effort and total catch ($p > 0.05$, $R^2 = 0.09$) with fishing effort varying between 3918 and 6397 boat days per year. Despite the variation in the catch and effort the number of vessels operating in the fishery remained relatively constant with the exception of 1990 and 1992. Some of the vessels that left the fishery in these years may have moved across to the spanner crab fishery that experienced a large period of growth at this time (Williams 1997).

Table 5.3 Catch, effort and number of vessels reporting catches in the Moreton Bay mixed (pot) and trawl fisheries.

Year	Fishery	Catch (tonnes)	Effort (days)	Number of Vessels	Year	Fishery	Weight (tonnes)	Effort (days)	Number of Vessels
1988	MIXED	218.84	5653	97	1988	TRAWL	89.26	4845	123
1989	MIXED	214.96	5238	95	1989	TRAWL	138.58	5704	125
1990	MIXED	211.89	4749	67	1990	TRAWL	127.46	6192	130
1991	MIXED	237.8	4969	85	1991	TRAWL	118.05	7253	151
1992	MIXED	115.31	3973	62	1992	TRAWL	107.85	6807	139
1993	MIXED	133.52	4871	90	1993	TRAWL	64.50	6648	138
1994	MIXED	149.65	5344	101	1994	TRAWL	84.43	6475	135
1995	MIXED	155.26	5999	94	1995	TRAWL	60.27	5515	122
1996	MIXED	156.95	5667	105	1996	TRAWL	93.36	6065	130
1997	MIXED	169.35	6013	99	1997	TRAWL	72.63	6916	132
1998	MIXED	226.67	6125	100	1998	TRAWL	63.91	6219	119
1999	MIXED	314.25	7822	99	1999	TRAWL	50.95	6154	115
2000	MIXED	294.21	7920	99	2000	TRAWL	38.55	5358	110

The trawl fishery in the Moreton Bay region was also marked by highly variable annual catches, with the highest catch of 136 tonnes occurring in 1989. The annual catch varied by up to 60% over the decade with catches declining over the latter years. The number of trawl vessels reporting blue swimmer crab catches in the fishery varied between 152 in 1991 and 110 in 2000.

The Bribie Island to Fraser Island region showed increasing catches in both the commercial pot and trawl fisheries over the logbook period (Table 5.4), with the commercial pot catch increasing to 87 tonnes in 1998. There was a significant relationship between catch and fishing effort for the commercial pot fishery in this region ($p < 0.0001$ $R^2 = 0.96$). The pot fishing effort showed a marked increase after 1995 with the number of boats operating in the fishery also increasing dramatically. The trawl catch for the Bribie to Fraser region likewise showed steady growth before peaking in 1997 and then subsequently declining. This increase in catch can be explained by the gradual increase in fishing effort and numbers of trawlers reporting crab catches.

Table 5.4 Catch and Effort in the Bribie to Fraser region.

Year	Fishery	Catch (tonnes)	Effort (days)	Number of Vessels	Year	Fishery	Weight (tonnes)	Effort (days)	Number of Vessels
1988	MIXED	24.21	385	34	1988	TRAWL	13.80	537	51
1989	MIXED	4.54	180	15	1989	TRAWL	14.73	843	56
1990	MIXED	10.33	306	17	1990	TRAWL	20.10	1194	69
1991	MIXED	6.57	208	24	1991	TRAWL	24.20	1427	69
1992	MIXED	19.20	473	37	1992	TRAWL	24.35	1241	84
1993	MIXED	18.74	365	27	1993	TRAWL	35.37	2078	108
1994	MIXED	11.92	335	28	1994	TRAWL	33.19	1938	110
1995	MIXED	15.86	339	30	1995	TRAWL	30.72	1813	81
1996	MIXED	26.88	504	26	1996	TRAWL	36.03	2499	113
1997	MIXED	27.23	624	43	1997	TRAWL	37.24	2811	128
1998	MIXED	91.79	1407	57	1998	TRAWL	31.20	2373	114
1999	MIXED	151.25	1836	72	1999	TRAWL	16.63	2149	90
2000	MIXED	99.25	1343	41	2000	TRAWL	17.82	2910	131

Table 5.5 Catch and Effort in the Hervey Bay region.

Year	Fishery	Catch (tonnes)	Effort (days)	Number of Vessels	Year	Fishery	Weight (tonnes)	Effort (days)	Number of Vessels
1988	MIXED	26.912	844	42	1988	TRAWL	6.75	482	47
1989	MIXED	17.766	590	35	1989	TRAWL	11.19	576	51
1990	MIXED	11.285	484	28	1990	TRAWL	15.16	1158	61
1991	MIXED	25.223	758	31	1991	TRAWL	29.81	2445	129
1992	MIXED	15.736	444	32	1992	TRAWL	47.27	3834	169
1993	MIXED	12.208	469	35	1993	TRAWL	116.15	6121	209
1994	MIXED	14.47	456	31	1994	TRAWL	163.05	5280	172
1995	MIXED	4.637	173	29	1995	TRAWL	164.04	7124	207
1996	MIXED	19.753	301	25	1996	TRAWL	70.21	4757	197
1997	MIXED	20.424	572	41	1997	TRAWL	151.82	6814	227
1998	MIXED	45.888	1328	52	1998	TRAWL	210.17	8385	217
1999	MIXED	83.602	1930	61	1999	TRAWL	172.62	7729	194
2000	MIXED	70.754	1756	61	2000	TRAWL	88.11	6133	194

The number of vessels operating in the Hervey Bay pot fishery varied between 25 and 61 during the period with no trends apparent (Table 5.5). The trawl fishery in the Hervey Bay region showed a large increase in both catch and fishing effort with a highly significant relationship between these two variables ($p < 0.0001$, $R^2 = 0.90$).

It must be noted that this fishing effort does not include all trawl vessels operating in Queensland. Only those vessels that recorded a catch of blue swimmer crabs were included in the analysis. Therefore small amounts of blue swimmer crabs may not have been recorded by trawl fishers as crabs which are not caught in large marketable quantities are at times not entered in the daily logbooks.

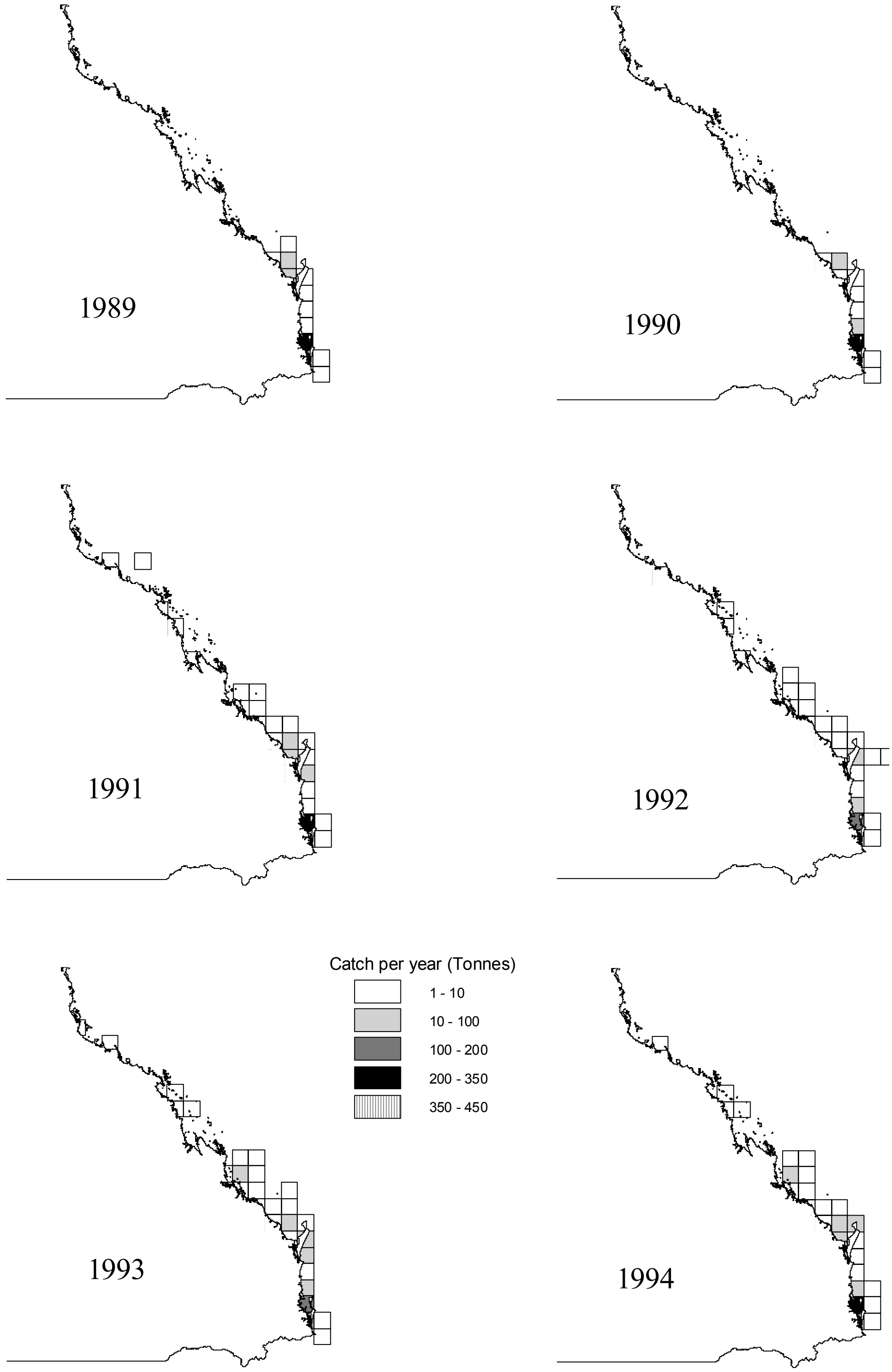


Figure 5.11a Geographic variation in the total annual blue swimmer crab catch recorded by commercial fishers (both pot and trawl) in Queensland (1989 to 1994).

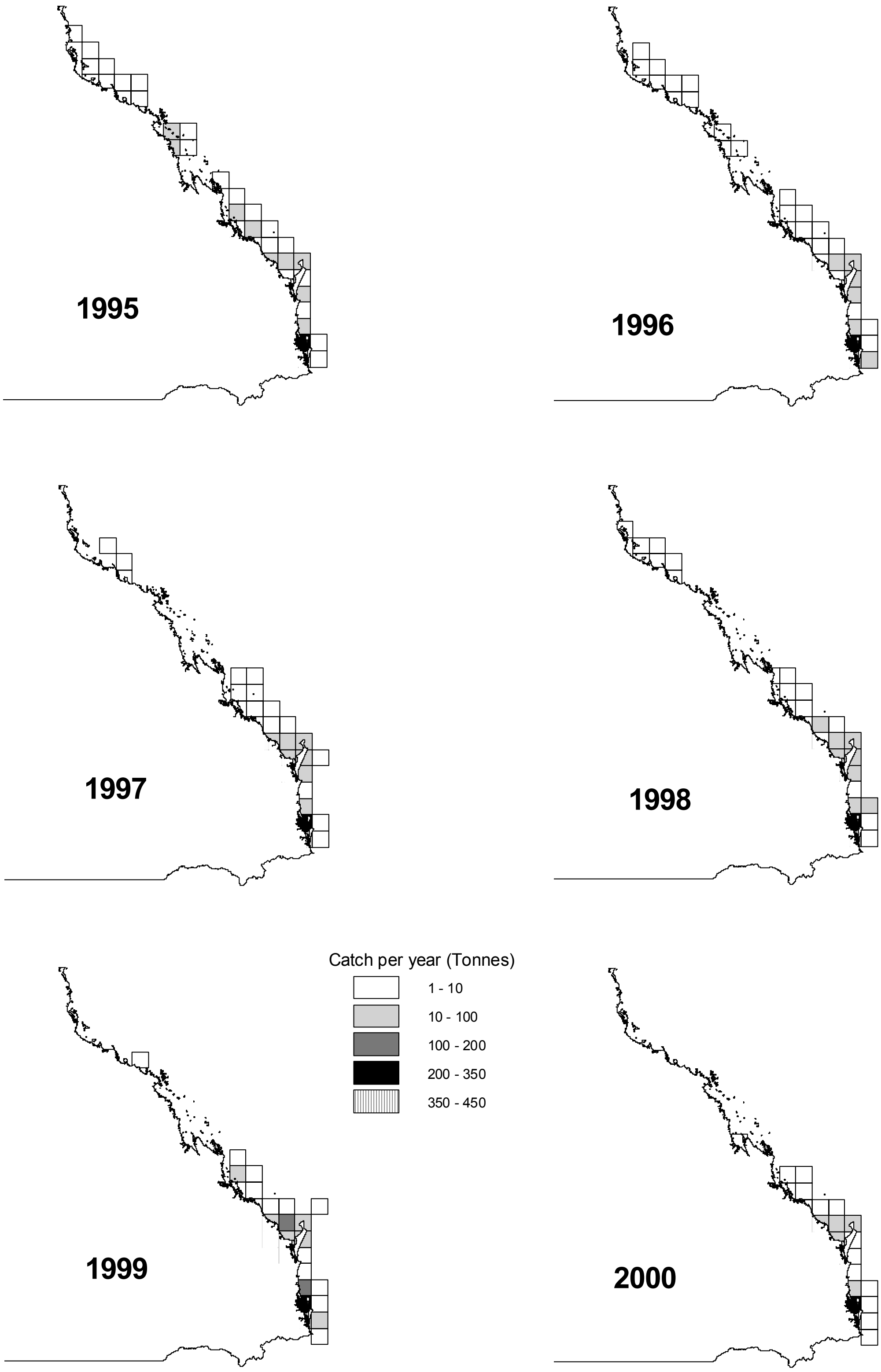


Figure 5.11b Geographic variation in the total annual blue swimmer crab catch recorded by commercial fishers (both pot and trawl) in Queensland (1995 to 2000).

The vast majority of the commercial catch of blue swimmer crabs is centred on the southern part of the State, particularly in Moreton Bay and Hervey Bay (Figures 5.11a – 5.11b). The overall pattern has changed little since the implementation of the logbook program. The main feature is the consistency in catch to areas around the main fisheries in Hervey Bay and Moreton Bay. Moreton Bay is clearly the main blue swimmer crab producing area of the State.

Discussion

A significant amount of the variation in catch and effort in both the pot and trawl fisheries can be explained by different management interventions that have occurred in the recent years. For example, the reduction in pot fishing effort in most regions in the early 1990s was partly due to fishers targeting spanner crabs (*Ranina ranina*) in those years. The Queensland spanner crab catch increased from 391 tonnes in 1988 to 3518 tonnes in 1994 (Williams 1997), a good deal of that catch being taken by crabbers who had previously fished blue swimmer crabs.

A full discussion of the CFISH data, particularly as it relates to these issues is presented in Chapter 6 (Impact of commercial trawling on the blue swimmer crab fishery). In addition the use of these data for stock assessment purposes is described in Chapter 14. However, analysis of the logbook data highlights a number of critical issues related to the use of these data for management purposes. The first of these relates to the recording of both trawl and pot effort. Since the importance of blue swimmer crabs to trawl fishers varies dramatically between fishers and areas, and is also related to the catch rates of other target species, the reporting practises likewise vary dramatically. The inclusion of only those trawl fishers who recorded blue swimmer crabs in their logs obviously results in a considerable reduction in the amount of trawl effort used in some analyses. However, it is equally unwise to include the massive amounts of trawl effort directed towards deeper areas or areas where blue swimmer crabs are only rarely reported and presumably do not occur in significant numbers. These problems mainly occur outside Moreton Bay since the vast majority of trawler operators in Moreton Bay regularly report blue swimmer crabs in their catches.

A second area that impacts the results is the reporting of catch by weight and numbers. The conversion factors used in the preceding analysis (which range from 3 to 3.5 crabs per kilo) can introduce a 17% error in either weight or numbers between catches of individual fishers. While these conversion factors represent accurate average conditions operating within the regions (based on observer data) they are not necessarily accurate for individuals. Related to this are other idiosyncrasies in the catch reporting practises of fishers. Abnormalities in wording of Fisheries Regulations have allowed a defacto reduction in size limit to approximately 135mm carapace width (compared to the intended 150mm). If crabs have damaged spines, fishers are able to use an alternative measure (known as the underbody measure) which is far more generous in its relationship to carapace width. Fishers have been known to break off spines from crabs under 150 mm to enable them to use the alternative measurement. Crabs that have damaged spines are commonly known as “tippers” or “spikers”. On some fishing trips “tippers” can constitute over 50% of the catch, particularly in Moreton Bay. Some fishers report catches of only those crabs that exceed 150mm while other record the “tippers” as well. There are also regional variations in these practises. In Moreton Bay, virtually all crabbers keep “tippers”, whereas only a minority of fishers land a significant number of “tippers” in Hervey Bay. Attempts were made to quantify the reporting practises of individual fishers by surveying most of the significant pot fishers (see Chapter 15) but results were not conclusive enough to enable the accurate quantification of these reporting abnormalities.

The consistency in recording 50 pots as the standard unit of fishing effort in the mixed fishery logs also introduces considerable inaccuracy and imprecision into the analysis. Observation trips and discussions with fishers have shown that it is very rare for fishers to use exactly 50 pots and in fact most would lift considerably more than this amount. This may not cause significant problems if the unit of effort chosen is the fishing day rather than the pot lift but it appears that the common recording practise masks a considerable amount of effort (over 100% for some individuals). Once again attempts to standardise for this using information provided by fishers was unsuccessful. Observers noted a 30 % increase in the effort of some long time fishers in the past decade while their reported effort was the same. This effort creep is extremely difficult to quantify given regional, and individual variations in recording practises and the reluctance of fishers to incriminate themselves by admitting using more than the prescribed maximum number of apparatus. While effort (in terms of average number of pots lifted per fisher per day) in

Moreton Bay appears to have remained relatively stable discussions with many fishers highlighted that effective effort had increased.

It was common for fishers to note that beach prices for their crabs had not increased in line with inflation. In order to meet overhead costs and maintain profit levels they had to increase their catch. One of the ways that this was achieved was by increasing the amount of gear used. Many fishers who once fished waters inside Moreton Bay had also been forced to fish in more productive areas further offshore, where catch rates were higher.

These issues suggest that a review of the logbook reporting procedures related to the crab pot fishers is urgently required. Such a review should focus on educating fishers to ensure consistent reporting procedures and the adoption of management regulations that do not encourage misreporting. This includes the elimination of regulations whose interpretation effectively allow for two size limits.

6. IMPACT OF TRAWLING ON BLUE SWIMMER CRABS

Introduction

Trawling is a relatively non-selective method of fishing that catches a far greater range of species than those being directly targeted. In Queensland, trawling for tropical prawn species results in high bycatch/prawn weight ratios, which may be as high as 11 to 1 in some areas (Robins and Courtney 1999). Some of this bycatch is marketed (as by-product), and although the extent to which trawlers rely on by-product varies greatly, it is fair to say that most trawler operators would market their blue swimmer crabs because of a well-established market and relatively high price obtained for the product. The importance of blue swimmer crabs differs between individual operators and is influenced by seasonal abundances, area of fishing and market demand for both prawns and crabs. It is a difficult and subjective judgement to determine when a species normally considered to be by-product becomes a target species in any fishery. This difficulty is central to much of the current debate surrounding the capture and marketing of blue swimmer crab *Portunus pelagicus* as a by-product of the East Coast Trawl Fishery.

The terms "bycatch" and "by-product" often create confusion as the former is sometimes used to describe the incidental catch of all but the target species, and also in a narrower sense that includes only non-marketed discards from the fishing operation. In this report "by-product" will be used in a broad sense to describe everything that is caught and marketed other than the target species. "Bycatch" or "Discards" will be used to describe that part of the catch that is not marketed and discarded at sea during the sorting process. Target species are those defined under Section 7 of the Management Plan listed as "principal fish" (which is a synonym for target species). These include prawns, scallops, bugs and squid. Section 8(1) also lists additional "permitted fish" that may be retained, these being:- balmain bugs, barking crayfish, cuttlefish, goatfish, mantis shrimp, octopus, pinkies, red spot crabs, sharks, syngnathids and whiptails. By the previous definition these species are essentially by-product. Section 8(2) also specifies that blue swimmer crabs were permitted fish only until 31 October 2000. However, subsequent to this date blue swimmer crabs have been included as a permitted species for a further 15 months pending further management arrangements. As well as listing the species that can be retained, the Management Plan imposes a prohibition on taking or possessing any fish other than permitted fish (Section 23).

The management of trawled blue swimmer crabs, both as retained by-product and discards (undersized and female crabs), is essential if trawling is to be ecologically sustainable and is to meet community expectations for the fishery. Achieving these aims will involve ensuring that trawl bycatch and by-product does not result in adverse ecological effects, for example through overfishing, or in inequitable catch sharing arrangements. The previous chapter has highlighted dramatic changes in the catch sharing arrangements between pot and trawl sectors in recent years as well as other shifts in catch and effort. There have also been a number of recent variations to the management of the trawl industry in Queensland that relate directly to the overall management of blue swimmer crabs which may have impacted on the analysis. These management measures are set out below:-

November 1995: Commencement of *Fisheries Regulation 1995*. Provisions for trawl fisheries to allow the take of prawns and saucer scallops, other than for T4 trawl symbol holders who can only take red spot or stout whiting.

December 1996: Release of *Discussion Paper for the Queensland Trawl Fishery* (QFMA 1996). This paper requested public input on a range of management issues including bycatch of blue swimmer crabs and other species. The issues surrounding the taking of blue swimmer crabs by trawlers were dealt with in some detail. It was recognised that the marketing of by-product components (such as blue swimmer crabs) was at that stage technically prohibited by the *Fisheries Act.*

August 1997: Release of *Strategic Statement for the Queensland Trawl Fishery* (QFMA 1997a). This paper was targeted at East Coast trawl symbol holders and discussed the bycatch issue with the stated objective of legitimising the sale of by-product including blue swimmer crabs while ensuring that the historical trawl caught share did not increase.

December 1997: Release of *Regulatory Impact Statement on Trawl Bycatch* (QFMA 1997b). This statement proposed changes to *Fisheries Regulation 1995* in respect to the provisions for species captured and retained by trawlers. It also proposed a list of species that were to be regulated by number, including 100 blue swimmer crabs in Moreton Bay and 1000 blue swimmer crabs elsewhere.

February 1998: Release of *Queensland Trawl Fishery: Proposed Management Arrangements 1998-2005* (QFMA 1998a). This document was developed from the consultation phase of the Discussion Paper, Regulatory Impact Statement and the Strategic Statement as outlined above. It dealt with issues of effort control and major seasonal closures, as well as bycatch and by-product of blue swimmer crabs.

October 1998: Release of *Regulatory Impact Statement on the Introduction of VMS, TEDs and BRDs* (QFMA 1998b). This statement proposed the introduction of Vessel Monitoring Systems (VMS), Turtle Excluder Devices (TEDs), and Bycatch Reduction Devices (BRDs) for the majority of the trawl fleet.

The purpose of a BRD is to reduce the level of bycatch taken by the use of the net to the lowest level that allows the economically viable use of the net, having regard to the sustainability of the fishery's ecological systems (Section 39 of the Management Plan). The Management Plan also described the types of BRD that may be installed in trawl nets. Approved BRDs are:- Square mesh cod end (Section 42), square mesh panel (Section 43), fisheye (Section 44), bigeye (Section 45) and radial escape section (Section 46). BRD's are placed in nets to provide an escape mechanism for non-target species such as blue swimmer crabs. The efficacy of the BRD will be influenced by a number of factors including the swimming ability (speed and stamina) of the fish. Current regulations stipulate that BRDs must be fitted to all trawlers working outside Moreton Bay, as well as for those working in southern Moreton Bay.

April 1999: Implementation of *Fisheries Amendment Regulation (No. 3) 1999.* This amendment addressed a number of issues surrounding bycatch and by-product in the East Coast Trawl Fishery. From this time the following species were legally "principal" target species:- Moreton Bay bugs, prawns, saucer scallops, squid. Other species that were allowed to be taken as "permitted" species included Balmain bugs, barking crayfish, cuttlefish, goatfish, mantis shrimp, octopus, pinkies, red spot crabs, sharks, syngnathids and whiptails. The provisions for blue swimmer crabs and winter whiting were only for the period 1 May 1999 to 31 October 2000. The regulatory amendment also allowed the retention of other fish taken when taking target fish, other than a specific list of regulated fish. It also introduced arrangements to phase in bycatch reduction devices (BRDs) in trawl gear. An in-possession limit of 100 in Moreton Bay and 600 elsewhere for trawl caught blue swimmer crabs was introduced as an interim catch sharing measure.

June 1999: Release of *Draft Management Plan for the Queensland East Coast Trawl Fishery* (QFMA 1999a). The draft Management Plan proposed the continuation of by-product management provisions as per the May 1999 amendments to *Fisheries Regulation 1995*.

November 1999: Implementation of *Fisheries (East Coast Trawl) Management Plan 1999.* The current provisions likely to impact the taking of blue swimmer crabs in the trawl fishery are contained within the Management Plan. These will be described in detail in later sections.

October 2000: Release of *Regulatory Impact Statement and Draft Amendments to the Fisheries (East Coast Trawl) Management Plan 1999.* This document further confirmed the in-possession limits of blue swimmer crabs implemented in April 1999 and asked for public comment on these proposed limits. Provisions for the taking of blue swimmer crabs by trawlers applied until midday on 1 January 2002 when reduced in-possession limits (30 in Moreton Bay and 500 elsewhere) came into force.

The review of bycatch and by-product provisions as they relate to blue swimmer crabs for the East Coast trawl fishery has been part of an over-all review of the trawl fishery that has been ongoing for over 5 years, as previously described. This review process has been central to the development of a Management Plan to ensure that the requirements of the *Fisheries Act 1994* are met, particularly the achievement of Ecologically Sustainable Development (ESD) in the trawl fishery. The requirements for ESD are outlined in the National Strategy for Ecologically Sustainable Development (Commonwealth of Australia 1992) and the desire for the trawl fishery to meet Environment Australia's criteria for sustainable fishing have driven many of these management changes. In addition, conflict between pot, trawl and recreational sectors has had a significant influence on the management of the crab catch of trawl fisheries.

The main issues confronting the blue swimmer crab fishery relating particularly to trawlers continuing to market blue swimmer crabs as a by-catch (permitted fish) component can be summarised as follows:-

- Sustainability of the fishery with respect to the biology and population dynamics of blue swimmer crabs
- Catch sharing arrangements (equitable sharing between trawl, pot and recreational fisheries)
- Economic and marketing considerations (product quality)
- Gear conflicts between trawl/trap and recreational interests
- Discard mortality rate of adults and juveniles
- Habitat damage and mortality of juveniles

Sustainability of the fishery

The biological characteristics of blue swimmer crabs make them highly resilient to fishing pressure. They are a fast growing, early maturing and highly fecund species that exploit a broad ecological niche. They area also distributed widely throughout Queensland and elsewhere in Australia. Recent genetic analysis has also shown that the east coast stock south of Mackay represents a unit stock (Chaplin *et al*. 2001) and thus localised depletions could be replaced with recruits from elsewhere in the species range. This means that blue swimmer crabs are not as threatened as a species that is very localised in its distribution and susceptible to localised, overfishing where once the population is diminished it is unlikely to be rebuilt by recruits from other areas. Generally speaking, for species such as blue swimmer crabs recruitment success is usually a function of environmental and hydrological conditions rather than stock size.

The blue swimmer crab fishery is managed by a range of controls including apparatus restrictions and limited entry conditions on the commercial fisheries. In addition, crabs are afforded protection through trawl fisher possession limits, a minimum legal size well above the size of sexual maturity and a prohibition on taking females (see Chapter 14). Yield per recruit analysis has also shown that the current size limit is very conservative and there exists considerable scope for sustainable increases in catch (see Chapter14) by reducing the size limit.

In 1999, the only year for which there is a reasonable estimate of recreational catches, reported trawl landings of blue swimmer crabs comprised about 25% of the total estimated harvest (including recreational and commercial pot sectors) of over 1100 tonnes. While the combined harvest is relatively large, the inherent variability in blue swimmer crab catches is well demonstrated by the catches in the following year. In 2000 reported commercial catches of blue swimmer crabs decreased by around 30% but it appears (based on figures gathered to September 2001) that the 2001 year will be the best on record. This level of variability in catches also illustrates the probable influence of environmental factors on crab abundance.

The historical CFISH catch and effort data presented in Chapter 5 also provide some indication of the sustainability of the fishery and these data are fitted to biomass dynamics models discussed in more detail in Chapter 14. The CFISH data show a recent decline in CPUE for trawl caught blue swimmer crabs in Moreton Bay and other areas. This could be interpreted as indicating a potential problem with the stocks but care should be taken in such interpretations, as management changes limiting the catch of trawl operators are likely to be more responsible for this decrease. On the other hand recent increases in daily pot CPUE suggests an under-exploited stock. This observation must also be tempered by the uncertainty about the accuracy of the most precise unit of effort, the pot lift and the possibility that the average number of pots lifted per day has effectively increased.

Advances in technology such as the greater use of radar and GPS have certainly increased the ability of fishers to trawl in previously non-trawled areas. As noted earlier, Potter and Sumpton (1987) have suggested that there might be sustainability problems if trawl effort was directed towards areas where females and juveniles are known to be more abundant (eg shallow bank areas). There are no indications that this has taken place, as these areas are generally not productive for prawns and other trawlable target product. Any change in management regulations that enables the retention of female blue swimmer crabs, or encourages trawling in shallow nursery habitat could, however, cause these areas to be targeted by trawlers to the detriment of the resource.

In summary, the biological features of blue swimmer crabs and the current conservative management measures ensure that the fishery, at least in terms of the regulated component of the stock, remains sustainable. There are, however, a number of features of the trawl fishery in particular that result in a greater ecological risk to the stock when compared with either the commercial pot or recreational fisheries. These features include the high proportion of the crab catch that is discarded, the mortality of those discards and habitat damage. These are discussed in later sections.

Catch sharing arrangements

Sectoral and sectional interests are becoming increasingly concerned that there should be appropriate catch sharing arrangements that benefit the community at large. Essentially there are two ways to assess and set catch shares. The first is to allocate catch shares on the basis of historic catch levels, with the assumption that maintaining the status quo is the fairest arrangement. While it is arguable that this may often meet the criteria of fairness, it does not address the growing expectation that fisheries resources should be managed for an optimum economic return (an alternative way of setting catch shares). Allocating catch shares on optimum economic returns is a complex task, which involves looking at all aspects of the benefit of the resource to the community. While the benefits derived from harvesting blue swimmer crab stocks could be optimised by allocating a greater share to the fishing sector that generates the greatest return for the community, measuring this return requires an appropriate method of attributing a value to fisheries resources. The likelihood that a study of relative economic values would resolve the issues surrounding the capture of blue swimmer crabs by trawling is considered to be small.

While catch share disputes and sectoral conflict over blue swimmer crabs has involved both recreational and commercial fishers the main area of conflict has been between the commercial pot and trawl fisheries. Prior to 1998 management regulations have resulted in almost equal sharing arrangements in terms of total harvest of the pot and trawl sectors (see Figure 5.7). The formalising of catch sharing arrangements in the form of a TAC or the like is an option, but such an arrangement would significantly increase management costs. It is also unlikely that a detailed economic analysis aimed at optimising the economic yield of blue swimmer crabs would assist in resolving the social and other issues associated with the catch allocation as mentioned earlier.

Based on previous analysis (and discussion that follows) the current in-possession limit for trawl caught blue swimmer crabs has the potential to cap the overall catch in that sector. It also has the potential to substantially increase the total trawl catch as some operators who previously were not taking crabs now (at least for the last few years) are legitimately able to retain them. It appears from the data presented in Chapter 5, that this has not taken place. Since the legitimisation of the trawl take of blue swimmer crabs the number of boats reporting catches of this species has actually declined. However, the setting of an in-possession limit does provide a mechanism by which the trawl share can be further reduced if that is found to be necessary due to sustainability or other concerns.

Up to 1998 between 120 and 150 trawlers reported catching about 100 tonnes of blue swimmer crabs per year in Moreton Bay. Since the discussion of management options in 1997/98 and the imposition of catch limits in 1999 both the number of trawlers reporting catches, as well as the catch itself has declined dramatically in Moreton Bay. During 1997 in Moreton Bay, blue swimmer crabs provided over 5% of the total income of 50 trawlers and over 10% of the income for 27 trawlers (Table 6.1) and thus were a significant part of many trawl fishers' incomes. As mentioned previously some catches reported in grids W37 and W38 may actually have been taken in waters outside Moreton Bay. However, as blue swimmer crab catches are not subject to problems of incorrect identification, the analysis of Moreton Bay catches included all reports from grids W37, W38 and W88. Blue swimmer crabs were clearly not as important to operators in the Hervey Bay Region with 38 % of boats deriving less than 1% of their income from blue swimmer crabs.

Table 6.1 Number of trawlers deriving various proportions of total income from blue swimmer crabs in Moreton Bay and Hervey Bay in 1997. Based on figures presented in Anon (1999).

		Proportion of income (GVP)					
	Total Boats	<1%	1-5%	5-10%	10-20%	20-30%	>30%
Moreton Bay	115	23	44	21	22	3	2
Hervey Bay	156	60	52	19	19	5	1

The distribution of daily catch sizes of blue swimmer crabs in Moreton Bay and Hervey Bay for the last 4 years is shown in Figure 6.1, which shows that over 90% of daily catches were less than 60 crabs in Moreton Bay. Hervey Bay was likewise dominated by daily catches of less than 60 crabs but there was a higher frequency of the larger catches (particularly those greater than 200 crabs) from Hervey Bay. In Moreton Bay the general pattern was for declines in the frequency in all catch sizes over the past 4 years except for the daily catches of 30 crabs or fewer, which have remained stable for the last 3 years. The situation in Hervey Bay differs marginally in that the frequency of larger catches was low in 1997 and it was not until management changes in 1998 that brought about increased reports of larger catches. These have now subsequently declined.

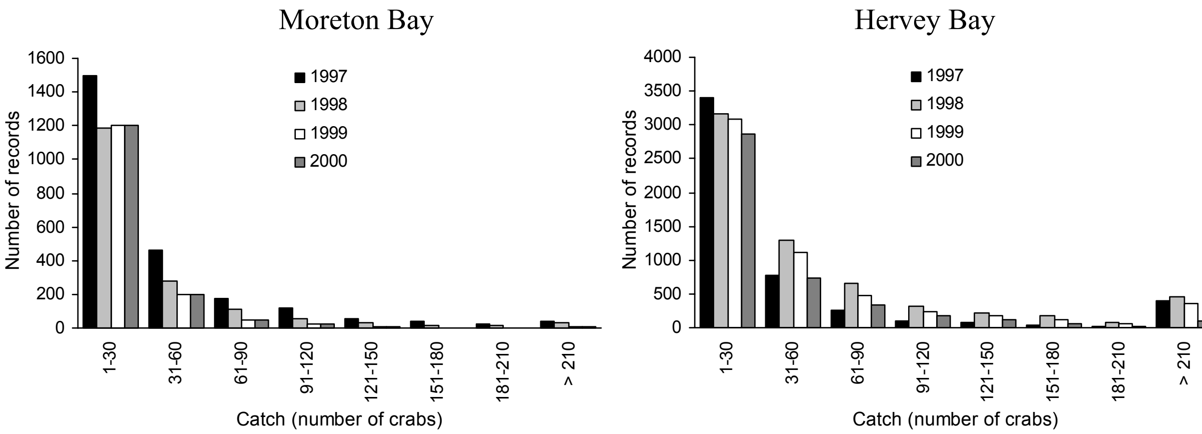


Figure 6.1 Frequency distribution of daily catch numbers for reported trawl caught blue swimmer crabs in Moreton Bay and Hervey Bay

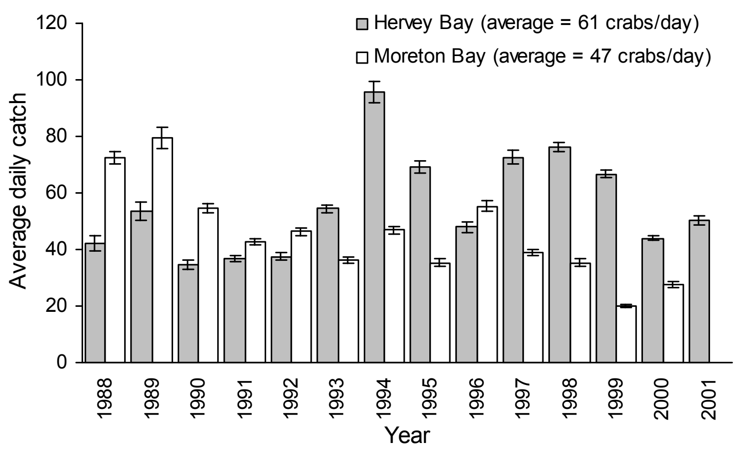


Figure 6.2 Annual variation in average daily (± standard error) catch of blue swimmer crabs by trawlers (which reported daily catches of crabs) operating in Moreton Bay and Hervey Bay.

When the overall average daily trawl catches were analysed, catch rates were about 30% higher in Hervey Bay than Moreton Bay (Figure 6.2). From 1988 to 1992 the average catch was higher in Moreton Bay but from 1993 this pattern was reversed, and in some years (particularly more recently) the average daily catches in Hervey Bay were twice those in Moreton Bay.

There was little difference in the cumulative catch graphs for both Moreton Bay and Hervey Bay (Figure 6.3). In both areas over 90% of catches were less than 120 crabs per day. Hervey Bay trawlers reported 7 times the number of catches greater than 1000 than did Moreton Bay boats (adjusted for differences in total effort), and a lower proportion of the smallest catches (<30 crabs per day). These two features are the main reason for the differences in average daily catches between the two areas shown in Figure 6.2.

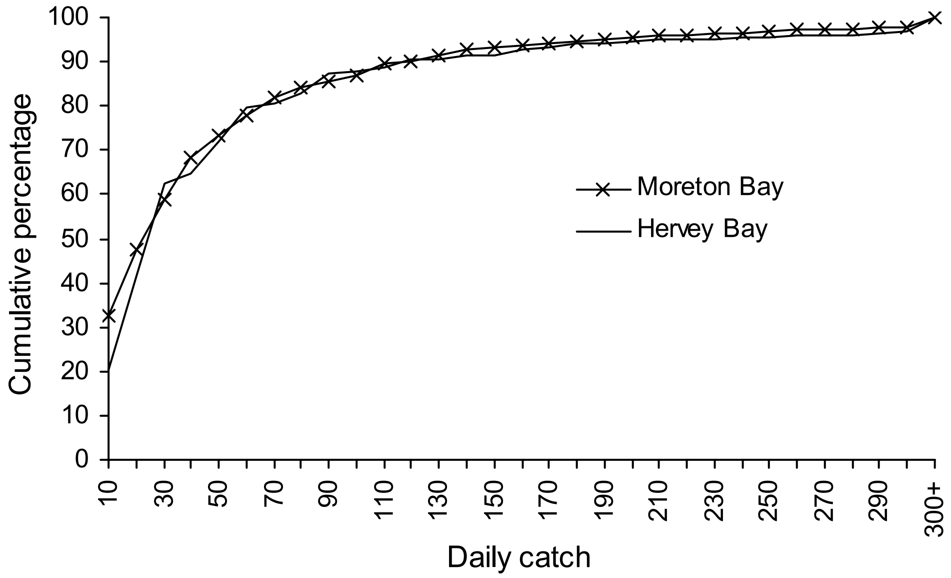


Figure 6.3 Cumulative percentage of various daily catches contributing to the total blue swimmer crab catch in Moreton Bay and Hervey Bay.

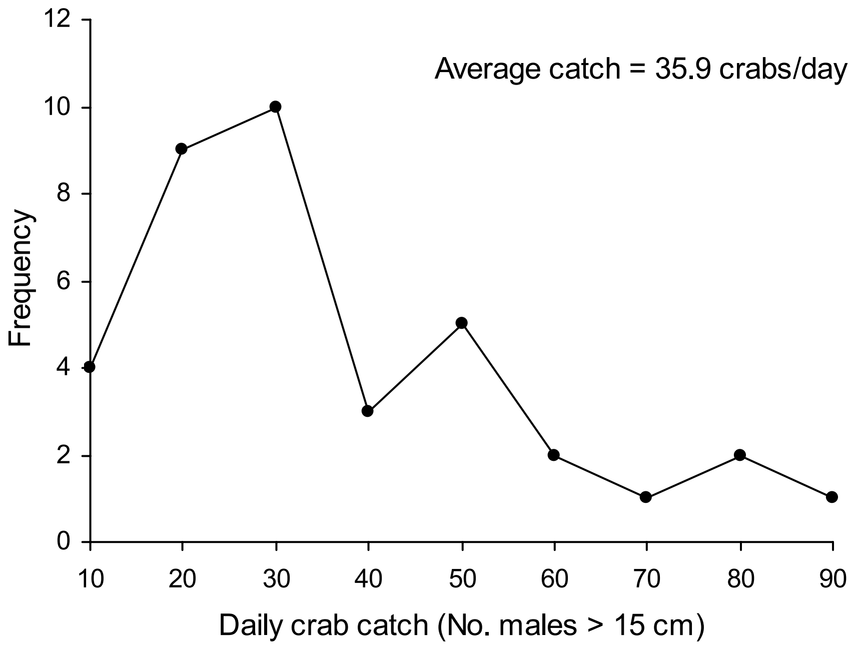


Figure 6.4 Daily catch rates of blue swimmer crabs obtained by a research trawler during 1985 and 1986. Data based on 2 days trawling per month (36 days).

Prior to the introduction of compulsory commercial logbooks in 1998, research conducted during 1985/86 using a research trawler fishing with the commercial fleet provides an indication of historical trawl catch rates in Moreton Bay. During that survey catch rates of blue swimmer crabs (Figure 6.4) averaged approximately 36 marketable crabs (>15 cm) per day. When the number of male crabs >140 cm (probably the size included in most recent logbook records, see discussion in Chapter 5) are included, average catch increases to almost 45 crabs per day. This correlates well with the reported trawl catches in the CFISH data system that range between 22 and 80 per day since 1988 and the overall average of 47 crabs per day. It is often argued that catch rates obtained by research vessels are not strictly comparable with those of the commercial fleet, but both the vessel and its skipper had previously been involved in the commercial prawn trawl industry and trawl gear was identical to that of the commercial fleet.

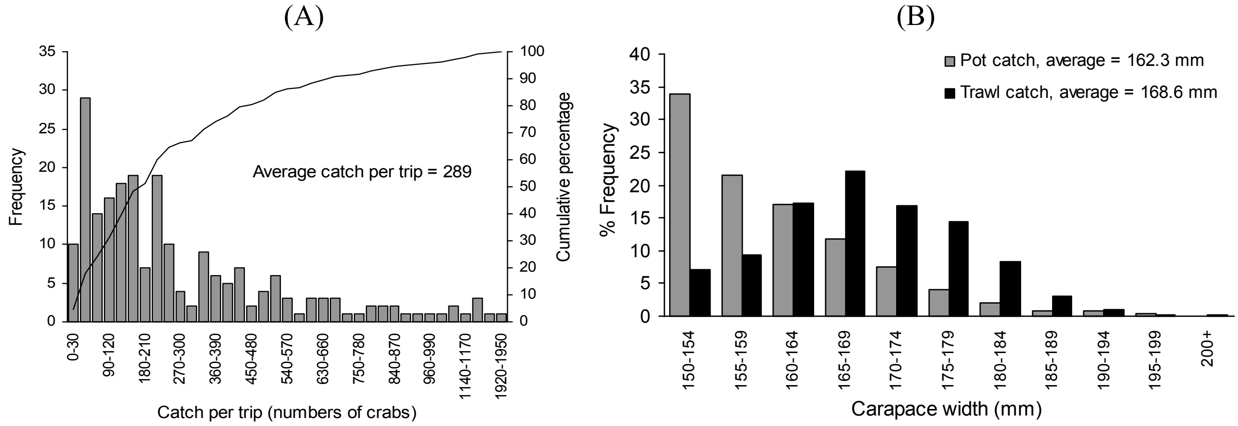


Figure 6.5 (A) Trawl catch per trip of blue swimmer crabs landed at processors in Hervey Bay during 1999/2000. Cumulative percentage is shown as a continuous line. (B) Size structure of pot and trawl catch from processors in Hervey Bay.

An examination of processor records in Hervey Bay during 1998 to 2000 showed that the average catch per trip was 289 crabs but no data were collected on the duration of these trips to allow for an estimate of daily catch rates (Figure 6.5A). Over 80 % of the total trawl catch came from vessels that had caught less than 500 crabs but there was still a low frequency of vessels that landed in excess of 1000 crabs. Obviously the larger catches were recorded prior to the imposition of the 600-crab catch limit but once again the processor records confirm the potential for significant catches of blue swimmer crabs to be taken by the trawl fleet. It is also interesting to note the difference in size structure of the Hervey Bay trawl and pot catches (Figure 6.5B). The size of crabs retained by trawlers was significantly larger than the pot fishery, reflecting fishing in areas further offshore that have a higher proportion of large crabs.

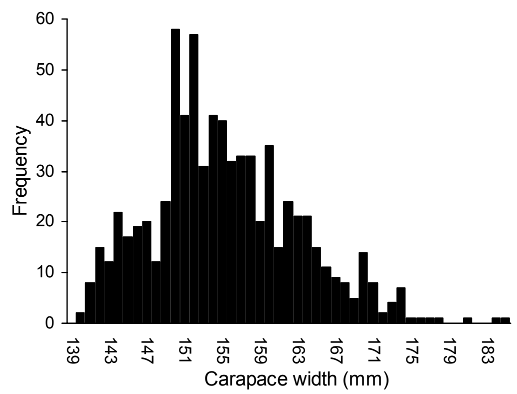


Figure 6.6 Size structure of trawl catch from processors in Moreton Bay.

In Moreton Bay the average size of the retained trawl product is significantly less than the Hervey Bay trawl catch having a much higher proportion of the smaller size classes, similar to that of the pot fishery

(Figure 6.6). Many of the Moreton Bay trawl crabs also had damaged spines. These crabs have had their lengths converted to carapace width in Figure 6.6 which shows a significant proportion of crabs being less than 150mm contributing to the catch. We also directly monitored individual trawl catches at processors in Moreton Bay but in most circumstances were again unable to accurately determine the number of days over which the catch was taken. However, since all boats were "wet boats" (product kept of ice) it is rare for trips to be longer than 3 days in Moreton Bay. Data were too few to provide as precise an estimate of landings distribution as that shown in Figure 6.5A for Hervey Bay but the average catch recorded was 39.5 crabs (n=64 landings). We consider that this is not an accurate estimate of average landing because of the small sample size and the probable bias introduced by only sampling a small proportion of processors. Most of the data were also collected during 1999 which, as Figure 6.2 shows was a poor year for trawl catches in Moreton Bay.

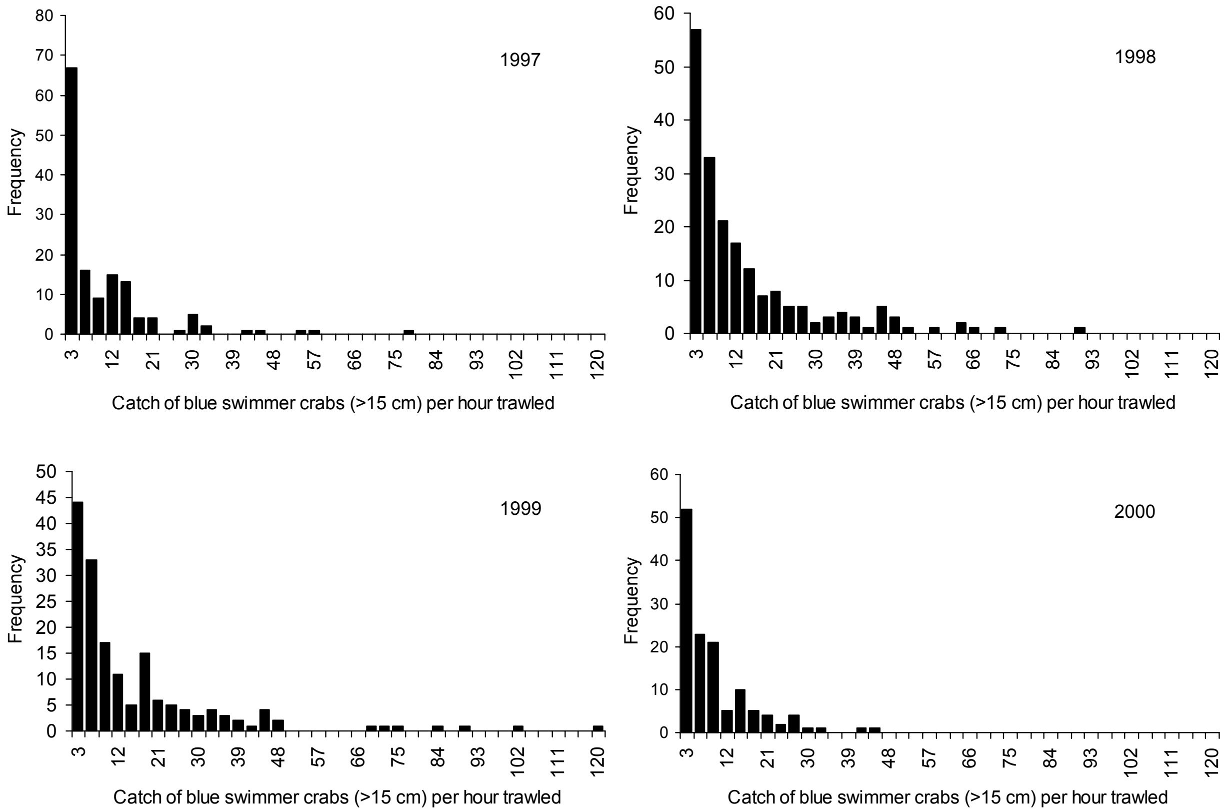


Figure 6.7 Catch rates of legal sized (> 150mm carapace width) male blue swimmer crabs (No. trawled per hour) during the annual October fishery independent survey of scallop grounds north of Hervey Bay.

The annual scallop survey also confirmed that high trawl catch rates of blue swimmer crabs in Hervey Bay were achievable (Figure 6.7). While there was considerable annual variation in catch rates, hourly catches of over 40 marketable crabs were achieved in all years using random trawl shots. On two occasions catches in excess of 100 per hour were observed which suggests daily non-targeted blue swimmer crab catches in excess of 500 are highly probable. The data do however show that most catch rates were under 30 per hour and in fact the most frequent catch was 1–3 crabs per hour in all years.

As can be seen in the data presented in the previous chapter the overall trawl effort for blue swimmer crabs, as measured by the number of boat days reported from 1988 to 1998, has increased steadily by about 1500 days each year. This increase in effort has been due primarily to the marked increase in the number of boats reporting catches in areas outside Moreton Bay. While the trawl catch rates throughout the fishery have declined slightly there are some notable differences between the trends in catch and effort in Moreton Bay and for the rest of the fishery. The Moreton Bay Region dominated the catch from 1988 to 1991 and contributed about half the state-wide catch in 1992. From that point there was both a fall in catch in Moreton Bay and a rapid rise in trawl catches, particularly in Hervey Bay where the number of boats reporting has grown from 47 to over 200.

Economic and marketing considerations (product quality)

A thorough economic analysis of the costs and benefits of marketing trawl versus pot caught product is beyond the scope of this report but the issue of differences in product quality between the two fishing methods is one that warrants further discussion. A full examination of the influence of various cooking and handling practises on blue swimmer crabs meat quality can be found in Death *et al.* (1987) but there are catching and handling practises specific to the trawl method which increase the probability of obtaining an inferior product. Early research conducted by the Queensland Department of Primary Industries showed that, providing crabs were handled in the same way following capture, there was no difference in the quality of pot or trawl caught crabs stored cooked. However, crabs caught by trawling were of poorer quality than pot caught crabs after 3 days stored on ice.

Trawling causes more damage to blue swimmer crabs than captures by pots (Sumpton *et al*. 1989, Melville-Smith *et al*. 2001). Trawl captured crabs have significantly fewer legs and a higher proportion of damaged claws than crabs which are caught in pots. In addition Potter *et al* (1994) noted that the recapture rate of crabs that were tagged after being trawled was significantly less than those tagged after being caught in pots, which suggests a higher degree of mortality imposed on crabs by trawling when compared to capture in pots. The greater damage may cause a less aesthetically marketable product and increase the stress on crabs but other factors may also contribute to poorer quality meat. The practise of holding crabs on board trawlers for many hours (or even days) prior to cooking is perhaps the main reason for the poorer quality trawl product.

There are also a number of location specific differences in handling and cooking practises. Most trawlers operating in Moreton Bay are “wet boats” that hold their product on ice. Most trips are less than 3 days as processors will generally not accept product held on ice for longer than this period of time. In contrast many trawlers working in offshore waters have freezers and will work up to 3 weeks or even longer before returning to port, although the average trip length of offshore boats is probably between 10 and 14 days. Again cooking and storage practises vary between operators with some fishers preferring to freeze green crabs while others freeze the cooked product. The former practise results in the most inferior product but freezing of crabs generally results in a poorer quality product compared with fresh chilled (Deeth *et al*. 1987). It is also common practise on board trawlers to cook product at the end of the night which may result in crabs being held prior to cooking for more than twice as long before cooking as is common in the pot fishery (particularly inside Moreton Bay).

Many of these problems could be addressed by the introduction of better cooking and handling practises on board trawlers. The range of handling practises results in a greater degree of variation in product quality than is seen in the pot fishery, which tends to have more consistent and better handling and cooking practises. The fact that blue swimmer crabs are the target of the pot fishery while they are a by-product component of most trawl operations means that trawler operators do not necessarily view them as a priority for best practise handling procedures when compared with prawns and scallops.

Gear conflicts between trawl/trap and recreational interests

The two main methods of capturing crabs (trawling and potting) crabs are incompatible and the two cannot successfully coexist in the one area (at least not at the same time). This incompatibility has been the source of ongoing debates for decades to determine so called “traditional” trawl and crabbing grounds. The issue of what method is used in a particular location is settled differently and informally in various locations. Management interventions as well as informal arrangements have to date not been successful at addressing this issue. What is clear is that trawlers usually take precedence in areas where both methods can be employed. This is because trawlers can trawl through lines of pots, simply trawling up the pots as they go. This can either happen on purpose or inadvertently. This practise may cause damage to the nets of trawl operators but once the pots are removed from an area trawling can then take place without further problems. Pots are not sufficiently large or heavy to cause dramatic problems to the nets of trawlers, particularly the larger and heavier plied scallop nets.

As trawling for prawns and other species in certain areas is highly seasonal, crabbers may still utilise grounds that are trawled at different times of the year but reports of large pot losses caused by "stray" trawlers are common amongst pot fishers. There are many instances of both trawlers and pot crabbers co-operating and establishing informal access relationships in some areas, particularly Hervey Bay, but this is not universally the case.

The delineation of pot and trawl areas is an important management issue but one that appears to be difficult to address to the satisfaction of all operators as the spatial and temporal distribution of target and by-catch species is highly dynamic, blurring the definition of fishing boundaries.

Discard mortality rate of adults and juveniles

Given that marketable as well as discarded blue swimmer crabs are caught in relatively large numbers by trawlers that are targeting prawns, it is important to determine the survival rate of the discarded catch. This was attempted in the current research aboard commercial trawlers by experimenting with crabs that were caught along with the target prawn species.

Blue swimmer crabs caught as part of prawn trawling operations in Moreton Bay were allowed to remain on the sorting tray with other by-catch components for 3 periods of time (15, 30 and 45 minutes). Once the experimental time was reached crabs were transferred to plastic holding tanks supplied with flow through seawater and observed hourly until the conclusion of fishing operations (usually 8 hours). Only smaller crabs (<120mm) were used in this experiment as we were mainly interested in checking mortality rates of juveniles because research in Western Australia was focussing more on the survival of larger crabs.

Table 6.2 Percentage mortality of juvenile blue swimmer crabs exposed on the sorting tray of a commercial prawn trawler for 15, 30 and 45 minutes. Sample sizes are shown in brackets.

Date	Trawl duration (min)	15 min exposure	30 min exposure	45 min exposure	Total
10/02/2000	60	0	0	22.22	7.69 (26)
05/04/2000	60	16.67	0	20.00	12.20 (41)
14/09/2000	80	0	11.11	0	3.70 (27)
02/11/2000	90	0	0	0	0 (24)
Total (all trials)		5.26 (38)	2.56 (39)	12.20 (41)	6.78 (118)

There was considerable variation in mortality of blue swimmer crabs between fishing trips (Table 6.2) but the overall mortality rate (7%) was comparatively low. The data were too few to make precise conclusions about the effect of duration of exposure, but the mortalities after 45 min exposure were over twice those of either 15 or 30 min. Melville-Smith *et al.* (2001) recently completed trials with larger crabs in Western Australia and have likewise found mortalities of a similar order of magnitude, suggesting that discard mortality in crabs may not be as great an issue as it is for finfish.

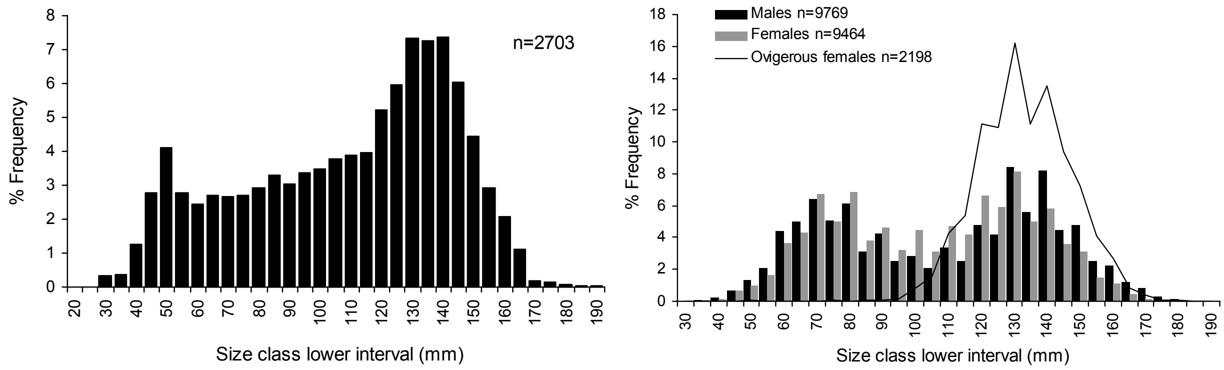
As mentioned earlier, trawling causes considerably more damage to blue swimmer crabs than does potting. In addition, the selectivity of the trawl gear tends to catch a high proportion of juvenile crabs. While it is difficult to assess the sorting and handling practises of various trawl operators, most of the sorting on board boats working in Moreton Bay would normally be completed within 45 minutes so the range of experimental treatments above represent realistic conditions found on trawlers. Vessels working in offshore waters are less likely to catch juvenile blue swimmer crabs because the preferred juvenile habitat is shallow estuarine areas. In addition, the mesh size used by scallop trawlers does not select for the juveniles caught in the smaller mesh of inshore prawn trawlers.

Despite the considerable variation in fishing and handling techniques, a code of best practise could have a dramatic impact on the survival of discarded trawl caught crabs. This would involve the minimisation of sorting times and the quick return of more sensitive discard species back into the water. The recent introduction of "hoppers" in some parts of the trawl industry is a positive move that should further reduce the mortality of discards.

Habitat damage, ecological damage and mortality of juvenile blue swimmer crabs

Trawlers may also impact on blue swimmer crabs by modifying the habitats of both adults and juveniles. As mentioned earlier, juveniles inhabiting shallow habitats may be particularly vulnerable to capture by trawlers or to damage caused by ground chains and other parts of the gear. It is not proposed to address the habitat modification issue in detail here as the impacts of trawlers on benthic habitat has received considerable recent attention in Australia (Stobutzki *et al*. 2000). Of relevance, though, is the potential impact of both sets of fishing apparatus on the benthic fauna in the fishing area. A pot fisher operating the same number of days as a trawler will impact on less than 0.01% of the area of bottom swept by that trawler and thus have a much lower ecological impact. In addition, the bycatch of the trap fishery is far less than that normally associated with the trawl fishery (see Chapter 12 for a discussion of bycatch issues in the pot fishery).

It should also be noted that trawling in Moreton Bay, in particular, tends to occur in areas where there are large numbers of juvenile blue swimmer crabs. During a survey in 1985 and 1986 a research trawler fishing with the Moreton Bay commercial trawl fleet caught large numbers of juveniles (Figure 6.8). During observer trips on commercial trawlers in 1998-2000 the size distribution of the catch was similar to that of earlier research with the majority of the catch consisting of juveniles.



Moreton Bay (1985/86) Moreton Bay 1998/2000

Figure 6.8 Size structure of blue swimmer crabs caught during monthly trawling in Moreton Bay during 1985/86 and from commercial observer trips in 1998 to 2000.

Despite the fact that there is some difference in the size structure of the trawl catch during the 1980's and 1990's overall the catch rates of legal male crabs (>150mm) did not differ significantly with these crabs making up 11.9% of the catch during the earlier surveys and 11.1% of the catch in the most recent survey. Small differences in target areas can have a dramatic impact on the size of crabs that are caught in trawls. Sumpton *et al*. (1995) and results of sampling during the present research clearly showed that smaller crabs were more abundant in the shallower waters on the western side of Moreton Bay (see Chapter 11). Small changes in the fishing patterns and depth preferences of the trawl fleet can have a dramatic impact on the resultant catch.

One of the main differences between the two survey periods relates to the greater proportion of the smallest size classes in the most recent surveys. This could be due to a range of factors including the type of nets used or their set up. The nets used in the earlier survey were paired, 4 fathom "Florida flyer" nets that had identical mesh size to those used by the majority of the fleet today although most of the vessels currently operating within Moreton Bay use "tongue nets". What is clear is that about 90% of the blue crabs caught by trawlers in Moreton Bay are undersized and therefore must be discarded. The mortality of these discarded crabs is critical to the subsequent sustainability of the resource, as discussed earlier. Even though the mortality of the discards is probably low, the amount of trawl fishing effort in Moreton Bay suggests that the number of crabs incidentally caught and killed by trawlers is substantial. The number of trawl days in Moreton Bay has varied over the last 12 years between about 5000 and 7000 days (See Table 5.3). Assuming approximately 10 hours trawling per night, models of likely impacts were produced under various trawl mortality and catch rate scenarios. Assuming catch rates of 50 discarded crabs per hour and a mortality rate of 10% the median trawl mortality is in the order of 250,000 crabs per annum. A worst case scenario suggests that well over 2,000,000 discarded blue swimmer crabs may die each year.

Another potential source of trawl damage relates to the crabs moult cycle. Potting relies on the attraction of crabs to some type of bait, usually fish. Between late-pre-moult and early post moult phases of the crabs' cycle they do not feed on the baits used in pots and it is therefore rare to catch these crabs in pots. By comparison the non-selective nature of trawling results in large numbers of these crabs being taken in trawl nets. During the early post moult stages in particular crabs have very soft shells and are highly susceptible to damage and most would not survive damage inflicted during capture in trawl nets. It is common for early post-moult crabs to have lost most limbs during capture, and in many cases they are crushed and dead before even being placed on the sorting tray. The proportion of the trawl catch which is "soft shelled" varies spatially and temporally but at times over 50% of male crabs > 140 mm in width are discarded because they are too soft to market. The discarding of soft crabs also occurs in the pot fishery but the most vulnerable stages are not attracted to pots.

Overall mortalities caused by commercial potting and recreational "dillying" would be expected to be at least an order of magnitude lower than those of the trawl sector. The proportion of the blue swimmer crab catch discarded from trawlers can exceed 90% whereas pot discard ratios are usually less than 50%. It is also rare for pots to catch juvenile blue swimmer crabs because of the mesh size and targeting practises of pot crabbers, who tend to concentrate their effort in areas where large male crabs are most abundant. Such areas tend not to have large numbers of juveniles (Chapter 9). In addition, the relatively rapid sorting of pot caught blue swimmer crabs would result in a lower mortality than those caught in trawl nets. Potter *et al.* (1991) found significantly higher tag return rates for pot rather than trawl caught crabs. Once again, handling practises vary between pot fishers, but experiments to assess the mortality of pot caught crabs resulted in mortalities of less than 2%, and as expected these mortalities were a function of exposure time. In Western Australia, where pot caught blue swimmer crabs are usually sorted after the pot has been emptied into an ice slurry mortalities were between 5 and 20% for pot caught crabs and between 0 and 30% for trawl caught crabs (Melville-Smith *et al.* 2001). The practise of placing crabs in an ice slurry for up to 20 minutes would cause more stress than the common sorting practises used by pot fishers in Queensland.

The impact of tangle nets or dillys used predominantly by the recreational sector was not assessed because of the lack of data on catch rates and mortalities caused by this type of apparatus. The greatest concern regarding dillies is that because they entangle crabs there is a greater possibility of limb damage during the process of removing crabs from the net, and this damage is very much influenced by the skill and patience of the operator.

The models clearly show an extremely wide range of possible mortalities, reflecting the considerable uncertainty surrounding the catch rate and mortality parameters. What is clear though is that trawlers potentially cause more damage than other forms of fishing for crabs because of the following:-

- Damage caused to juveniles and soft-shelled post-moult crabs in the trawl net
- Mortalities caused by longer exposure time due to catch sorting
- The tendency for trawlers to have much higher discard ratios than pot fisheries because of the selectivity of their nets.
- The smaller average size of crabs caught in trawl nets.

Trawl logbook validation

Much of the previous discussion has been based on catch and effort information supplied by commercial fishers and recorded in the CFISH system. Discussion in Chapter 5 highlighted several flaws in the CFISH data pertaining to both catch and effort records in the pot fishery, but there are also possible inadequacies in the trawl data. As the accuracy of the trawl catch and effort information was vital to discussions on catch sharing and other aspects of the fishery it was important to gain an independent assessment of the accuracy of the trawl data. The Queensland East Coast trawl fishery has approximately 840 licensed vessels, of which only 459 recorded capturing legal blue swimmer crabs in 1998. Utilising data from the 1997 to 1999 QDPI scallop surveys (see Chapter 11), the validity of trawl logbook entries were examined for the Hervey Bay region. The validation analysis used both scallops and blue swimmer crabs in order to determine whether or not the recording practises changed with species. This comparison was necessary as scallops are considered a target species and blue swimmer crabs are primarily considered a by-product species, and as such may not be recorded as accurately.

The QDPI scallop surveys are comprehensive surveys of the scallop and blue swimmer crab stocks in the Hervey Bay region (see also Chapter 11 for a detailed discussion of the survey methodology and overall results pertaining to blue swimmer crabs). The survey includes approximately 400 randomly allocated sites that are stratified by commercial fishing effort based on areas identified from logged trawl effort. Commercial trawlers are chartered for the survey, which occurs over a 10 – 12 day period in October each year. Sampling consists of a series of random 20-minute trawl shots between dusk and dawn throughout the scallop grounds north of Hervey Bay. The catch (mainly scallops and blue swimmer crabs) at each site is measured to determine size frequencies and relative densities of the two species. In order to standardise catches between vessels based on their different fishing abilities, one day of the survey is allocated to determine the relative fishing power of each vessel.

The relative densities of crabs and scallops were assumed to be proportional to the expected commercial catch for a twenty-minute trawl at each site. This indicative catch was then multiplied by 31.8 to determine the average expected catch per boat day for a vessel fishing exclusively at that site. It was assumed that on an average night a vessel would have trawl gear on the bottom for 10.6 hours. The scallop and blue swimmer crab densities were then averaged for each 30min QFISH grid, giving the mean expected catch for a boat day in each grid.

Using the CFISH logbook database, all trawl effort was extracted for the month of October during the years 1997, 1998 and 1999. These data included all trawl activities within the scallop survey area that recorded catches greater than 0 of any species. The total scallop catch within this area was also extracted from the database and these figures are henceforth referred to as the "observed catches".

The difference between the observed and expected catches was only examined for the month of October as the scallop survey was conducted over approximately a 10-day period in that month. In order to determine the expected catch of scallops and blue swimmer crabs for each grid within the scallop survey area, the total number of logged boat days for each grid was multiplied by the corresponding mean catch per night calculated from the scallop survey data. No data were extracted for 2000 as management changes brought about a seasonal closure in the trawl fishery in October rendering the analysis redundant from that year on.

The total observed and expected scallop catch for October 1997 and 1998 is shown in Figure 6.9. The number of scallops per basket was assumed to be 500. This value was determined using unpublished data acquired on the scallop surveys (Dichmont *et al*. 1999).

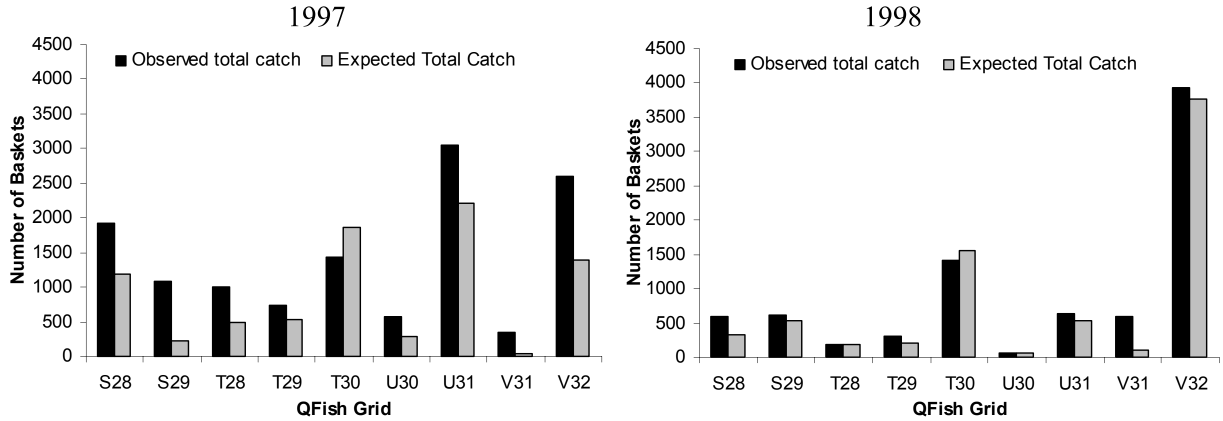


Figure 6.9 Catches of scallops in the Hervey Bay region, during October 1997 and 1998. Observed catches are those derived from the CFISH logbook system and the expected (predicted) catches are those estimated from the scallop survey data.

The observed and expected scallop catches for both years showed high variability between grids. In 1999 the observed catch was higher than the expected catch for all but one grid (T30), with the observed catch on average 42% ± 10% higher in 1997. The observed and expected scallop catches were almost equal for most grids in 1998, with the observed catches on average 20 ± 9% higher than the expected catches. The October 1998 data displayed a greater parity between the observed and expected scallop catch than the October 1997 data. One possible explanation for this could be the introduction of mandatory Vessel Monitoring Systems (VMS) in 1998. VMS effectively eliminated the high rates of illegal fishing within closed areas, possibly resulting in decreased peak catches. The validation did not include any relative densities from sites within closed areas, therefore any catches from illegal fishing activity that were logged as if caught legally would bias the 1997 catches.

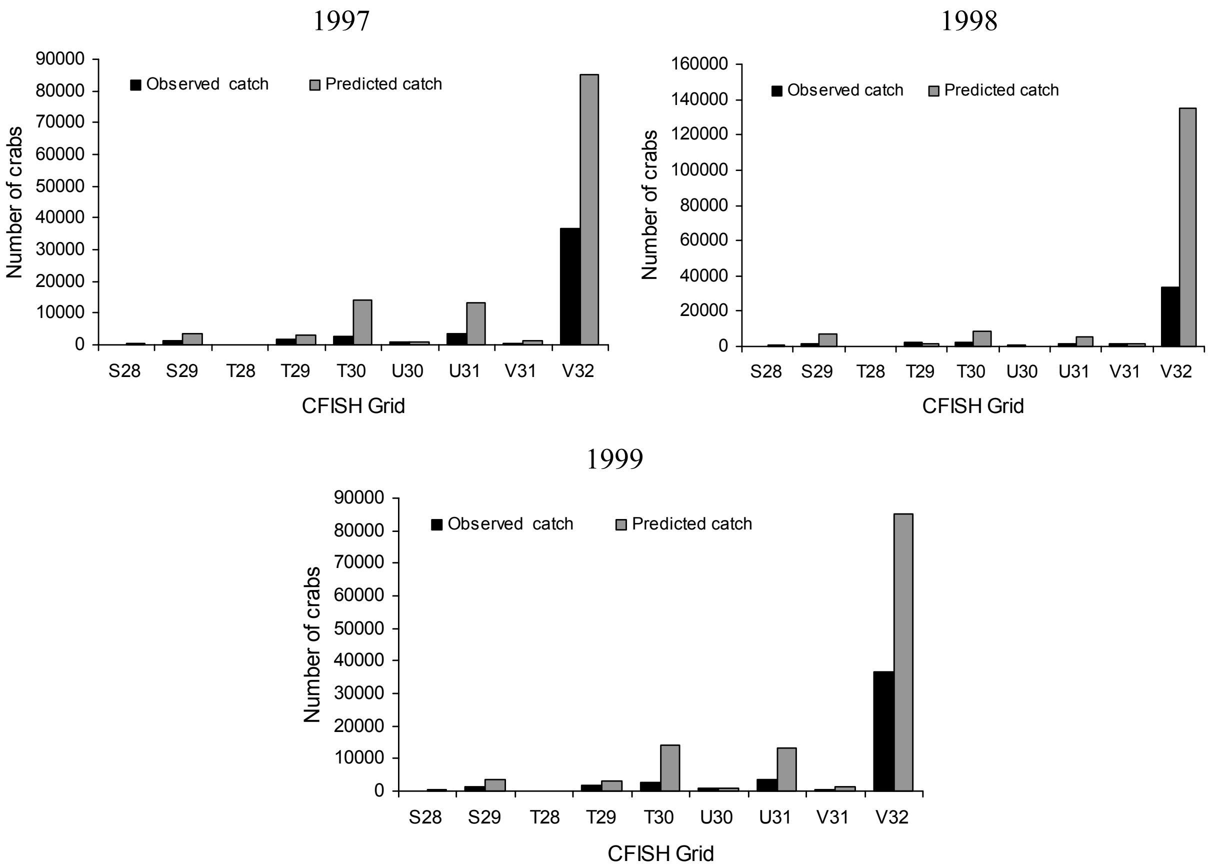


Figure 6.10 Observed and expected catches of blue swimmer crabs in the Hervey Bay region, during October 1997, 1998 and 1999.

The observed and expected blue swimmer crab catches in October 1997, 1998 and 1999 are displayed in Figure 6.10. A large discrepancy existed between the observed and expected catches with the observed catch consistently lower in all years and grids (in sharp contrast to the scallop data). The most marked difference between the two catches occurred in grid T30 where predicted catches were almost 5 times the observed catches. In grid V32, the area with the highest blue swimmer crab catches, the predicted catch was always at least twice that recorded in the logbooks and in 1998 it was over 3 times that observed. The logbook validation for blue swimmer crabs appears to be appropriate, as the scallop survey tended to underestimate the scallop logbook data. This underestimation can be explained by a number of factors. Firstly, prawn nets were used to capture scallops and crabs for the survey. This was necessary to capture the smaller scallops that are not normally taken in scallop nets. The mesh of commercial scallop nets, which is considerably larger, is more efficient at capturing scallops, leading to the scallop survey vessels having a lower catchability than the standard commercial operation. In addition, it can be expected that target trawling for scallops would achieve considerably higher catch rates than those obtained by a random survey as fishers would exploit high density beds of scallops when they were found. The smaller prawn mesh used in the survey would presumably also reduce the catchability of blue swimmer crabs, therefore the expected catches would tend to be even more conservative, effectively emphasising the discrepancy between observed and expected blue swimmer crab catches described in this analysis.

The discrepancy between observed and expected blue swimmer crab catches was considerably larger than that for the scallop catches, and may have been the result of under-reporting of the crab catch. It has been speculated that trawl logbook reliability changes in response to perceived, proposed or anticipated management changes (Queensland Fish Management Authority 1999). The many management events impacting on the trawl fishery and occurring since 1997 could influence the reporting practises of fishers. In addition, since blue swimmer crabs are not a major target species it is likely that trawler operators have been less meticulous in completing their logbook returns than for other species. Also, the retention of such by-product was not allowed for in the regulations controlling trawling until April 1999, which may also have influenced logbook-reporting levels. This uncertainty in the reliability of trawl logbook records casts some doubt on apparent trends in the trawl fishery that result from analysis of logbook data (see Chapter 5). Based on this validation analysis it is possible that actual trawl catches could be three times higher than that reported in the CFISH system. Further complications have occurred with the recent introduction of a new logbook for trawl fishers that has increased the possibility of crabs being recorded in numbers rather than weight.

Compliance Surveillance

A further indicator of the importance of blue swimmer crabs to commercial trawl operators can be seen in records of the Queensland Boating and Fisheries Patrol. Between October 1999 and June 2000 Queensland Boating and Fisheries Patrol officers conducted 202 compliance checks of trawlers, specifically noting on-board quantities of all product, including blue swimmer crabs. Thirteen of the trawlers examined had no product on board at the time of inspection. The amount of product was highly variable, due at least partly to the random nature of the inspections, however the data provide some indicative figures on the proportion of the catch retained as by-product.

Table 6.3 Major species recorded in compliance checks conducted by the QB&FP

Species	Weight recorded (t)	Number of reports
Prawns	75.8	151
Scallops	46.3	56
Bugs	3.7	104
Squid	2.1	89
Blue swimmer crabs	***1.9***	***77***
Winter whiting	0.4	22
Cuttle fish	0.4	25
Octopus	0.2	18
Shark	0.1	12

Overall 131 tonnes of product was recorded during the inspections, with nine species having a combined weight of 100kg or more (Table 6.3). Blue swimmer crabs comprised less than 1.5% by weight of marketable product on board the inspected trawlers yet they were present on board almost half the vessels which had product on board.

A regional breakdown of the product retained on inspected trawlers is shown in Table 6.4. It should be noted that the compliance check records relate to where a vessel was boarded, and were not necessarily conducted while the vessel was actively engaged in fishing. This is clearly demonstrated by one report in Moreton Bay of a trawler in possession of 360kg of scallops when no scallops are taken in commercial quantities in that area.

The reports for Hervey Bay support the other indicators that blue swimmer crabs are a significant component of the catch of scallop trawlers in that area. However, there was no evidence that any of the trawlers were specifically targeting crabs, with the greatest number of crabs being found on boats with the greatest number of scallops. Approximately 9% of the weight of trawled product recorded in Hervey Bay inspections were blue swimmer crabs, which supports suggestions that that the actual catch of blue swimmer crabs is higher than reported in the CFISH logbook system. Analysis of CFISH records showed that about 5% of the trawl catch in this area in 1998 were blue swimmer crabs. Five of the boats inspected had in the order of 500 to 600 crabs on board, so there is clearly a potential for trawlers to exceed the proposed in-possession limit in this area.

Table 6.4. Results of compliance checks conducted by Queensland Boating and Fisheries Patrol.

Area		Total catch (kg)	Scallops (kg)	Prawns (kg)	BS crabs (kg)
Moreton Bay		8153	360	6102	212
	Range	9-1085	—	5-1000	0.5-23
	Proportion	100%	4.4%	74.8%	**2.6%**
	Number	54	1	53	23
SE Qld –		2752	2	2388	69
Outside Moreton	Range	11.5-283.5	—	45-250	1-6
Bay	Proportion	100%	0.1%	86.8%	**2.5%**
	Number	24	1	23	21
Hervey Bay		12879	11500	60	1144
	Range	70-4952	15-4900	—	1-195
	Proportion	100%	89.3%	0.5%	**8.9%**
	Number	17	16	1	16
Central Region		35018	31980	729	486
(1770 to Mackay)	Range	13-3575	35-3575	1-504	0.5-90
	Proportion	100%	91.3%	2.1%	**1.4%**
	Number	28	25	9	16
Northern Region		7298	2387	3421	—
(Whitsundays to	Range	21-1344	3-700	15-444	—
Hinchinbrook)	Proportion	100%	32.7%	46.9%	—
	Number	19	9	18	—
Cairns & Far North		65050	31	63069	7
	Range	2-5060	1-20	2-4910	—
	Proportion	100%	0.05%	97%	**0.01%**
	Number	47	4	47	1

With 54 reports submitted for Moreton Bay the results are probably more representative than those for Hervey Bay. Almost half the boats examined had blue swimmer crabs on board but they were still a relatively minor components of the overall catch, which was clearly dominated by prawns. None of the boats examined exceeded the in-possession limit for blue swimmer crabs (at that stage 100 crabs), although 4 boats had between 50 and 80 crabs on board. The QB&FP data suggest that the current proposed limit of 30 crabs for Moreton Bay would have a greater impact in that area than would the limit proposed for outside waters (500 crabs).

Although the compliance reports do not provide a quantitative estimate of by-product they do provide an opportunity for a random snapshot of the fishery that is independent of both fishers and marketers. In general terms the compliance reports support the other sources of information suggesting a possible underestimation of the trawl catch by the CFISH system. The greatest weakness in trying to analyse the reports is the small sample size, particularly in some regions outside Moreton Bay.

Discussion

Despite the possibility of recent changes in regulations (making the retention of trawled caught blue swimmer crabs legal) having the potential to increase trawl targeting of this species, there was no indication that this was occurring. The analysis showed that the majority of the trawl fleet had relatively small daily catches of blue swimmer crabs, consistent with them being a by-product. There was a small proportion of records where disproportionate catches were recorded suggesting that some operators were indeed targeting blue swimmer crabs. The extent of targeting is difficult to quantify given that large catches have been reported in random fishery independent research trawling in the scallop grounds of Hervey Bay. While it may be argued that trawlers in Hervey Bay have traditionally always caught blue swimmer crabs it is interesting that it is only since 1993 that daily catch rates have exceeded those of Moreton Bay trawlers. The imposition of in-possession limits in recent years should have caused a proportionally higher reduction in the trawl catches. Yet the data do not support this prediction. Since the introduction of limits there has been an almost uniform proportional reduction in all categories of daily catch. At the same time there has been a dramatic increase in catches in the pot fishery. While such an observation is welcomed as it suggests that management measures have been effective at altering the proportional catch distribution between the sectors, it is a difficult observation to explain.

The response of the trawl fisheries of Moreton Bay and around Hervey Bay to the recently introduced management measures are quite different (Figure 5.6). In Moreton Bay there has been a decrease in CPUE and overall catch by trawlers while the pot fishery has grown steadily. In Hervey Bay the pot fishery has remained stable apart from a recent increase since 1997. The trawl catch rapidly increased from 1992 to peaks in 1994/95 and 1999 but in recent years since the introduction of catch limits there has been a significant decline in reported trawl crab catch.

Historically it appears that most of the trawlers that have operated in Moreton Bay and Hervey Bay have reported catches of blue swimmer crabs and all trawlers operating in those areas would certainly catch blue swimmer crabs. As discussed previously the accuracy of logbook reporting is problematic, which makes it extremely difficult to determine whether any changes in the reported trawl catch are real or simply the result of more accurate reporting. Evidence has been presented for a possible under-reporting of the trawl harvest of blue swimmer crabs. There is also large discrepancy between the CFISH data and the validation data for some individual boats. While this may be an artefact of one or both sets of data, it imposes a requirement that the catch and effort data be interpreted with caution.

Data collected by measuring catches at processors in Hervey Bay and Moreton Bay did not give an accurate indicator of blue swimmer crab catches for a number of reasons. Firstly, logistic constraints meant that not all processors were sampled and it was clear that some processors dealt in the larger volume catches while others preferred the higher quality low volume catches. In addition, there were temporal differences in when the larger catches appeared on processor floors and it was not possible to effectively randomly sample catches at all times. Trip duration also varied enormously.

Average daily catch rates of blue swimmer crabs derived from analysis of the CFISH system are certainly higher outside Moreton Bay but not dramatically so. Despite showing considerable annual variation, offshore catch rates were only 30% higher in the Hervey Bay scallop fishery area compared with Moreton Bay). In certain areas of the scallop fishery (particularly grid V32) trawl catch rates of blue swimmer crabs were quite high as found by the analysis of both the scallop survey and CFISH records. However, a proportion of vessels fishing in Moreton Bay also achieved high daily catch rates of the same order as of those obtained in Hervey Bay. Given that the average trip duration in Moreton Bay is 3 days compared with approximately 14 days in offshore waters, and the average catch is only 30% higher in offshore areas, logic would suggest that the in-possession limits should differ by a factor of six. Such a multiplier was originally proposed in the *Fisheries Amendment Regulation No 3* (April 1999) which set the limits at 600 outside Moreton Bay and 100 inside Moreton Bay. The magnitude of any in-possession limit is clearly a complex issue and different analyses yield different conclusions, but a 6 times differential between the two proposed areas is supported by the available data. This is further demonstrated by analysis of the data in Figure 6.3. Using this figure it is possible to interpret the number of trawl days affected by proposed in possession limits under whatever assumptions are made about average trip duration in each fishery. For example under the proposed limits of 600 crabs offshore and 100 crabs in Moreton Bay (assuming 14 day and 3 day trips respectively) the management changes will impact on approximately 33% of days when blue swimmer crabs are caught both offshore and in Moreton Bay. A limit of 500 offshore and 30 inshore will impact on 36% of days in Hervey Bay and 67% in Moreton Bay. These percentages vary from year to year and also depend on the spatial definition of both Hervey Bay and Moreton Bay, the average length of trips as well as whether days on which no crabs are caught are included in the analysis. Given the discrepancies in logbook recording practises and management changes the average conditions probably represent the least biased conditions on which to calculate these impacts. This information can be used in conjunction with social and economic information to achieve an appropriate level of impact of each fishing sector.

BRD's have recently been introduced into most parts of the trawl fishery in Queensland in an attempt to limit bycatch. They are widely used and have proven effective in South Australia to limit the catch of blue swimmer crabs and King George whiting by Spencer Gulf trawlers (McShane *et al*. 1998). The effectiveness of these BRD’s as well as closed waters declarations in minimising the impact of trawling on the harvest of blue swimmer crabs however is largely unproven in Queensland but one would expect that appropriately operated BRD’s would minimise trawl catch of adult blue swimmer crabs by trawlers. The elimination of juveniles from the catch is more problematic as these are of a similar size to prawns and will not be removed by grids or similar BRD’s. The design of a BRD that will minimise the catch of small crabs, whilst a high priority is probably a very difficult, if not impossible task without impacting adversely on the target species catch (particularly prawns). As mentioned previously, the larger mesh used by scallop trawlers catches a much lower proportion of the smaller crab size classes.

Table 6.5 Relative impacts of various parameters on the sustainability of the blue swimmer crabs when fished by the trawl and pot catching method. (***** Represents the most favourable response, * the least favourable)

Parameter	Trawl Fishery	Pot Fishery
Discard mortality of blue swimmer crabs	***	****
Potential impact on threatened species (marine turtles)	**	***
Potential for habitat damage	*	****
Catch composition (% of species caught that is marketable)	*	****
Quantity of fish and other bycatch caught by the fishery	*	****
Ease of monitoring	**	***
Precision and accuracy of logbook data for monitoring	**	**
Product quality	****	*****

As mentioned earlier the question of whether trawlers should be able to land blue swimmer crabs is complex and involves social, economic and political considerations as well as biological issues of ecological sustainability. The quantification of risk of stock failure or other negative outcomes under a range of management scenarios or catch sharing arrangements is a complex task involving many parameters. Some of the biological parameters include recruitment, habitat usage and damage, discard mortality and catch composition. Then there is the difficulty of monitoring a stock that is fished by multiple sectors. It is not possible to provide a numerical distribution of likely responses for a range of catch sharing options for all these parameters but estimates can be made of the difference in relative impacts of the two fishing methods. Table 6.5 sets out the relative impacts of each of these parameters for the trawl and pot sectors.

The magnitude of the differences of these predicted impacts are clearly debateable, but where possible the ratings were determined using quantifiable data (see previous section). In some cases however, the 5 categories mask the magnitude of the potential difference between the two methods. For example, there are clearly several orders of magnitude difference in the habitat impact of a trawler (using swept area calculations) compared with the area of impact of a pot. The community benefit based weighting factors applied to each of these as well as the incorporation of appropriately weighted economic and other parameters would be necessary to model the utility of particular catch shares. Examination of Table 6.5 suggests that the range of likely outputs is enormous even for the biological considerations. It also needs to be noted that the negative impacts of these fisheries can be improved. For example it is possible to increase the product quality of the trawl sector by a more uniform implementation of improved handling practises. Likewise progress is being achieved in minimising trawl impacts on threatened species and reducing bycatch.

In summary it is clear that the harvest of blue swimmer crabs by the pot method presents the least risk in terms of ensuring ecological sustainability. Should possession limits be further considered in the trawl fishery, biological and fisheries data suggests a six-fold difference in possession limits between Moreton Bay and offshore waters would be appropriate. Finally, as is the case with the pot fishery, there is much uncertainty about the accuracy and precision of the catch and effort data recorded in the CFISH system. For the trawl data this is particularly the case for by-product species such as blue swimmer crabs.

7. FACTORS INFLUENCING CATCH OF BLUE SWIMMER CRABS IN MORETON BAY

Introduction

Both total catch and catch rates of blue swimmer crabs show seasonal fluctuations that appear to be broadly consistent from year to year. This pattern is particularly evident in the commercial pot fishery that typically has the lowest catch rates during the winter (See Chapter 5). Following winter, minimum catch rates increase during the spring and then decline in summer before reaching the usual annual autumn peak in catch rates, usually during March and April. This consistent annual cycle is partly related to recruitment patterns but may also be affected by environmental factors, and in particular temperature, since catch rates within the fishery are lowest during winter. There are a number of other observations that suggest the environment may play an important role in determining the success of the fishery in any given year. The rapid growth rate (Chapter 9) and relatively short life cycle of blue swimmer crabs means that the fishery relies predominantly on a single age class, the strength of which could be influenced by environmental factors during the spawning season and early juvenile development stages. Females are also not fished in Queensland and virtually all females that are capable of mating are inseminated, thereby maximising egg production (Sumpton *et al* 1994). The success of the annual recruitment may thus be heavily influenced by environmental conditions at critical times of the life cycle.

In addition to the seasonal temperature cycles there are small-scale temporal variations in catch rates. Commercial fishers have noted that catches from the same set of pots can vary by more than 50% on a daily basis. Fishers have hypothesised a number of reasons for these variations including, effects of tide, wind speed and direction and temperature. While the small-scale variations are interesting, it is the large-scale annual variations that are the most relevant to both the fishers and managers since it may be possible to link year class strength and catches with environmental factors. This chapter examines some of the likely environmental effects on blue swimmer crab catch rates. Environmental influences on blue swimmer crab megalopae are investigated in the next chapter (Chapter 8).

Materials and Methods

In order to gather information on small scale changes in temperature within Moreton Bay an array of small temperature data loggers (Stowaway Tidbit™) were deployed on six navigational beacons at the following locations):- Caboolture River, Cabbage Tree Creek, Gilligans Island, Measured Mile, Rous Channel and the Hanlon Light (See Figure 7.1). These sites were chosen because they were close to significant concentrations of crab fishing effort and also because of ease of deployment of equipment (all locations had navigational beacons on which loggers could be easily positioned. The depth of water at all the locations was between 3 and 8 metres, aside from the Measured Mile that was located in 12 metres of water in the middle of the Bay. Loggers were positioned within 2 m of the seabed at all locations except the Measured Mile where the logger was positioned approximately 5m above the seabed. Loggers were initially deployed in December 1998 and were subsequently replaced and the data downloaded every 6 months thereafter until January 2001 (Temperature loggers continue to be deployed but this analysis includes data collected up until January 2001). One of the Cabbage Tree Creek loggers was lost resulting in the loss of data at that site during the period 27/3/99-18/6/99.

Commercial catch and effort data was extracted from the CFISH database to match temperature records. Only records from boats that fished for more than 100 days over the period were included. This was to ensure that only records from fishers specifically targeting crabs were included in the analysis. Although temperature data were collected about every 10 minutes the analyses presented here only focussed on daily average (or morning average) temperature.

A longer-term data series of environmental data was obtained from a wave-rider buoy situated off Point Lookout, North Stradbroke Island during the period 1996 to 2000. Data included sea surface temperature, wave direction, and wave height. Data collected from other sources included Southern Oscillation Indices (SOI), moon illumination intensity, relative humidity, barometric pressure, rainfall collected from the Bureau of Meteorology.

Statistical analysis

Principal component analysis (PCA) was employed to explore the relationship between temperature and position within the Bay. To explore relationships between catch weight of crabs and variables such as site within the Bay, temperature and lunar phase, general linear models were used. In some cases a number of models are presented in the results as there was little difference between the predictive power of each. In the following results and discussion the following terms are defined:-

VSN	(Vessel Sequence Number) A unique identifier of each licensed commercial fisher.
Month	The calender month in which the catch was recorded
Site	The closest data logger position to where the catch was recorded
Morning Temperature	Average morning temperature between 0400 and 1000 hrs
High Tide	Height of the high tide immediately prior to the day the catch was recorded
Moon Illumination	Illumination of the moon on a continuous linear scale where 0= New Moon and 1 = Full Moon
Log Pot Lifts	The log of the number of pot lifts

Time-series analysis was also undertaken involving cross-correlations of catch and temperature with different temporal lags.

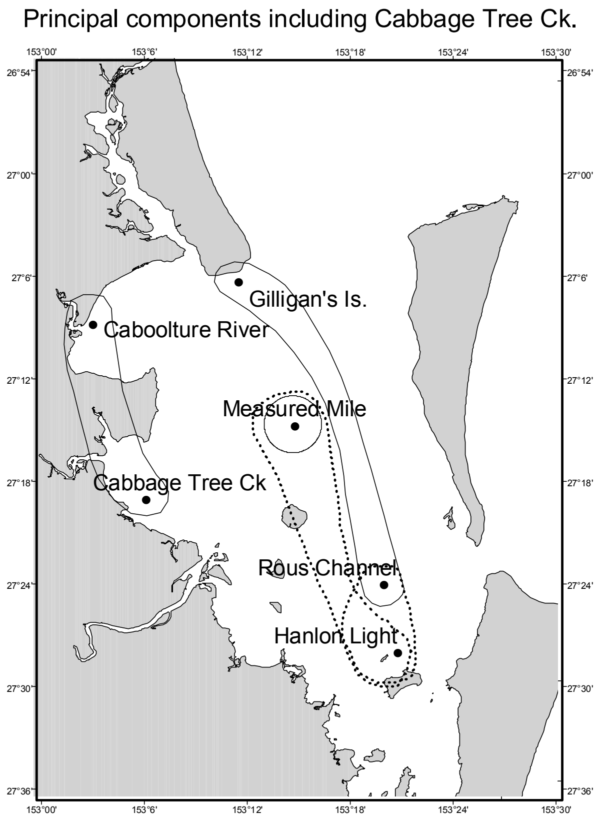


Figure 7.1 Location of temperature data loggers in Moreton Bay and site similarity based on temperature according to principal component 2 (PC2).

Results

Temperature at various sites within Moreton Bay;1999-2001 data series

There was little variation in temperature between sites within Moreton Bay. For all sites, principal component one explained 98.9% of the variation between sites, with principal component two only explaining a further 0.7% (Figure 7.2). Separation only occurred on the axis of PC2, with Cabbage Tree

Creek and Caboolture River displaying similar temperature ranges (and similarly for Rous Channel and Gilligan's Island). Hanlon Light and the Measured Mile were separated more from the rest of the sites.

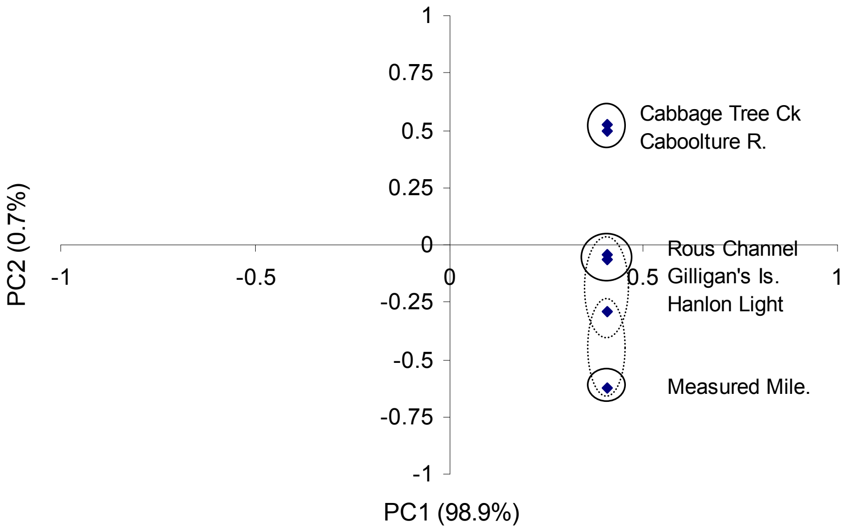


Figure 7.2 Principal Components analysis based on average daily temperature at six sites within Moreton Bay.

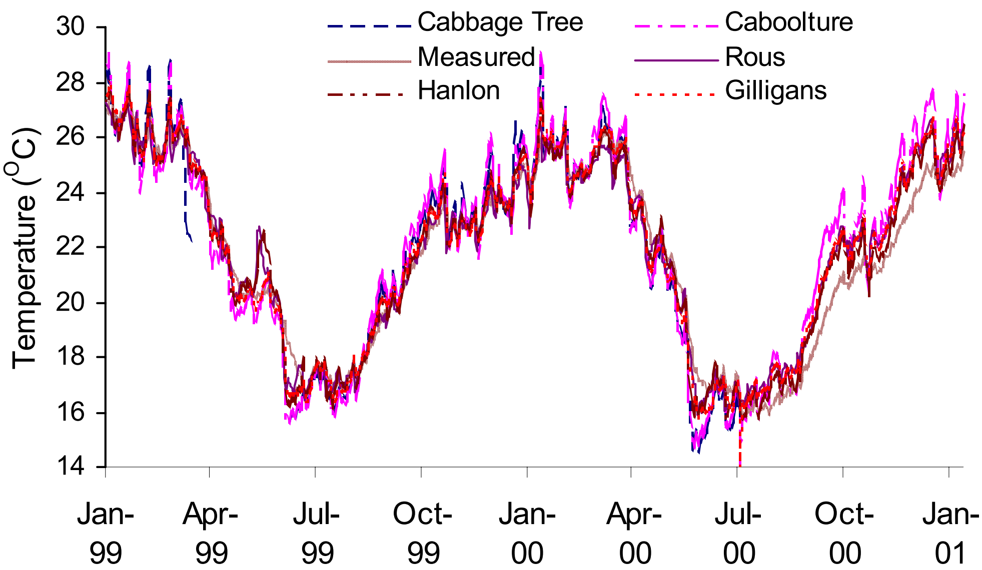


Figure 7.3 Temperature range of sites within Moreton Bay for the period (01/10/1999-01/01/2001). Cabbage Tree Ck is missing data between 27/3/99-18/6/99 and 17/7/00 onwards.

Figure 7.1 illustrates the spatial separation between sites based on principal component 2. Separation seems to be a function of position within the bay and depth. Sites in the western part of the bay are similar to each other than sites in the eastern bay although no site differed significantly in temperature ($P>0.05$). The Measured Mile is in a deeper section of the Bay and this may explain its separation from the rest of the sites.

The overall range of temperature at sites over time is also shown in Figure 7.3. For this analysis half-hourly temperature records were used to calculate the mean morning temperature between the hours of 0400 and 1000 as this is considered the time when crabs are most active and more prone to being caught in pots. Temperatures ranged between about 15°C and 29°C. Generally temperature at all sites follows the expected seasonal pattern of warmer temperatures in the summer months and cooler in the winter months, although there were several anomolies. Many of these were related to lunar/tidal cycles, particularly noticeable during the warmer months of the year. These variations were most probably the result of increased solar radiation causing elevated temperatures during low tide periods. Obvious spikes occurred in May 1999 at the Hanlon and Rous sites, whilst a spike in January 2000 was attributed to Cabbage Tree Ck. and Caboolture R. sites.

Modelling catch rates at sites within Moreton Bay

One of the main aims for collecting temperature data within the Bay was to model catch against temperature and location within the Bay, in addition to other abiotic variables. Natural logarithms of catch weight and catch weight per unit effort (pot lifts in this case) were used as response variables in regression models. In the models that follow both catch and catch rate have been used.

Models with log catch weight as the response variable

Best subsets regression suggested that there were two models, each with 3 parameters (see Appendix 3.1) for explaining the variation in log catch weight. Because VSN and Site are aliased with each other (in that certain fishers commonly fish the same area) both models are presented (see ANOVA tables and parameter estimates in Appendix 3.1). Only data from 7 fishers within Moreton Bay were recorded with enough accuracy and sufficient spatial resolution in the logbooks to allow their inclusion in the model. In both models fishing effort was clearly the driving factor determining catch rates and there are strong seasonal as well as fisherman skill effects. Both prediction models were similar reflecting the aliasing impact of site and fisher (Figure 7.4). Water temperature, lunar and tidal effects were only marginal influences on catch in either model.

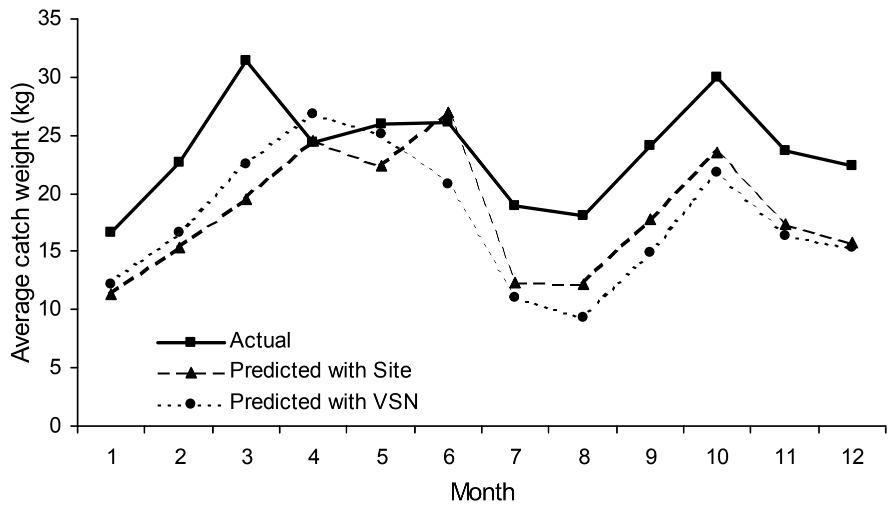


Figure 7.4 Actual vs. Predicted catch weight based on 3 parameter regression models. Other variables in model are averaged or marginalised for predictions.

Replacing month with period in regression models

Catch rates were significantly different in 2000 than for other years and did not follow the same trends (see Figure 7.5). For this reason treating months in different years as a seasonal effect may mask patterns within the data due to a strong year effect. In the following analyses months were treated as a continuous classification variable resulting in 24 time periods over the time when abiotic data were collected. The following results are in similar format as previous models with ANOVA tables and model parameter estimates shown in Appendix 3.2.

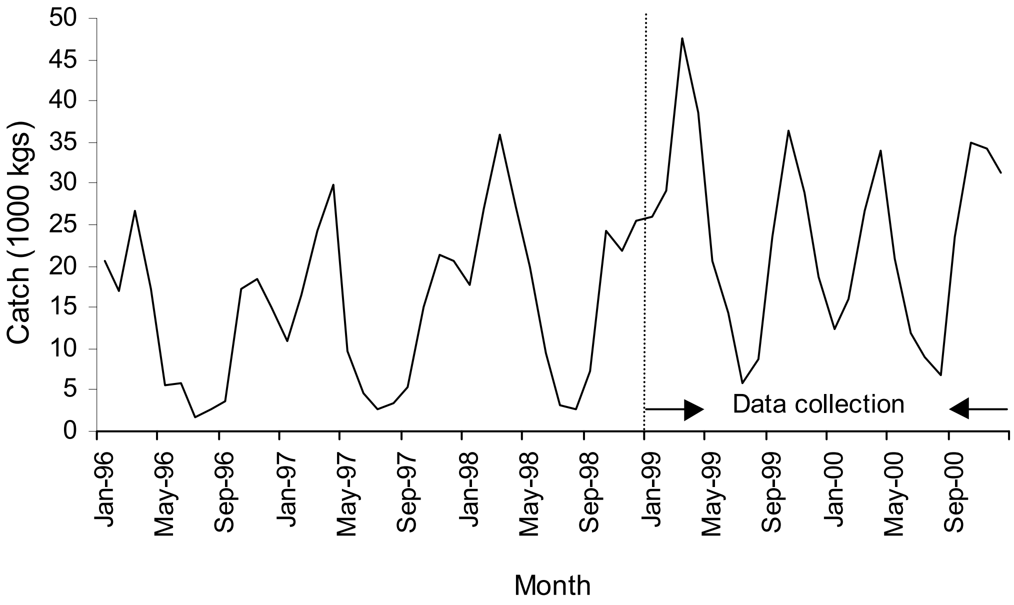


Figure 7.5 Mean monthly catch for the total pot fishery in the Moreton Bay region. Dashed line indicates beginning of temperature data collection at various sites within Moreton Bay.

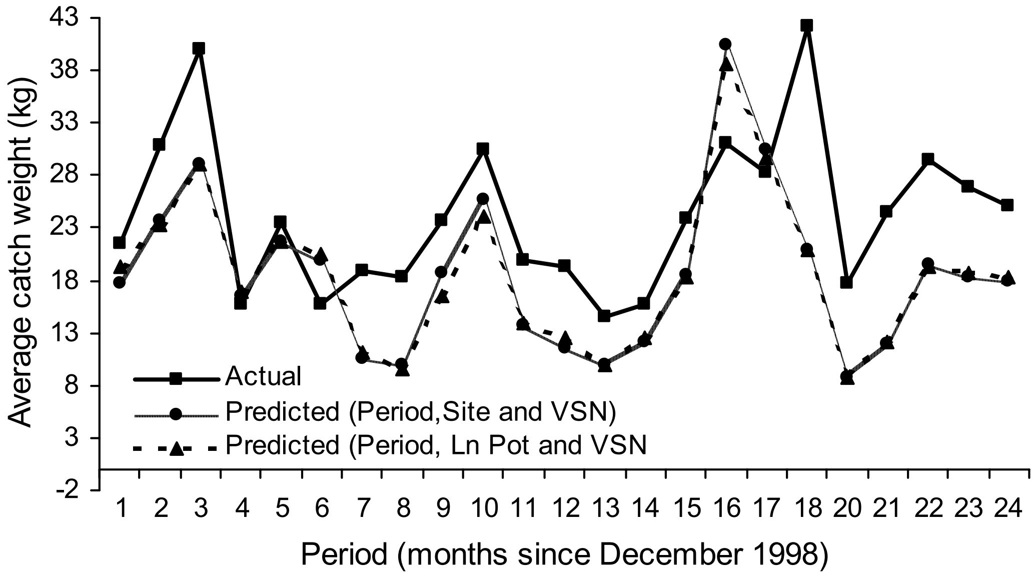


Figure 7.6 Actual vs. Predicted catch weight based on 4 parameter regression models described in Appendix 3.2.

There was no significant difference between the best three-parameter models (Period, Site, VSN) and (Period, Log Pot, VSN), as evident in Figure 7.6. Both predicting similar values and both having similar power, r^2=69.37 and 69.02 respectively (see Appendix 3.2). What can be concluded from these analyses is that in accounting for Period and VSN, either Site or effort (Log pot lifts) are both equally suited for predicting catch to a certain degree. However, both terms are included in the best four-parameter model. This indicates that they are independently predicting catch. This is evident in the comparison of parameter estimates for Site and effort. Neither variable changes to a significant degree when the other is added to the model. For example, the parameter estimate for Effort in the 3-parameter model is 0.577. When site is added to make a four-term model effort only changes less than 1% to 0.5816.

Models with Log Catch Per Unit Effort (CPUE) as response variable

Since fishing effort was the main factor contributing to variations in catch the response variable data was standardised as catch per unit (CPUE). With effort missing from the model, Site, VSN and average morning temperature were the best predictors of Log CPUE. However, most sites were aliased with VSN. This means that the CPUE at a particular site can be attributed to a linear combination of boats. In effect, subsets of boats consistently fish at particular sites. Therefore, a three-parameter model such as VSN, Month and Temperature may be more appropriate. Fitting a more explanatory model such as month, temperature and site only explained 32.8% of the variation in Log CPUE. However, as was the case for the previous models, using a continuous time sequence and not averaging data for months provided a better fit to the data as shown in Figure 7.7.

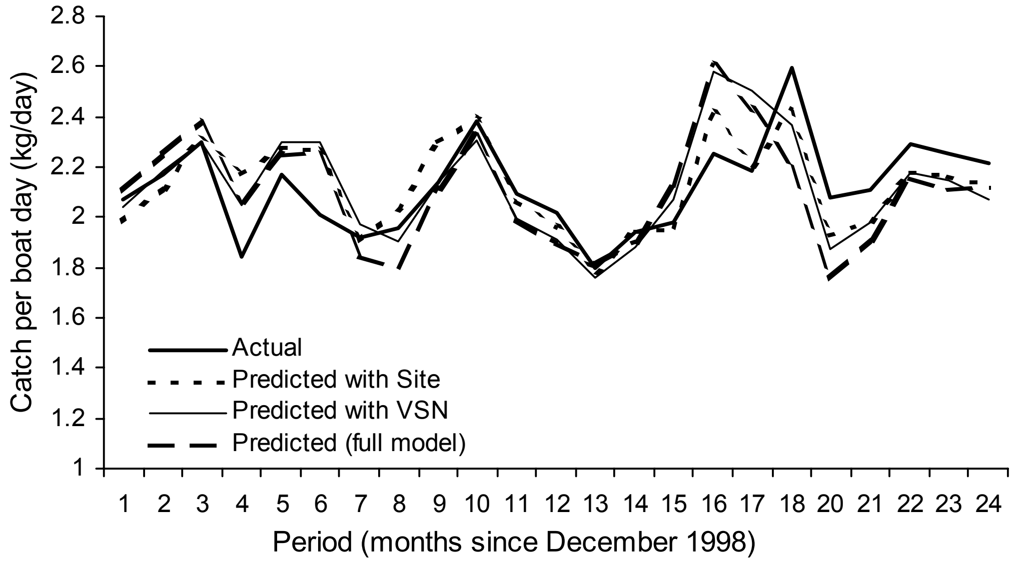


Figure 7.7 Predicted and actual (observed) CPUE for above model. VSN is confounded by Site and both parameters should be plotted seperately. Other variables in model are averaged or marginalised for predictions.

By ignoring aliasing a full model can be used for prediction, however results need to be interpreted with caution as parameters are aliased and co-linearity may be present.

Modelling catch rates overall with remote auxiliary data

Catch per unit effort (CPUE) data from 1996 to 2000 were also compared against variables such as sea surface temperature taken from a wave rider buoy situated off Point Lookout, North Stradbroke Island (just outside Moreton Bay) and monthly SOI's. This auxiliary temperature data set, although not coming specifically from Moreton Bay, is probably relevant since oceanic currents influence the abiotic environment within the bay due to the extensive exchange of water that occurs predominantly at the extensive northern opening to the bay and also via the south passage. Of the variables tested only log of pot lifts (log pot-lift), month, pressure and temperature predicted catch weight well. Model selection information, ANOVA table and parameter estimates are shown in Table 7.1 to 7.3

Table 7.1 Model selection of log mean monthly catch weight for Moreton Bay using temperature data from Point Lookout and other climatic data such as SOI.

Adjusted r^2	Log Pot-lift	Period	Pressure	SOI	Temp
Best single terms					
50.09	-	0.00	-	-	-
30.96	0.00	-	-	-	-
27.19	-	-	-	-	0.00
5.51	-	-	0.00	-	-
0.56	-	-	-	0.003	-
Best 3 terms					
58.49	**0.000**	**0.000**	**-**	**0.000**	**-**
57.27	0.00	0.00	0.00	-	-
56.55	0.00	0.00	-	-	0.02
Best 4 terms					
58.9	0.00	0.00	0.00	0.00	-
Best 5 terms					
59.14	0.00	0.00	0.00	0.00	0.003

Table 7.2 ANOVA table for regression models using climatic data.

Source	DF	SS	MS	VR	F prob
Log pot-lift	1	3.44736	3.44736	43.49	<.001
SOI	1	0.3694	0.3694	4.66	0.036
Temp	1	0.30661	0.30661	3.87	0.055
Error	45	3.56685	0.07926		
Total	48	7.69021	0.16021		

Table 7.3 Parameter estimates for Log pot-lift, SOI and Temp model

Parameter	Estimate	SE	t(45)	t prob
Constant	-8.38289	2.16154	-3.88	0.0003
Log pot-lift	2.76805	0.62693	4.42	<.0001
SOI	0.006	0.00306	1.96	0.0561
Temp	0.04566	0.02322	1.97	0.0554

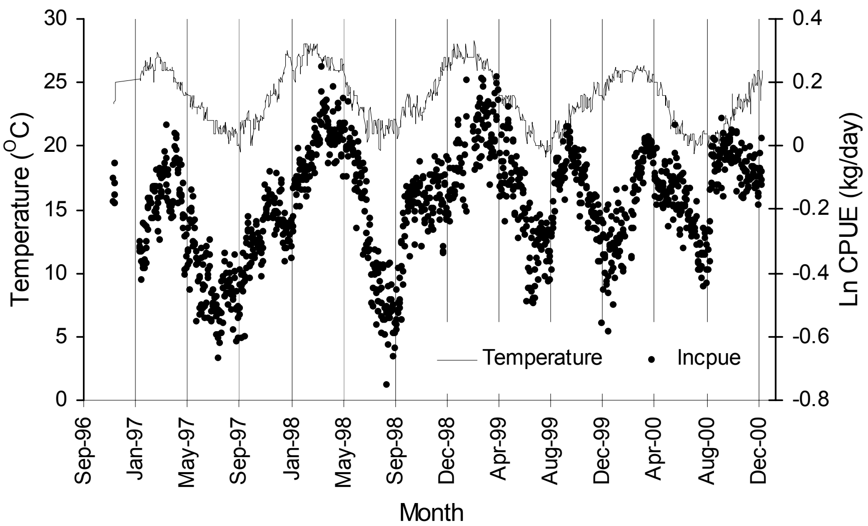


Figure 7.8 Catch Rates and temperature for Moreton Bay from Oct-96 to Dec-00. Temperature data is surface seawater temperature from a wave rider buoy located near Point Lookout, just outside the south passage entrance to Moreton Bay.

As expected the broad seasonal patterns for the offshore area (Figure 7.8) were similar to those in Moreton Bay however the minima and maxima were not as large with the Point Lookout data only varying between a winter minimum of about 19°C and a maximum of 28°C compared with a range of 14

– 29°C for Moreton Bay. Although too few data have been collected to accurately make seasonal comparisons it appeared that the anomalous pattern of a milder and more extended spring/summer period for 99/2000 was evident in both data sets.

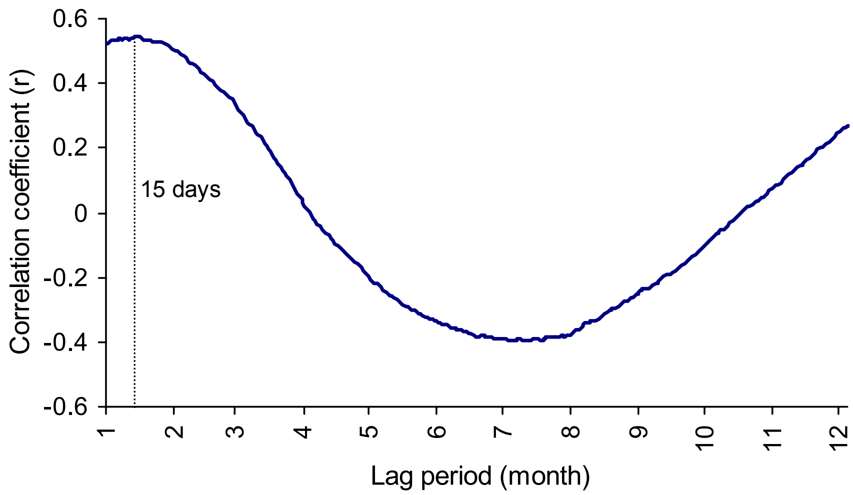


Figure 7.9 Changes in the Pearson product moment correlation between the log of blue swimmer catch and wave buoy log temperature time-series when the temperature is lagged for different times of the year.

The highest value of Pearson's correlation co-efficient between temperature and catch was 0.53 and occurs with a lag in catch of approximately 15 days as shown in Figure 7.9. Other lagged correlations were run such as lunar illumination intensity and SOI with catch, but were not found to be significant. The biological interpretation of this result (or even if there is a biological cause) is speculative but may be linked to the crabs moult cycle (see later discussion). Crabs are known not to be actively attracted to baited traps for several days after a moult, as they require time for the shell to harden.

Lagged data were used in a General Linear Model (GLM) to see if the overall predictive power was increased. This only resulted in a marginal increase in R^2 to 58.2% for the four-parameter model compared to the previous models presented. However it should also be noted that this model was fitted with daily data as opposed to monthly data.

Discussion

The fact that effort is the main factor influencing catch and catch rates was not surprising and temperature was only a relatively minor determinate of catch rates (at least on a small scale). The lack of a tight relationship between catch rates and temperature suggests that other factors were also contributing to the daily variations in catch rates so there may be a lag in the effect of temperature as demonstrated in Figure 7.9. The 15-day lag between temperature and high catch rates may be related to the crabs moult cycle that has been demonstrated to be influenced by temperature. Broadly speaking there is a seasonal pattern to moulting with little moulting activity during the winter months when crabs tend to be less active. Once temperatures increase in spring over-wintered crabs resume moulting but there are no specific times when moulting takes place since moulting activity (as evidenced by the proportion of "soft" crabs in both fishery dependent samples and research samples) occurs throughout the year (see Chapter 9). However, the 15-day lag between temperature and catch rate can also be interpreted as an effect of recruitment timing causing a strong seasonal effect. Lunar trends may also play a role in determining the lag period as periods of elevated temperature during the warmer months of the year were also associated with tidal influences. This could be exacerbated by problems with using baited traps as a sampling method. The movement of the "bait odour plume" influences the attraction of crabs to baited traps. Fishers have noted that there are optimal tidal currents for maximising catch. Too little tidal run and there is insufficient dispersion of the bait plume. Too much run and the plume dissipates and is diluted too rapidly. All these factors combine to limit the information that can be used to correlate catch rates with short-term environmental change.

There is a lack of small-scale spatial resolution in the logbook data. It was often difficult to determine accurately where particular fishers were concentrating their fishing effort. Generally this should not pose too great a threat to the analysis, as there was little variation in temperature between sites in Moreton Bay and therefore assigning a fisher to the wrong site should not have a marked biasing effect. A greater problem to the analysis was the practise of some fishers to record daily catch averages over a week (see Chapter 15). Any recording practise that "smooths out" the daily data reduces the precision of catch and effort records and significantly impacts on the ability to describe small-scale temporal trends.

Overall the abiotic data were too few to enable an accurate predictive model of seasonal variations in catch rates to be developed but the ongoing monitoring of environmental conditions should provide data that may be able to be linked with annual variations in catch. Unlike the small-scale environmental effects a major seasonal shift in temperature or other factor may result in a major change in recruitment or spawning success that may be easier to measure than the smaller scale impacts. The environmental conditions during the 1999/2000 fishing season were anomalous in a number of respects. The spring and autumn fishing peaks were similar in magnitude with a much reduced summer minimum in catch rates. During this time the seawater temperature, as shown by the wave rider buoy data, also differed from the previous two years in that the summer peak was not as great and the spring warming began earlier causing a more extended period of moderate temperature. Hypotheses to explain this result are speculative at this stage as there is no long-term environmental data sets to link with catch rates. This anomalous season provided further evidence negating the hypothesis that temperature had a dramatic effect on the small scale catch rates because the lag effects of temperature were not evident at all during this period. Catch rates indeed peaked shortly after winter and there was a dramatic minimum in catch rates during December 1999. Although catch rates tend to drop off after the initial spring increase in rates the decline witnessed in December 1999 was unprecedented since commercial catch and effort data were first collected in 1988.

In conclusion, it appears unlikely that temperature has a dramatic impact on small-scale daily variations in catch rate. Influences such as wind and other weather conditions not investigated directly may have an important small-scale effect. Fishers have often speculated that such events as lightning storms have a detrimental influence on catch rates and there has always been much debate on the effects of wind on catch rates. Traditionally fishers have noted an increase in catch rates in the northern Bay after a period of SE winds and conversely those in the south have suggested that their catch rates are improved after a periods of northerly winds. This influence of wind conditions has also been supported by data presented in Chapter 13 which showed elevated catch rates in the ghost fishing experiment after a period of strong southerly winds. We attempted to link wind conditions with catch rates recorded in the logbooks but the resolution difficulties described previously for the temperature data further impacted on the analysis. There were also the difficulties in determining an appropriate lag period to apply as well as determining an appropriate way of treating different duration and strengths of wind conditions. Despite these limitations we plan to further analyse the data once a longer time series of environmental data is available.

8. VARIATION IN PLANKTONIC AVAILABILITY AND JUVENILE ABUNDANCE OF BRACHYURAN CRABS IN MORETON BAY

Introduction

There has been considerable research on the recruitment dynamics and factors affecting megalopae of the crab *Callinectes sapidus* in the USA. Results of these studies have shown lunar patterns of settlement on artificial collectors with high settlement following the new and full moon phases (Metcalf *et al*. 1995). More recently the importance of tidal and wind driven transport of larvae has also been established (Welch *et al*. 1999; Goodrich *et al*. 1999). There has also been some interest in using megalopae densities as a predictor of future recruitment success and year class strength in the *Callinectes sapidus* fishery.

Like its close relative, *Portunus pelagicus* is an important commercial and ecological species and may also be amenable to forecasts of year class strength. The settlement and early recruitment dynamics of blue swimmer crabs are poorly understoood but we know the timing of spawning and the broad locations that support high juvenile densities based on earlier research (Sumpton *et al*. 1994). Generally juveniles are abundant in shallow inshore areas and move offshore as they increase in size. In Queensland the peak spawning months are August and September although there is some spawning activity throughout most of the year (Sumpton *et al*. 1994). Given this knowledge and known information about the duration of the egg and larval phase it is expected that megalopal densities should be highest from September to November.

Due to the rapid growth rate and relatively short life cycle of blue swimmer crabs, the majority of the population is comprised of two year classes (Sumpton *et al.* 2000) with the 1+ group being the main target of the fishery. Maintenance of sustainable population levels are therefore heavily reliant upon megalopal recruitment back into habitats suitable for maturation (Boylan and Wenner, 1993) and these areas may be suitable sites to sample megalopae. This chapter explores factors which cause variation in megalopal densities and discusses the use of megalopal abundance as an indicator of fishery production. Initially we were also concerned with trying to establish the relationship between the availability in planktonic megalopae and their settlement on artificial collectors. However, poor settlement on the artificial collectors precluded this comparison.

Materials and Methods

Field Sampling

Ten one-nautical mile transects were established in Deception Bay (27°09'S, 153°04'E), on the north-western side of Moreton Bay, Queensland (Figure 8.1). Five of the 10 transects were randomly selected and sampled every third night between 14 September and 23 November 1998. Transects were located inside a trawl closure to negate possible effects of commercial fishing operations on the results and sites were randomised to reduce the possibility of depletion effects occurring as the sampling program progressed. Sampling of the first transect began shortly after sunset, but because the field program took place during spring-early summer, sunset occurred progressively later in the day. Sampling of the first transect therefore was progressively delayed by a few minutes on each trip to ensure it commenced 15 - 20 minutes after sunset. All other sampling times were fixed. A Differential Global Positioning System (DGPS) was used to locate and maintain accurate position along each transect.

On each sampling night a beam trawl sample and plankton sample were taken. Transects were trawled at a speed of 2.5 knots and at set times of the night (1800-1930hr, 2030hr, 2300hr, 0130hr and 0400hr).

Surface plankton samples were collected with a 500µ plankton net mounted on a 0.5m by 0.5m weighted frame. The net was 1.58m in length and tapered to an 85mm cod end. A “U” shaped grid with a bar spacing of approximately 7cm was mounted over the mouth of the net to prevent clogging of the net by large jellyfish (*Catostylus sp.*) which were common in the area (See Figure 8.2). The net was equipped with a flowmeter (General Oceanics model 2030) in order to quantify the volume of water filtered.

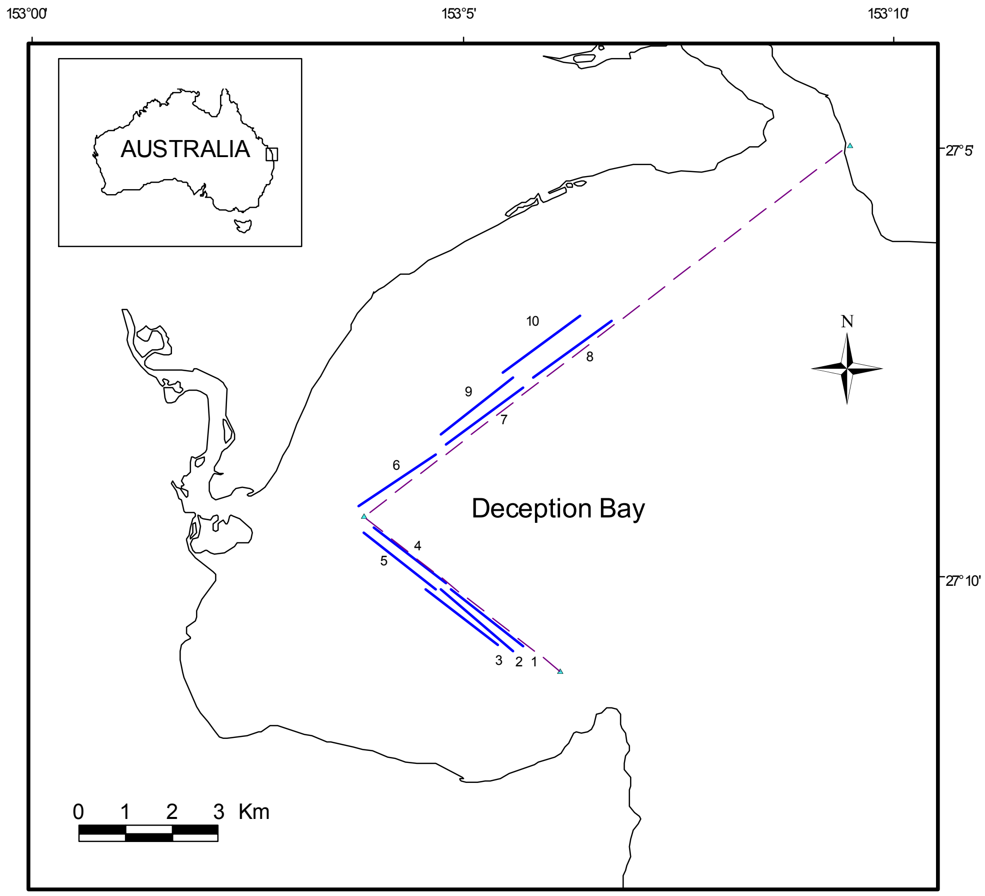


Figure 8.1 Map of Deception Bay showing the 10 transects where beam trawl and plankton samples were collected. The boundary of the trawl closure is marked as a dotted line.

Trawl gear consisted of a 9-ply polyethylene 3.5 fathom Yankee Doodle net with 1" mesh attached to a 5m-beam trawl (Figure 8.2). A tickler chain was also fitted ahead of the ground rope of the net. A bycatch reduction grid was inserted in the throat of the net to reduce catches of large jellyfish (*Catostylus* sp) and other large bycatch species, such as rays and turtles that interfered with the efficiency of the gear.

The plankton net and beam trawl were deployed for 25 and 30 minutes respectively. Plankton samples were preserved in a 5% saline formalin solution for later sorting. All brachyuran megalopae were sorted in the laboratory and identified to family level. Members of the family Portunidae were identified to the highest taxonomic level possible and all *Portunus pelagicus* and *Scylla serrata* were identified based on characteristics of reference material that had been cultured at the Bribie Island Aquaculture facility. The abundance of particular crab taxa in samples was standardised as the number of megalopae per $10m^3$ of water filtered. Crabs caught in the beam trawl were sexed and measured on board the vessel, with the carapace width (± 1mm) taken across the ninth pair of anterolateral spines before being returned to the water.

Figure 8.2 FRV Warrego showing the 5 m beam trawl used to sample juvenile blue swimmer crabs. Plankton net showing grid used to exclude large jellyfish from entering the net.

Abiotic Data

Sea surface water temperature (± 0.1°C) and salinity (± 0.1ppt) were measured with an Horiba™ water meter at the start of each transect. These records were supplemented by measurements of bottom temperature logged every 30 seconds with a "Stow Away Tidbit™" temperature data logger attached to the trawl beam. Depth was measured during each trawl to the nearest 0.1m using an on-board depth sounder. Barometric pressure (hPA) readings, wind speed and wind direction were obtained from three hourly records taken by the Bureau of Meteorology at the Brisbane Airport (approximately 25 km from the sampling area).

Each night of sampling was assigned to a lunar phase within a lunar monthly cycle. Sampling was conducted over four lunar monthly cycles, two of which (cycles 2 and 3) were sampled over their entirety while the first and last (cycles 1 and 4) were only partially sampled (Table 8.1). Within each lunar cycle four lunar phases were identified; phase 1 = new moon (± 3 days), phase 2 = half moon waxing to full moon (± 3 days), phase 3 = full moon (± 3 days) and phase 4 = half moon waning to new moon (± 3 days). A generalized linear model (GLM) was used to examine any variance in megalopal densities. The treatment factors were lunar cycle, lunar phase, shot number (time of night), transect, surface temperature, barometric pressure, wind and tide. Initially a model including all treatment factors was used for each group. Treatment factors which accounted for little variation in densities were then ommitted in a best subsets regression approach. A different model was used for each megalopal taxa.

Megalopal and juvenile densities typically exhibited a large proportion of zero values. Data were therefore transformed using ln(x + c) where c is the minimal counting unit/2 (0.0093 for blue swimmer crab megalopae and 0.5 for juveniles). Predicted values from the Genaralized linear model were back transformed and bias corrected using $y_{mean} = \exp[x_{mean} + (n-1)s^2/2n] - c$ (Kendall *et al.* 1983).

Table 8.1 Details of sampling dates, lunar phases and lunar cycles over the sampling period. Five transects were randomly selected and sampled during each trip.

Trip	Date	Lunar Phase	Lunar Cycle
1	1998 Sep 14-15	4	1
2	1998 Sep 17-18	1	2
3	1998 Sep 20-21	1	2
4	1998 Sep 23-24	1	2
5	1998 Sep 26-27	2	2
6	1998 Sep 29-30	2	2
7	1998 Oct 02-03	3	2
8	1998 Oct 05-06	3	2
9	1998 Oct 08-09	3	2
10	1998 Oct 11-12	4	2
11	1998 Oct 14-15	4	2
12	1998 Oct 17-18	1	3
13	1998 Oct 20-21	1	3
14	1998 Oct 23-24	1	3
15	1998 Oct 26-27	2	3
16	1998 Oct 29-30	2	3
17	1998 Nov 02-03	3	3
18	1998 Nov 04-05	3	3
19	1998 Nov 07-08	4	3
20	1998 Nov 10-11	4	3
21	1998 Nov 13-14	4	3
22	1998 Nov 16-17	1	4
23	1998 Nov 20-21	1	4
24	1998 Nov 23-24	2	4

Results

A total of 22,313 megalopae were collected during 120 plankton tows in Deception Bay. Numerically abundant taxa are listed in Table 8.2. The most abundant were from the family Ocypodidae and the species *Portunus pelagicus*, contributing 84% and 10% of the total megalopae respectively. Due to the low numbers of *Scylla serrata* and *Portunus sanguinolentus* they were excluded from further analyses.

Table 8.2 Abundance of various crab megalopal taxa in plankton samples collected from Deception Bay.

Taxa	Family	Total Abundance	% Abundance
Portunus pelagicus	Portunidae	2,290	10.263
Thalamita sp. 1	Portunidae	478	2.142
Thalamita sp. 2	Portunidae	215	0.964
Scylla serrata	Portunidae	4	0.018
Portunus sanguinolentus.	Portunidae	1	0.004
Mictyris spp.	Mictyridae	230	1.031
Ocypodidae spp.	Ocypodidae	18,819	84.341
Macrophthalmus spp.	Ocypodidae	276	1.237

Table 8.3 Factors used in "best subset" regression models to analyse variations in megalopal desities. Probability levels from accumulated analysis of variance are shown in bold for all factors included in the model. NU = factors analysed but not used in the final models.

Taxa	Treatment Factors						
	Lunar Cycle	Lunar Phase	Transect	Shot No.	Temp.	Baro. Press.	Tide
Ocypodidae	**0.162**	**< 0.001**	**0.188**	NU	NU	NU	NU
Macrophthalmus spp	**0.116**	**0.030**	NU	NU	NU	NU	NU
Mictyridae	**< 0.001**	**0.008**	**0.150**	NU	NU	NU	**0.016**
Portunus pelagicus	NU	NU	**0.022**	**0.072**	NU	NU	NU
Thalamita sp1	NU	**0.039**	**< 0.001**	**0.032**	NU	NU	NU
Thalamita sp2	**0.024**	**<0.001**	NU	NU	**< 0.001**	NU	NU
Juv. *P. pelagicus*	**< 0.001**	**< 0.001**	**<0.001**	NU	NU	**0.003**	NU

In general the environmental factors measured contributed little to explain the variation in any of the enumerated megalopae (Table 8.3). The exceptions to this were temperature and tide for Mictyridae and *Thalamita sp2* respectively. Barometric pressure was also linked to juvenile blue swimmer crab abundance. Lunar phase was an important explanatory factor for all taxa apart from *Portunus pelagicus*. Likewise, the factor of lunar cycle was important reflecting temporal variations in megalopae abundance of most taxa. Spatial differences in abundance, reflected in significant transect effects for some taxa, were also noticeable. Wind speed and direction were modelled in a range of different ways, predominantly reflecting different lag periods, but in no model did they result in a significant effect. Due to the relative consistency in the effects of lunar and transect variables these were included in models of some species even if their effect was overall non significant. However, if the probability of a treatment factor was greater than 0.19 it was still not included in the model.

A total of 704 portunid crabs were captured in 120 trawls and of these 491 were juveniles. Of the juvenile crabs caught, 479 (97.6%) were *P. pelagicus*, 11(2.2%) were *Charybdis callianassa* and only a single three spot crab (*Portunus sanguinolentus)* was caught. *P. pelagicus* juveniles were also occassionally collected in the plankton tows(< 2 per night), however they occurred too infrequently for statistical analysis.

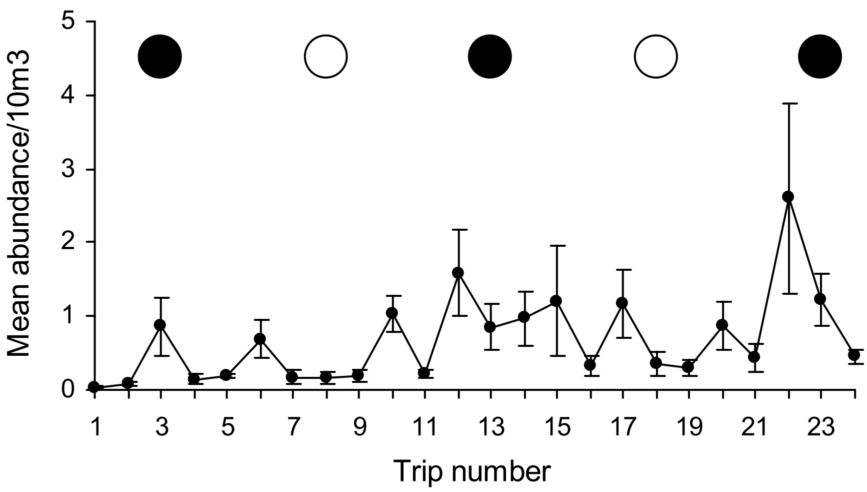


Figure 8.3 Variation in density (± SE) of *Portunus pelagicus* megalopae in plankton samples collected during 24 sampling trips in Deception Bay. Periods of full and new moon are also shown.

The abundance of *Portunus pelagicus* megalopae increased during the sampling period (Figure 8.3) although as mentioned previously there were no significant lunar effects. The analysis of variance table (Table 8.4) shows that transect was the only significant factor with sites 3,7,8 and 9 having high predicted blue swimmer crab densities (Figure 8.4).

Table 8.4 Analysis of variance table examining the impact of various factors on the density of *Portunus pelagicus* megalopae.

Change	d.f.	S.S.	M.S.	Var. Ratio	Probability
Shot No.	4	23.662	5.915	2.22	0.072
Transect	9	54.983	6.109	2.29	0.022
Residual	106	283.081	2.671		
Total	119	361.725	3.04		

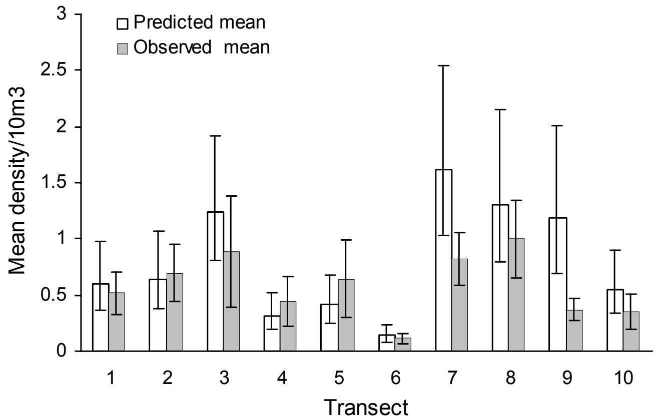


Figure 8.4 Model predictions of *Portunus pelagicus* megalopal densities adjusted for various factors. Observed densities are also shown. Standard errors are shown as vertical bars.

In contrast to the megalopae, *Portunus pelagicus* juveniles were effected by a range of factors (Table 8.5). There was an even stronger trend of increased abundance over time (Figure 8.5 and Figure 8.6) and there were very few juveniles caught during the first half of the sampling program. The transects that had high densities of megalopae were different from those where juveniles were abundant (Figure 8.4 and Figure 8.6).

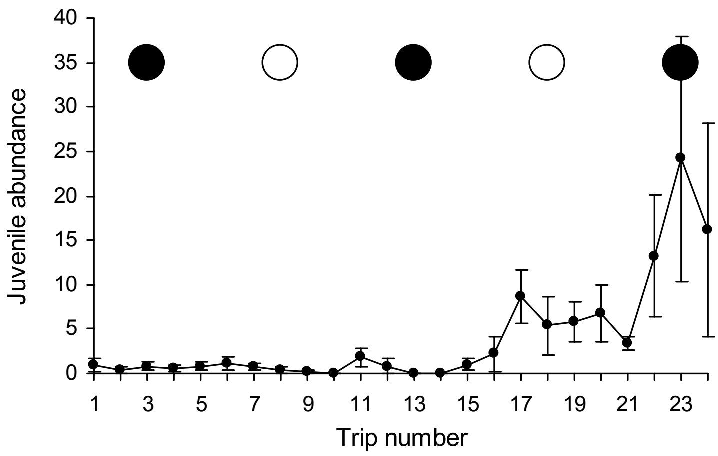


Figure 8.5 Variation in density of *Portunus pelagicus* juveniles from beam trawl samples collected during 24 sampling trips in Deception Bay. Periods of full and new moon are also shown.

Table 8.5 Analysis of variance table showing the effects of various factors on the abundance of *Portunus pelagicus* juveniles in beam trawl samples taken in Deception Bay.

Factor	d.f.	S.S.	M.S.	Var. Ratio	Probability
Cycle	2	68.5966	34.2983	48.48	<.001
Phase	3	15.7678	5.2559	7.43	<.001
Transect	9	38.3692	4.2632	6.03	<.001
Baro. Pressure	1	6.5451	6.5451	9.25	0.003
Residual	104	73.5744	0.7074		
Total	119	202.853	1.7046		

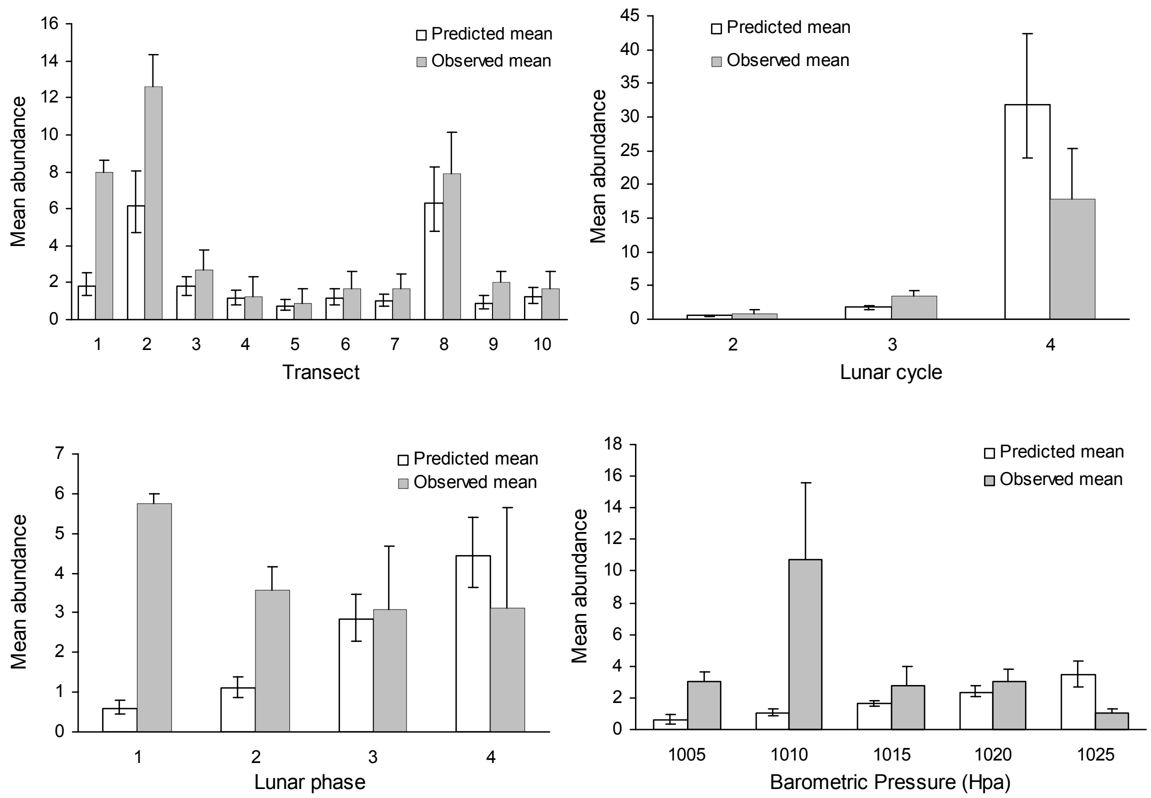


Figure 8.6 Model predictions of *Portunus pelagicus* juvenile abundance adjusted for various factors. Observed densities are also shown and standard errors are shown as vertical bars.

Ocypodidae

Ocypodid megalopae were significantyly effected by lunar phase with most megalopae being caught around the times of new and full moon (Table 8.6 and Figure 8.7 and Figure 8.8).

Table 8.6 Analysis of variance table showing the effects of various factors on the density of crab megalopae from the family Ocypodidae in plankton samples taken in Deception Bay.

Factor	d.f.	S.S.	M.S.	Var. Ratio	Probability
Cycle	2	11.903	5.952	1.85	0.162
Phase	3	75.147	25.049	7.8	<.001
Transect	9	41.087	4.65	1.42	0.188
Residual	105	337.353	3.213		
Total	119	465.49	3.912		

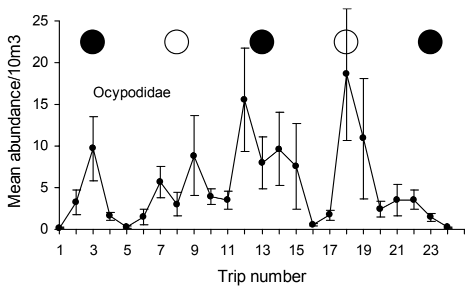


Figure 8.7 Variation in density of Ocypodid megalopae in plankton samples collected during 24 sampling trips in Deception Bay. Periods of full and new moon are also shown.

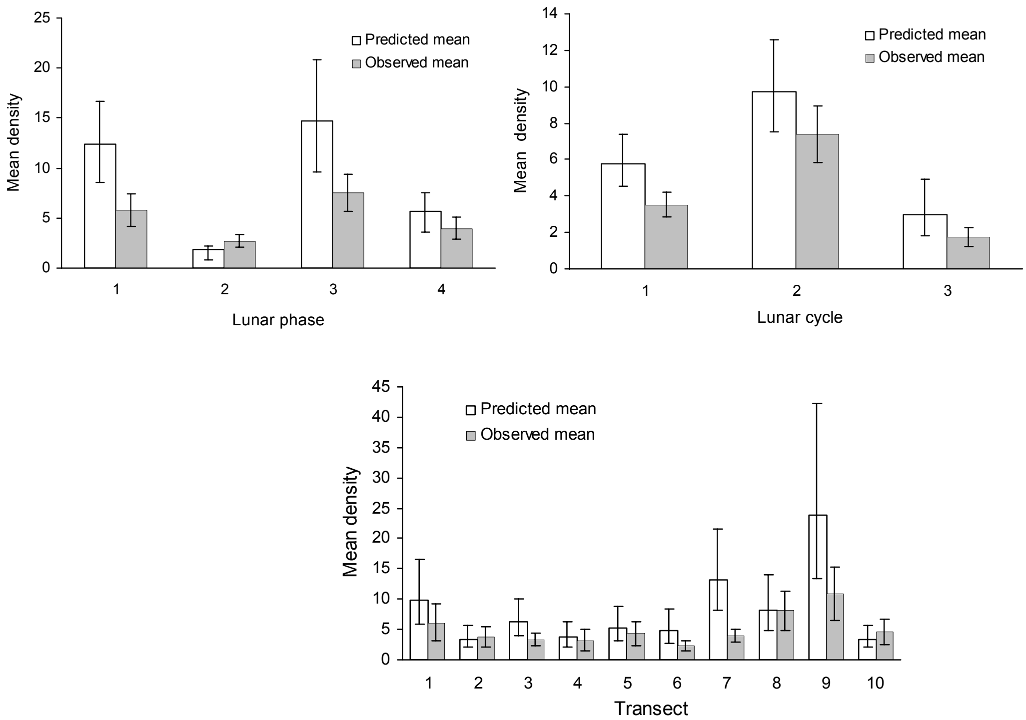


Figure 8.8 Model predictions of Ocypodid megalopal density adjusted for various factors. Observed densities are also shown and standard errors are shown as vertical bars.

Thalamita sp1.

One of the *Thalamita* species that was common in samples also was very abundant around the full moon (Figure 8.9) and also had significant time of night and location effects (Table 8.7 and Figure 8.10).

Table 8.7 Analysis of variance table showing the effects of various factors on the density of megalopae of *Thalamita* sp1 in plankton samples taken in Deception Bay.

Factor	d.f.	S.S.	M.S.	Var. Ratio	Probability
Phase	3	15.08	5.027	2.89	0.039
Shot No.	4	19.09	4.773	2.75	0.032
Transect	9	68	7.556	4.35	<0.001
Residual	103	178.917	1.737		
Total	119	281.091	2.362		

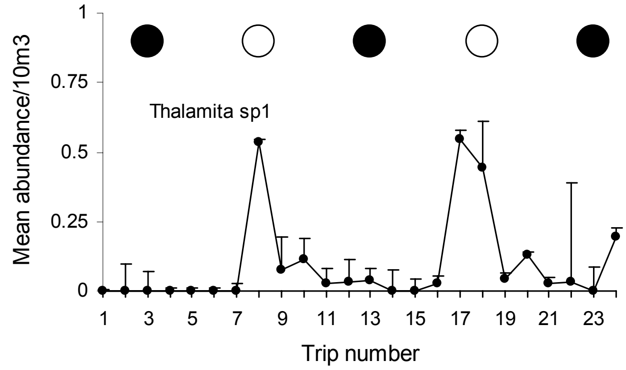


Figure 8.9 Variation in density of *Thalamita sp1* from plankton samples collected during 24 sampling trips in Deception Bay. Periods of full and new moon are also shown.

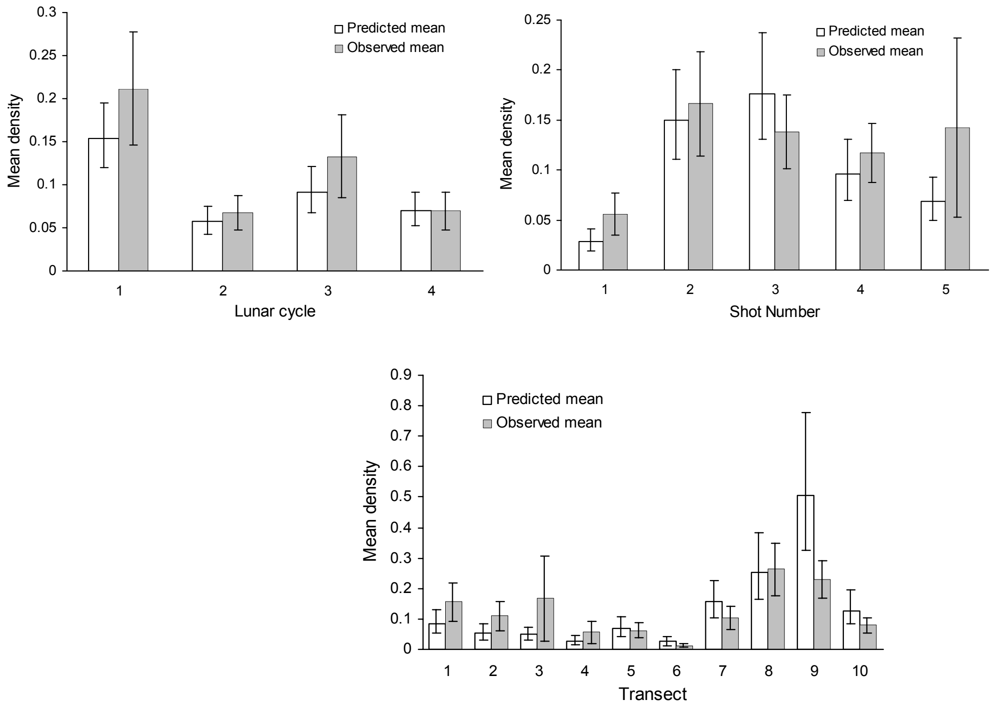


Figure 8.10 Model predictions of *Thalamita sp1* megalopal density adjusted for various factors. Observed densities are also shown and standard errors are shown as vertical bars.

Discussion

The typical portunid pattern of migrating offshore to spawn that is evident in other portunids from the region (eg. *Scylla serrata*) is not as evident for *Portunus pelagicus.* It appears that blue swimmer crabs may not undergo the extensive migrations common among other portunids. Ovigerous blue swimmer crabs are found in high abundance on the western side of Moreton Bay and in many cases these crabs have eggs that will hatch within hours (see Chapter 9). In addition blue swimmer crabs have hatched in the laboratory in salinities of around 30ppt, significantly less than offshore oceanic conditions (Campbell 1984) further suggesting that offshore spawning migrations may not be a feature of this species biology. While Moreton Bay is certainly classed as an estuarine embayment, salinity conditions throughout much of the Bay (particularly the eastern side of the Bay) are very similar to those experienced in adjacent offshore waters. It is only after heavy rainfall that river run off from the Brisbane River, Pine Rivers and others lower salinities in the Bay. Even then the western Bay can maintain relatively high salinities because of the oceanic influx of water from the northern opening and south passage between Moreton and Stradbroke Islands. To what extent megalopae abundance is driven by wind or tidal related influence remains unclear. The presence of onshore winds may be important since the period in which most spawning takes place (September –November) is also a time when NE and SE winds predominate, conditions which would tend to move larvae and megalopae across to the western side of the Bay (Bureau of Meteorology). On subsequent sampling trips conducted in other areas during 1999 large numbers of megalopae and zoeae were seen in plankton samples collected on the western side of Moreton Bay as part of other research. In one instance over 1 kg (wet weight) of portunid zoeae (predominantly *P. pelagicus*) were collected along a tidal and wind "line" close to the western shore of the Bay during a period of strong SE winds.

None of the factors tested explained much of the variation in *Portunus pelagicus* megalopal density that occurred during the sampling program. Despite this some of the other species of crabs that are present in the plankton were present in sufficient numbers to describe factors that influenced their abundance.

The sampling program however clearly showed that small juveniles were not available until late October, a result supported by previous research (Sumpton *et al*. 1994) and current trawl sampling (see Chapter 11). Even though spawning occurs throughout most of the year and small juveniles (<60mm) are always found in samples, it is the spring spawning and associated recruitment of juveniles that occurs predominantly during the spring and summer that drives the fishery for blue swimmer crabs. The independent sampling of these juveniles that first become present in trawl samples during the late spring may provide a better predictive tool than the sampling of megalopae both because of ease of sampling and other logistic reasons. The sampling and identification of small juveniles is significantly less time consuming than the sampling, identification and enumeration of plankton samples. As an example, over 120 person hours were required to sort and identify the several hundred blue swimmer crab megalopae found during the plankton survey and by comparison samples of several hundred blue swimmer crab juveniles can be sexed and measured within 1 hour.

In terms of designing a program of monitoring the recruitment of *Portunus pelagicus* using megalopae abundance, the lack of understanding of any of the factors causing the variation in megalopae abundance means that it is unwise to use megalopae relative abundance as a predictive tool. The fact that there were orders of magnitude variations in the abundance of *P. pelagicus* megalopae over very small temporal and spatial scales means that there would be insufficient power to detect changes unless there are large numbers of samples taken over a reasonably long temporal scale.

9. GENERAL BIOLOGY OF BLUE SWIMMER CRABS IN QUEENSLAND

Introduction

In Australia, studies of blue swimmer crab biology have been predominantly confined to temperate latitudes of southern Australia (Meagher, 1971; Penn, 1977; Smith, 1982; Potter *et al.* 1983). In subtropical waters, Thomson (1951) examined the composition of the commercial Moreton Bay catch but described little of the crabs' growth or reproductive biology. Weng (1992) compared the biology of *Portunus pelagicus* from the Gulf of Carpentaria and Moreton Bay and Sumpton *et al*. (1994) described aspects of the biology of the blue swimmer crabs in Moreton Bay during 1985 and 1986. Most other Australian work on *P. pelagicus* has concentrated on parasitic infection by *Sacculina granifera* (Phillips & Cannon, 1978; Bishop & Cannon, 1979), the crabs' feeding habits (Williams, 1982; Wassenberg & Hill, 1987) and trap entrance behaviour (Smith and Sumpton, 1989).

Since these studies, the fishery for blue swimmer crabs in Queensland has expanded greatly into offshore waters where little is known about the recruitment, growth and other aspects of the species biology. This Chapter describes various aspects of blue swimmer crab biology such as growth, mortality and reproductive cycles and compares the biology of the Moreton Bay population with the biology of those found in other areas not previously assessed. We also describe the size structure of the commercial pot catch in each region and discuss regional differences in the structure and characteristics of the fishery.

Materials and Methods

Samples of *Portunus pelagicus* were taken opportunistically from commercial pot and trawl catches in northern and southern Moreton Bay, Hervey Bay and in offshore waters between Bribie Island and Fraser Island. Crabs were usually returned to the laboratory within 6 hr of collection and examined in the laboratory within 48 hr.

The carapace width (cw) was measured to the nearest millimetre across the tips of the epibranchial spines and individual wet weights of a subsample of the crabs were recorded to the nearest gram. Crabs were classified as juveniles if the abdominal flap was firmly attached to the thorax (Van Engel, 1958). The moult stage of each crab was assessed using the method of Hiatt (1948) i.e. newly moulted, recently moulted, intermoult, premoult and ecdysis.

Female crab gonads were categorised as one of the following stages:

Stage 1: No macroscopic sign of gonad;
Stage 2: Gonad immature, white or translucent, oocytes up to 0.14 mm in diameter;
Stage 3: Gonad maturing, light orange, not extending into hepatic region, oocytes 0.15 - 0.21 mm;
Stage 4: Gonad mature, bright orange, extending into hepatic region, oocytes 0.22 - 0.40 mm.

A spermathecum of each mature female was examined for spermatophores and the incidence of ovigerous females was recorded and females staged as follows:

Stage 1: Non-ovigerous;
Stage 2: Ovigerous with pale to dark yellow egg mass (no eyespots visible in eggs);
Stage 3: Ovigerous with yellow-grey egg mass (eyespots present);
Stage 4: Ovigerous with grey egg mass (eyespots and chromatophores discernible);
Stage 5: Egg remnants (spent).

Seasonal oscillating Von Bertalanffy growth functions (Somers 1988) were derived for blue swimmer crabs using monthly length frequency data collected during the 1980s as well as data collected as part of regular sampling carried out as part of the current research (Chapter 11).

Results

Sexual maturity of blue swimmer crabs was reached at a smaller size for males than females with 50% maturity occurring at a carapace width of approximately 100mm and 110mm for males and females respectively (Figure 9.1). Maturity was achieved over approximately a 40mm size range and there were still rare individuals of both sexes that were not sexually mature by 120mm CW.

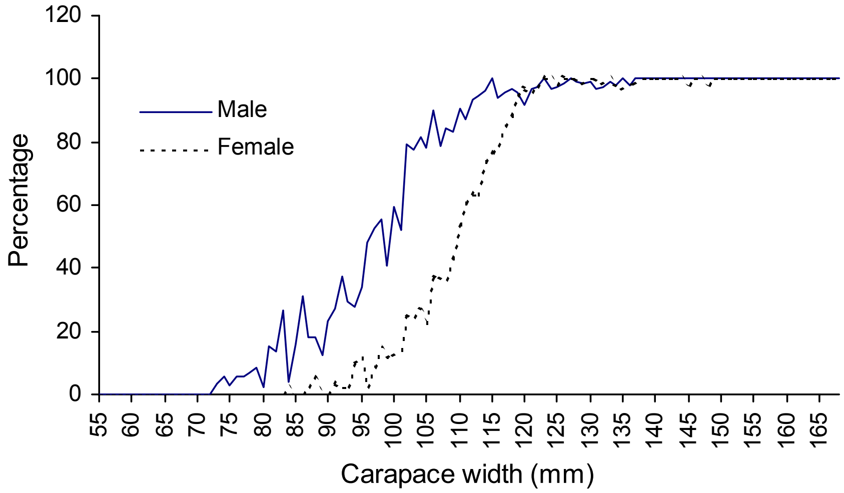


Figure 9.1 Percentage of the sampled populations that were sexually mature as assessed by condition of the abdominal flap.

The size frequency of the sexually mature and ovigerous female populations were displaced towards the larger size classes with a higher proportion of larger females being ovigerous (Figure 9.2). In fact the two largest females sampled were carrying eggs.

(a) (b)

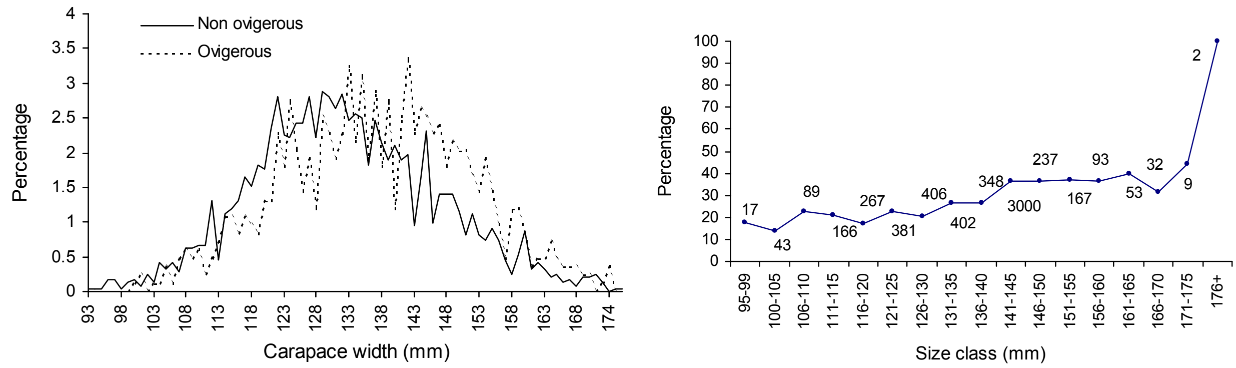


Figure 9.2 (a) Size frequency of the sexually mature and ovigerous female blue swimmer crab population. Maturity was assessed by the condition of the abdominal flap. (b) Sample sizes and percentage of various size classes of females that were ovigerous.

Ovigerous females were present in the samples throughout the year in all regions sampled, although the ovigerous proportion was lowest during May and June (Figure 9.3). During late winter and spring almost 70% of females were carrying eggs in some areas. Southern Moreton Bay and Hervey Bay were the two regions that had the highest proportion of ovigerous females in the sampled population. The data clearly indicates that some spawning activity takes place throughout the year but with a peak in spawning activity in early spring. There were no clear spatial or temporal trends in the incidence of the various stages of eggs with both recently extruded eggs and eggs that were close to hatching being found in all regions throughout most of the year.

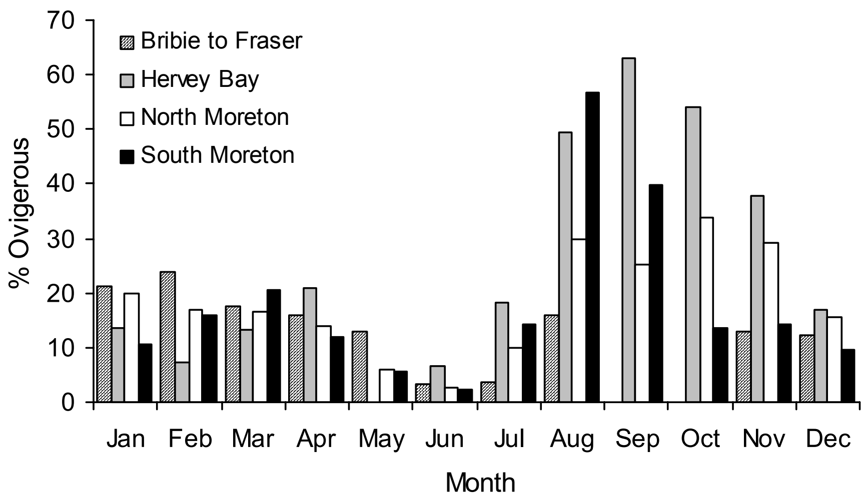


Figure 9.3 Seasonal variation in the percentage of ovigerous female blue swimmer crabs in commercial pot samples from 4 areas in southern Queensland. No females were sampled during September and October in the Bribie to Fraser region.

Mating activity, as assessed by the presence of recently implanted spermatophores, likewise took place throughout the year but again all regions displayed a similar pattern with most mating taking place during May and June (Figure 9.4). Whilst ovigerous females were more commonly sampled during spring there appeared to be little mating activity in any of the regions during this time. However sampling in the offshore areas during the spring was not as extensive as other areas and therefore the rates described here may be biased for that region.

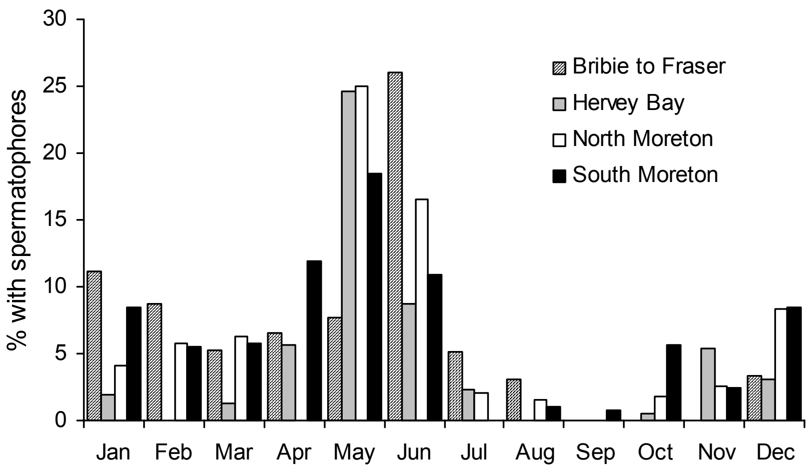


Figure 9.4 Seasonal variation in the percentage of mature females from 4 sampling areas in southern Queensland with recently implanted spermatophores in their spermathecae.

Despite the fact that baited pots select against pre-moult and early post moult crabs a large number (n=140) of immediate post moult females were sampled. Based on the condition of their spermathecae all of these females had been inseminated by males. In many pots it appeared that males had also entered in a pre-copulatory hold with a pre-moult female.

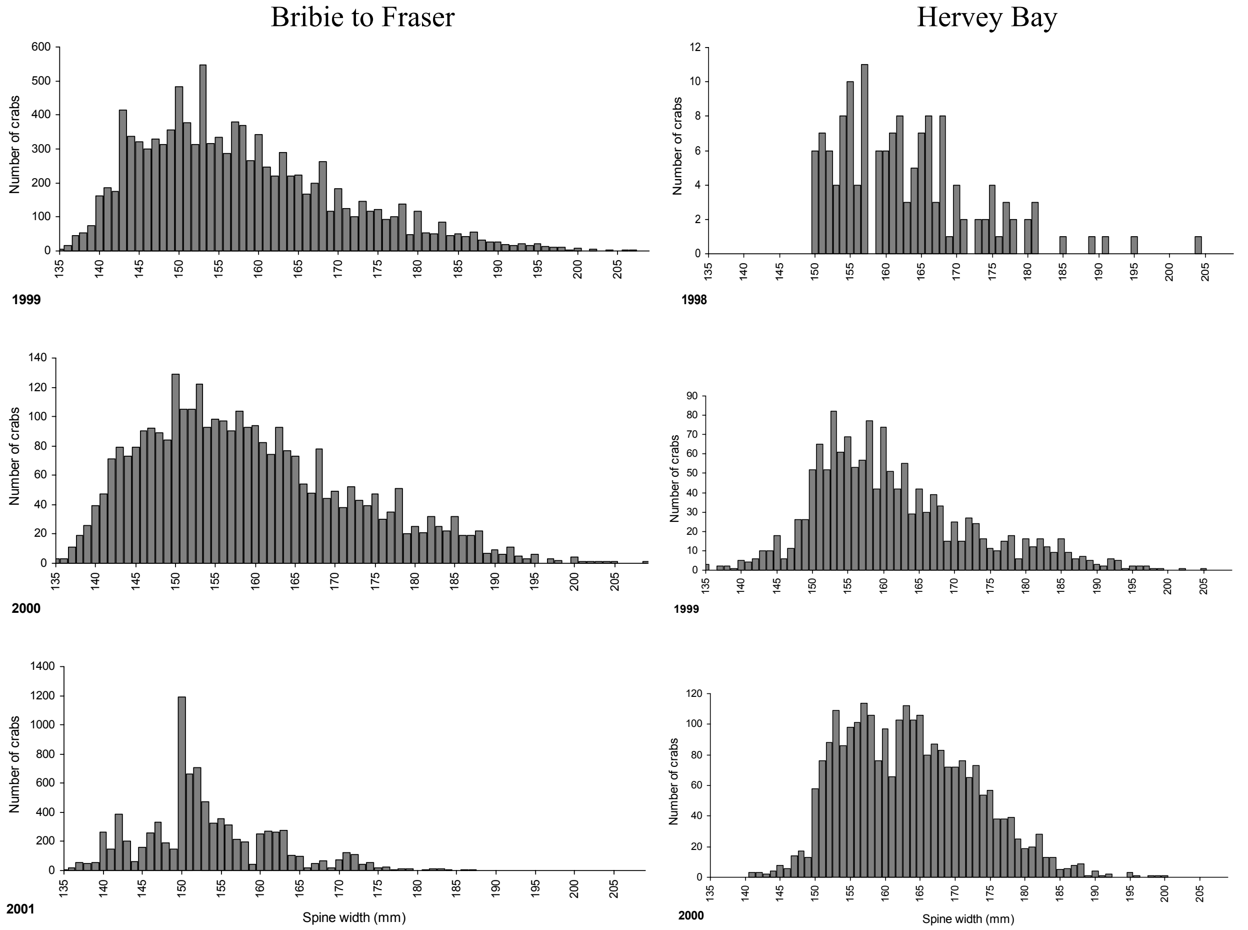


Figure 9.5 Size frequency of the retained commercial pot catch (male) of blue swimmer crabs from Hervey Bay and Bribie to Fraser Island.

Size frequency data collected from commercial pot fishers showed that there were very few crabs less than 120 mm caught in commercial pots and it was rare to catch any sexually immature crabs in the any of the pot designs used by commercial fishers. This is despite a wide variation in mesh sizes of the different pots. Generally there are few crabs less than 150mm carapace length landed in Hervey Bay (Figure 9.5). In the Bribie to Fraser area they make up approximately 30% of the catch (in terms of numbers). The 2001 catch is anomalous as it was based predominantly on the catch of only two fishers who fished the same area. The measurements during in 2001 were also in part recorded by the fishers themselves and therefore display considerable rounding errors and other inaccuracies.

In Moreton Bay during some years male crabs <150mm can make up to 50% of the catch (Figure 9.6). There is considerable variation in this trend both among fishers and seasonally. The crabs that are less than 150mm in carapace width tend to have their spines damaged which restricts their measurement to the alternative under-body measure. This measurement effectively lowers the size limit to 138 mm as it is based on the lower 95% confidence limit for a crab with a spine width of 150mm. Due to the wide variation in spine lengths of blue swimmer crabs there is considerable variation in the relationship between spine width and under-body measurement.

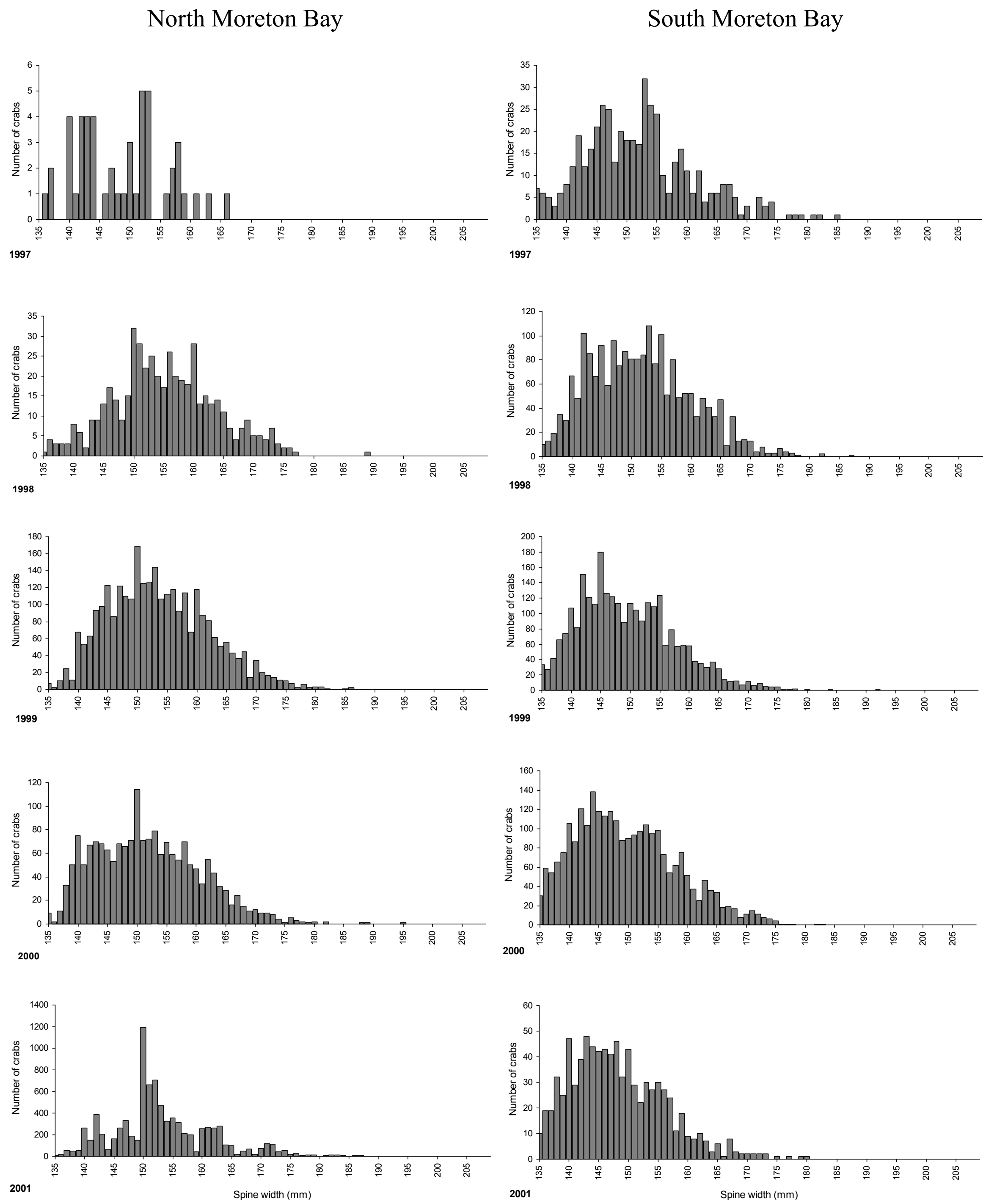


Figure 9.6 Size composition of the marketable commercial pot blue swimmer crab catch from northern and southern Moreton Bay from 1998 to 2001.

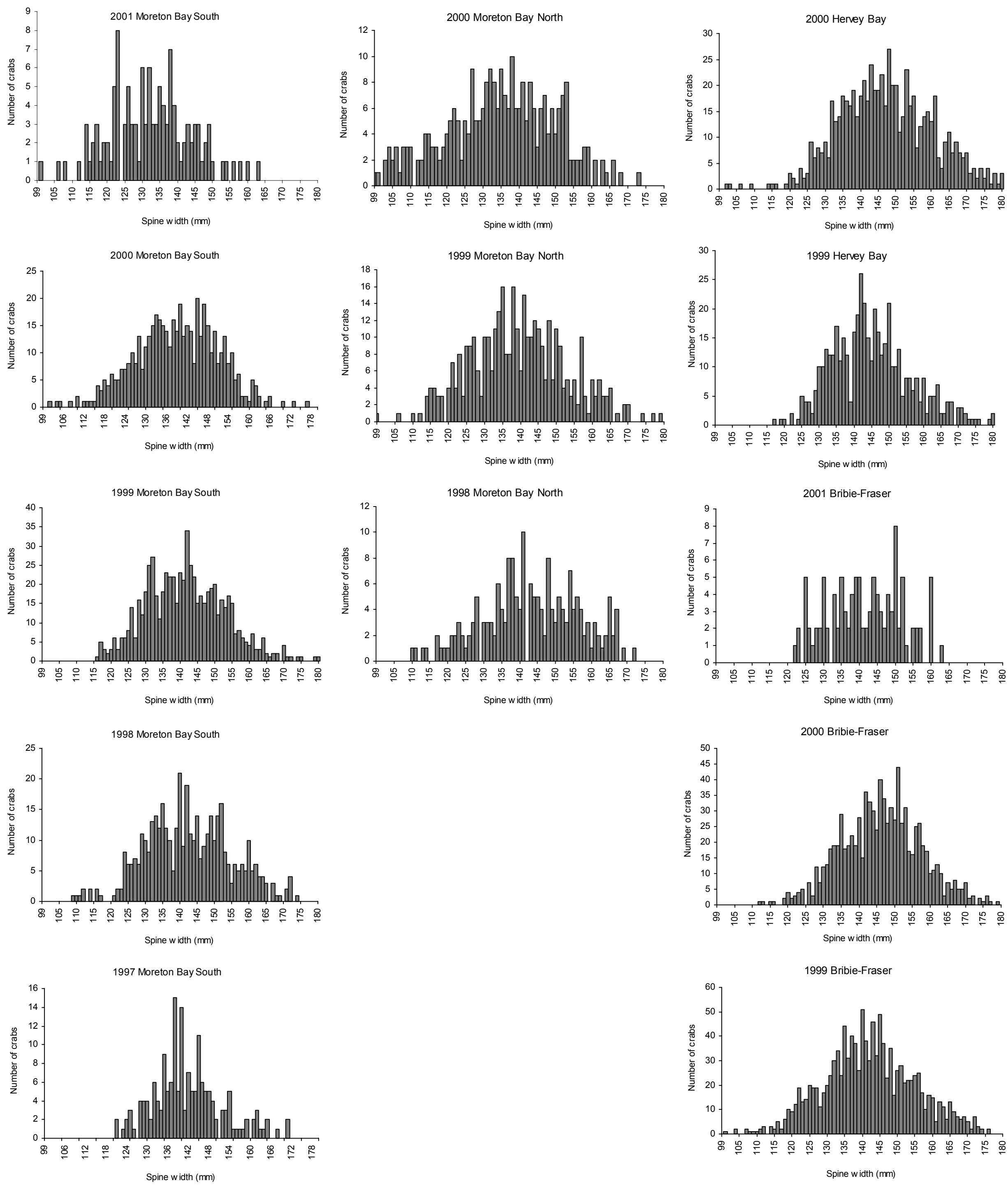


Figure 9.7 Length frequency of female blue swimmer crabs caught in commercial pots from 4 areas in southern Queensland.

The length frequencies of females sampled from all areas is shown in Figure 9.7. As was the case with males there were few immature female crabs taken in any of the pots with the maximum and minimum sizes of females seen in pots being broadly consistent among regions and times. It appeared that the small sample size was mainly responsible for the lack of numbers at the extreme end of the size distributions in some cases. The main sexual difference in the size frequency data was the similarity in maximum size of females sampled in the different regions when the larger size classes of males were virtually absent from Moreton Bay samples.

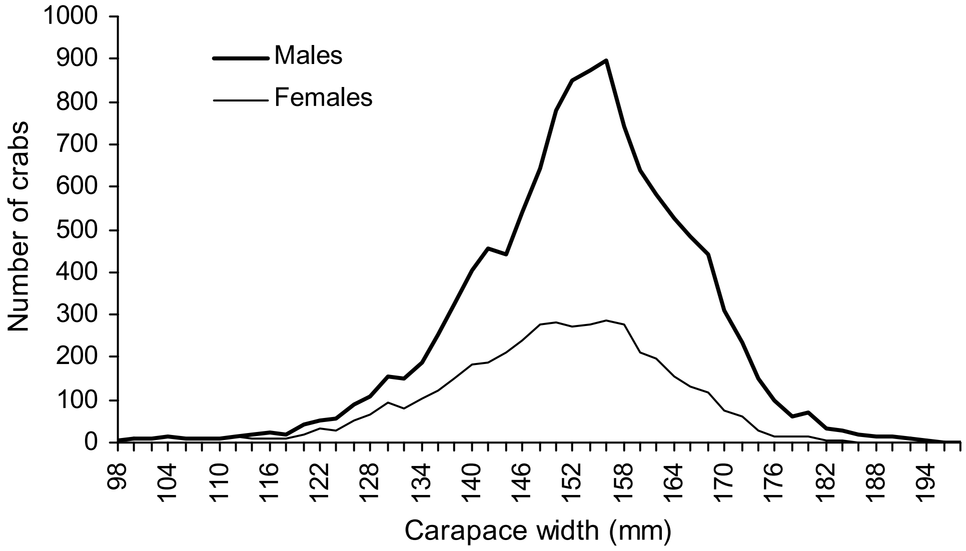


Figure 9.8 Size frequency of male and female blue swimmer crabs sampled in commercial pots and nets from western Moreton Bay during the late 1940s. Data adapted from Thomson (1951).

Size frequency data collected in Moreton Bay during the 1940s show that the size structure of both females and males differed markedly from the current size structure with a higher proportion of larger individuals represented in the samples.

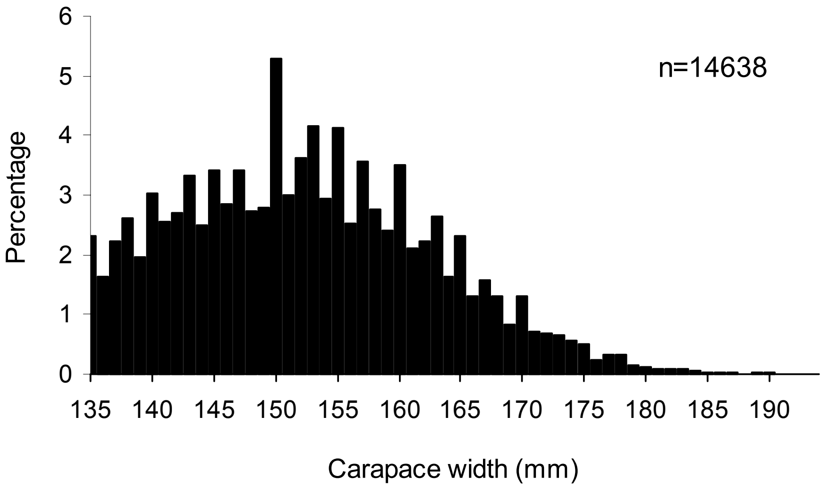


Figure 9.9 Size frequency of male blue swimmer crabs able to be marketed in the catch during 1985/86.

During 1985/86 observers accompanied commercial pot fishers and measured the catch on over 100 trips. During these trips fishers generally only retained male crabs >150mm carapace width with the undersized portion of the catch being returned to the laboratory for further analysis. However, if similar handling and retention practises were employed back then the size structure of the retained catch would resemble Figure 9.9. This figure was generated by including all crabs that could have been retained by fishers. It also included that portion of the catch that was returned back to the laboratory but would have had an under-body measurement that allowed crabs less than the MLS to be taken. It needs to be remembered that this figure includes data from both southern and northern Moreton Bay. The data also shows that a larger proportion of crabs less than 150mm is caught in pots nowadays compared with 15 years ago.

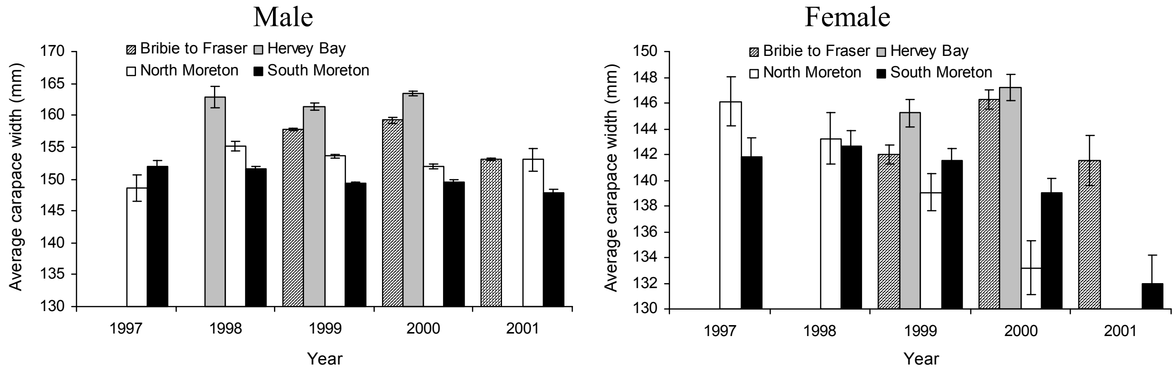


Figure 9.10 Average size of retained males and all females taken in commercial blue swimmer crab pots from 4 regions in SE Queensland. 95% confidence intervals are shown as vertical bars.

The average size of the retained male catch differed more spatially than temporally (Figure 9.10) with the offshore regions having significantly larger male crabs than either of the areas in Moreton Bay. Hervey Bay males were on average larger than all other areas largely because of the practise of many fishers from that region to not retain “tippers”. This was not the case however for the Bribie to Fraser region where all such crabs were generally retained. The relatively tight confidence intervals in some years are a reflection of the large sample sizes recorded with a total of over 41,000 marketable male crabs being measured during the study. As mentioned earlier the 2001 sample of males was anomalous due to the fact that it came from the catch of only two crabbers. The difference in size of females among regions was not as dramatic as that of marketable males with few significant differences evident (Figure 9.11). During 2000, when sampling was most intense, females sampled from the offshore regions were significantly larger than Moreton Bay samples but the pattern was not repeated in any other year.

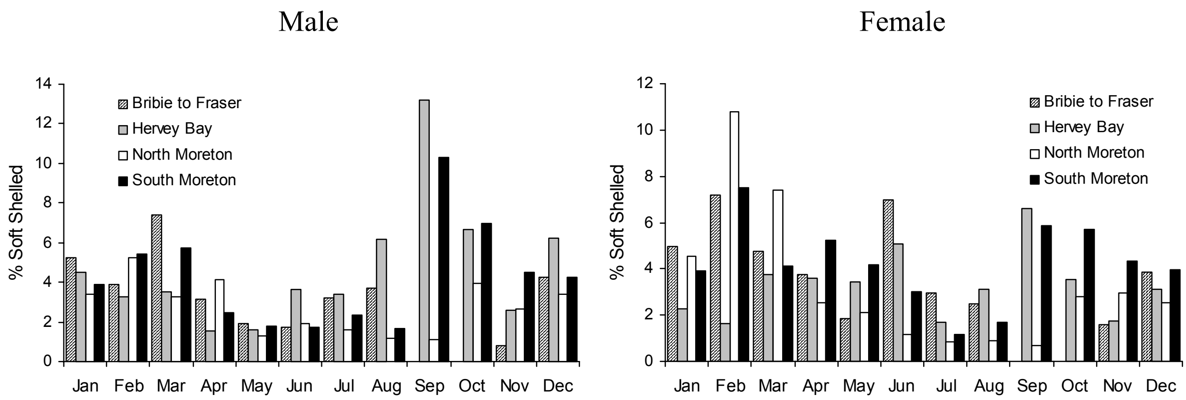


Figure 9.11 Percentage of soft-shelled male and female blue swimmer crabs caught in pots from 4 sampling regions in southern Queensland.

Information on the number of soft-shelled crabs in samples (an indicator of moulting) confirmed that there was some moulting taking place throughout the year in all sampled areas. There was no significant difference ($P<0.05$) in the proportion of both male and female crabs moulting based on pot catches. There was considerable variation both spatially and seasonally and no consistent trends.

Seasonally oscillating growth models were applied to length frequency information from Moreton Bay (Figure 9.12).

Figure 9.12 Seasonally oscillating growth curves for male and female blue swimmer crabs derived from monthly length frequency data collected in Moreton Bay.

The growth parameters derived from the monthly catch data size frequencies using both seasonal and non-seasonal growth models are shown in Table 9.1. They were derived for Moreton Bay samples only because juveniles were not sampled in any of the other areas. This was despite considerable effort, particularly in the offshore areas of Bribie to Fraser (see Chapter 11).

Table 9.1 Non-seasonal and seasonal von Bertalanffy growth parameters for male and female blue swimmer crabs in Moreton Bay.

Area	K	$L\infty$	t_o	C	t_s
Moreton Bay (Male)	1.62	177	0.20		
Moreton Bay (Female)	1.61	172	0.19		
Moreton Bay seasonal (Male)	1.59	180	.17	0.63	0.74
Moreton Bay seasonal (Female)	1.63	174	.20	0.60	0.79

Given that females are not retained it may be possible to estimate fishing mortality of blue swimmer crabs by calculating the total mortality of both sexes. Assuming that female crabs are theoretically unexploited and that natural mortality rates of the sexes do not differ it should be possible to subtract their mortality from that of males to estimate fishing mortality. While this may be a bold assumption this is probably the best way to split total mortality estimates into their component estimates of natural and fishing mortality. Table 9.2 shows the results of estimating mortality using age converted catch curves derived from size frequency data and growth parameters from Table 9.1.

Table 9.2 Estimates of total mortality for male and female blue swimmer crabs based on length frequency data and growth parameters derived in Table 9.1. The range is shown in brackets.

Method	Hervey Bay	Bribie to Fraser	North Moreton Bay	South Moreton Bay
Males	0.669 (0.42-1.17)	1.309 (.82-2.29)	2.129 (1.33-3.73)	2.553 (1.59-4.47)
Females	0.837 (0.25-2.23)	1.106 (0.32-2.78)	1.287 (0.53-3.03)	1.710 (0.66- 3.25)

There is a wide range in the estimates derived for each sex and region largely reflecting the uncertainties in the estimates of growth parameters. We chose to vary the value of K by 50% and $L\infty$ by 10% because the parameters were derived without uncertainty. Mortalities of males and females were highest in Moreton Bay, particularly, southern Moreton Bay. There was more variability in the estimates of male mortality but female mortality still varied by over 100% despite the fact that females are not fished in any of the regions. The total mortality of females in Hervey Bay exceeded that of males despite the fact that females do not undergo any significant fishing mortality or discard mortality (See Chapter 6).

Discussion

The biological parameters which have been derived for blue swimmer crabs in Moreton Bay previously (Sumpton *et al.* 1994) are broadly consistent among the other areas that have recently undergone expansion. Reproductive seasonality, maturity, moulting etc are similar among all areas investigated. What does differ is the size structure of the catch in the pot fisheries. Areas that have a long history of exploitation (such as Moreton Bay) tend to have smaller sized male crabs than areas that have only recently been exploited. Whether this is due to heavy exploitation pressure or differences in population structure and gear selectivity is addressed in the following discussion.

In contrast to males, the size distribution of female crabs do not differ significantly among any of the areas sampled suggesting that the unexploited populations do not differ at least in terms of female size structure. This points to exploitation being the cause of the differences in size structure of males as has been hypothesised in the blue crab (*Callinectes sapidus*) fishery in the USA (Abbe 2002).

There are, however, other lines of evidence that suggest that the smaller size of males in Moreton Bay is not due to exploitation pressure. The data collected using observers on boats during the 1980s overall did not indicate a size structure too dissimilar to that of the present day in Moreton Bay (if both northern and southern Moreton Bay are included). Although there is little quantitative catch and effort data for the mid 1980s, effort in Moreton Bay during the 1980s was probably similar to the present day and may have indeed been greater in some areas (based on observations of pot numbers from research logs collected for a proportion of the fleet during that time). Thomson (1951) investigated the blue swimmer crab fishery in Moreton Bay almost 50 years ago when the exploitation pressure on the resource was not as great as it is now and found size structures that contain a higher proportion of larger crabs (of both sexes) than those found in the present day fishery. Fish Board records presented by Thomson show a fishery with a catch less than 20% of what it is currently in Moreton Bay today. During this period there was also little recreational effort and trawling in Moreton Bay did not really begin until the 1950s. The fact that in Thomson's study the relative difference in the size structures of males and females was similar to the present day suggests that selectivity of the gear was the main contributing factor of the differences. The data collected during the 1940s was also collected by mesh net with the relative contribution of each method to the overall sample is not discernable from Thomson's data.

The use of pots as a sampling method for determining population structure is problematic not only because of the selective nature of the apparatus but also due the targeting practise of the fishers that set the traps. Thomson (1951) noted that there was considerable selectivity of the gear and it is unwise to interpret the differences as being caused by fishing. Blue swimmer crabs are known to segregate by size and sex at times and fishers are readily able to target particular sizes, tending to avoid areas where there are large numbers of females and undersized crabs (Unless there is a high proportion of marketable crabs in the area as well).

It is possible that male crabs in the offshore areas undergo an additional moult causing a higher proportion of larger animals to be available in these areas. While Hervey Bay has comparatively recently been exploited by pot fishers the deeper areas further offshore have been fished extensively by scallop trawlers over the last few decades. Yet this is the area that apparently has the lowest fishing mortality and the larger size classes of male crabs dominate the size structure of the blue swimmer crab trawl catch. These larger crabs may be either crabs from the embayments moving out into deeper water once they reach a certain size or particular moult stage (probably the terminal moult). In addition the parasitology data suggests that the crabs may be from different populations (see Chapter 10).

The growth data obtained for blue swimmer crabs appears accurate for the first years growth but separation of modes for the faster growing 0+ year old crabs and the 1+ year old crabs is difficult particularly during the winter and early spring when the smaller size classes are not as common in trawl samples (Sumpton *et al*. 1994). Because growth is estimated by modal progression it is difficult to obtain precision estimates for growth parameters because of the subjective way of determining size modes for analysis. The lack of good growth information for the second (and possible subsequent) year(s) of life probably results in an underestimation of $L\infty$ because crabs up to 220mm have been found and it is common to catch crabs in excess of 180mm, particularly in the offshore waters. The discrepancy in $L\infty$ in particular has a significant impact on estimates of fishing mortality based on age converted catch curves.

While there is some uncertainty about the reliability of the mortality estimates they do suggest that fishing mortality is considerably higher inside Moreton Bay compared to the more remote offshore areas. It will be interesting to see if the size structure of the offshore fishery becomes more like those of the more heavily exploited Moreton Bay as the offshore fishery develops further.

The fact that all immediate post-moult females that were sampled had been mated suggests that there are sufficient reproductively active and capable males in the population to mate with females. This result is identical to the situation during 1985/86 when research in Moreton Bay showed that all reproductively capable females had been mated (Sumpton *et al*. 1994). The present survey indicated that even if there has been a decline in the average size of males in the population there are still sufficient large males in the population to mate with the reproductively active females. It is a well-established fact that of a copulating pair the male is always larger (and usually considerably larger) than the females. In over 50 copulatory pairs that have been measured the male was on average 13% larger (in terms of carapace width) than the female. Indeed most of the pairs observed in this and previous research have been males in attendance of females in their first maturity moult and few pairs have been observed where the females exceed 150mm CW. Despite this, ovigerous females were found throughout the size range and in fact the two largest crabs sampled were carrying eggs. The trend was for a higher proportion of large females to be carrying eggs than for smaller females. One of the hypotheses that may explain this observation is that females in their final moult may suffer higher levels of natural mortality once they have extruded all their eggs than females in the first maturity moult.

We attempted to address the question of sperm limitation by assessing the egg batch size and fertilisation rates of females and comparing this with previous information supplied by Campbell (1984) but unfortunately the variation in egg batch size was so great and imprecision in egg counting so high we were unable to gain sufficient power in any of the tests to detect a difference. Fertilisation rates were also imprecise and there is still some debate as to whether infertile eggs attach to the pleopods following extrusion in any case. It may be more informative in future to actually measure the volume of sperm in the spermathecum and develop methods to determine at what stage of development (in terms of egg batch extrusion) the female is. It is a simple matter to determine immediate post moult females and measure the volume of sperm prior to any egg extrusion but the following batches extruded during a moult are more difficult to determine. Nevertheless the volume of sperm in the spermathecae immediately after mating is probably a better indication of sperm limitation, should such be occurring. The number of females that a male can mate with and the volume of sperm inseminated is still not known and warrants further investigation.

10. PARASITOLGY OF BLUE SWIMMER CRABS IN QUEENSLAND

Distribution of barnacle symbionts of the crab *Portunus pelagicus* in the Moreton Bay region,

Introduction

Due to the economic importance of blue swimmer crabs there have been a number of studies on its parasites and symbionts in Moreton Bay. These have concentrated mainly on infestation by the Rhizocephalan barnacle *Sacculina granifera,* Boschma, (Thomson, 1951; Phillips and Cannon, 1978; Bishop and Cannon, 1979; Weng, 1987; Shields and Wood 1993; Sumpton *et al*, 1994.) which is known to cause sterilisation, and thus have a detrimental impact on fishery production.

Phillips and Cannon (1978) and Shields (1992) recorded the occurrence of barnacle symbionts from the genus *Octolasmis* and *Chelonibia* within Moreton Bay, although the biological and ecological implications of infestation were not described. Jeffries *et al*. (1982) recorded five species from the genus *Octolasmis* on *Portunus pelagicus* from the seas adjacent to Singapore, and at least two species (*Octolasmis angulata* and *Octolasmis warwickii*) are known to settle on *Portunus pelagicus* within Moreton Bay (Walker, personal communication).

Lepadomorph barnacles of the genus *Octolasmis* are frequently found attached to many decapod crustaceans (Jeffries and Voris, 1996). The cyprid larvae attach themselves to the exoskeleton of the host and filter feed on particulate matter transported through the host's ventilatory system (Gannon, 1990). As adults they are permanently attached to the host with the life cycle of the barnacle governed by the host's intermoult period (Jeffries and Voris 1996). Reproductive success is dependent upon the barnacle reaching maturity before the host moults. Thus to achieve reproductive success, a cyprid larva must select a host with a sufficient intermoult period to attach, metamorphose to adult form, oviposit and release nauplii (Jeffries *et al*., 1992).

The symbionts of the commercially important North American portunid *Callinectes sapidus* have received much attention with the genus *Octolasmis* reported by Walker (1974), Jeffries and Voris (1983), Gannon (1990), Gannon and Wheatly (1992), Gannon and Wheatly (1995), Jeffries and Voris (1996), Key *et al.* (1997). Gannon and Wheatly (1992) noted that excess symbiont load may represent a potential threat to crab populations through obstruction of the ventilatory current and decreased ventilatory effectiveness, leading to high mortality in stressed crabs. A similar situation may also exist for *Portunus pelagicus* since it shares many common attributes with the blue crab *Callinectes sapidus*, including life history, habitat, commercial importance and symbionts. Without an understanding of the spatial and temporal prevalence of *Octolasmis spp* it is impossible to determine the magnitude of any impact of the symbiont on crab populations.

Despite the negative consequences of infestation by barnacle symbionts, the parasites and symbionts of commercially exploited populations have the potential application as biological tags for use in stock discrimination. This method of stock discrimination is particularly suited to crustaceans where artificial tags can potentially alter the behaviour of tagged hosts and are often lost due to moulting (Mavkenzie and Abaunza, 1998). *Octolasmis spp* may be particularly suited as a biological tag for *Portunus pelagicus* because of the relatively short intermoult period. This paper examines the spatial and temporal patterns of the barnacle symbionts of *Portunus pelagicus,* with particular emphasis on *Octolasmis spp*. The potential of these symbionts as biological tags is also discussed.

Materials and Methods

Blue swimmer crabs were collected mainly using baited commercial crab pots in three areas from the Moreton Bay region in Queensland, Australia (Figure 10.1). Only male crabs <15cm carapace width and female crabs were available since males >15 cm were retained for sale by the commercial fishers. A sample of approximately 40 male and 40 female crabs were collected from each area over a 14-day period during the months of January, April, July and October 1999 representing 4 seasonal samples. The winter sample from the North Moreton Bay area was obtained using commercial prawn trawl gear since there were no commercial fishers using pots in that area and season. Crabs were kept on ice and subsequently frozen on returning to the laboratory. All crabs were sexed with adult females further classified as ovigerous or non-ovigerous. Crabs were classified as adult if the abdominal flap was not firmly attached to the thorax (Van Engel, 1958). The carapace width, taken between the notch between the eighth and ninth anterolateral spines, was measured to the nearest millimetre. The dorsal and ventral surfaces of all crabs were examined for barnacles with the number of each species recorded. Barnacles that settled on other appendages were not included due to the geographic and temporal variation of limb autotomy in portunid crabs (Smith and Hines, 1991). Parasitism of crabs by the Rhizocephalan *Sacculina granifera* was staged according to the methodology of Sumpton *et al*. (1994).

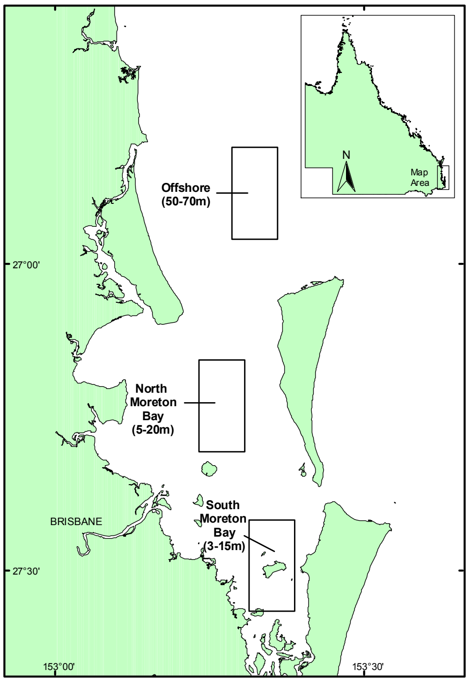


Figure 10.1 Map of study region showing areas and depth range where crabs were sampled.

All crabs were dissected, with one randomly selected branchial chamber visually inspected for gill barnacles. Settlement sites were recorded with respect to gill chamber, (left or right), aspect (hyperbranchial or hypobranchial), gill number (1= posterior to 8 = anterior) and area on the gills (proximal or distal). Settlement was also recorded on the epipodites of the three pairs of maxillipeds (hypobranchial gill rake, epibranchial gill rake and scaphognathite) and the inner wall of the branchial chamber.

Barnacles of the genus *Octolasmis* were broken into two arbitrary groups, those that were "recently settled" were translucent and less than 1.5 mm from the base of the carina to the tip of the tergum. The second group contained the "adult" octolasmids that were generally pink in colour and greater than 1.5mm from the base of the carina to the tip of the tergum.

The time involved in identifying to species level the large numbers of both recently settled and adult *Octolasmis* found in the brancial chambers of crabs (sometimes over 1000 per crab) necessitated a compromise in terms of taxonomic accuracy. Positive identifications of *Octolasmis angulata* were commonly made but as each individual *Octolasmis* was not identified the precise species composition was not determined beyond the generic level. Each crab was moult staged according to the setagenic methodology of Lyle and McDonald (1983) (See Table 10.1). This involved the classification of the excised distal half of the epipodite of the first maxilliped, which were mounted in water on glass slides.

Table 10.1 Moult stages used in setagenic methodology (see Lyle and McDonald 1983).

Moult stage	Macro stage	Micro stage	Sub stages
Post moult	AB	-	-
Inter moult	C	-	-
Pre moult	D	D0	-
		D1	D11, D12, D13
		D2	-
		D3-4	-

Spatial, temporal and sexual trends in *Octolsamis* infestation of intermoult crabs was analysed by Generalised Linear Models (GLM) fitted to the natural logarithm [ln(x + c) where c = smallest count/2] of *Octolasmis spp.* abundances. Carapace width was used as a covariate to standardise the effects of differing crab sizes between treatments. Means presented are predicted means from the GLM's, based on a standardised carapace width. All means were bias corrected and back transformed using the method outlined by Kendall *et al*. (1983).

$$y = \exp[x + (n-1)S^2/2n] - c$$

Where: y = bias corrected, back transformed mean.
x = Natural log transformed mean.
n= Error degrees of freedom
S^2= Variance (Residual mean square)
c = Constant from ln(x + c), 0.5 in this case.

Results

A total of 952 crabs were collected, of which 472 were female and 480 male. The females consisted of 85 (18%) ovigerous and 387 (81.4%) non-ovigerous, with 3 (0.6%) immature. Of the males, 475 (99%) were mature with 5 (1%) immature. The carapace width of sampled crabs ranged from 80 to 159mm and 78 to 137mm for females and males respectively. The crabs exhibited an overall prevalence of *Octolasmis spp*. of 92%. with infestation across all size classes sampled (Figure 10.2). Prevalence of *Octolasmis spp*. ranged up to 914 barnacles per gill chamber, but 90% of crabs had a barnacle abundance of between 1 and 200 barnacles per gill chamber.

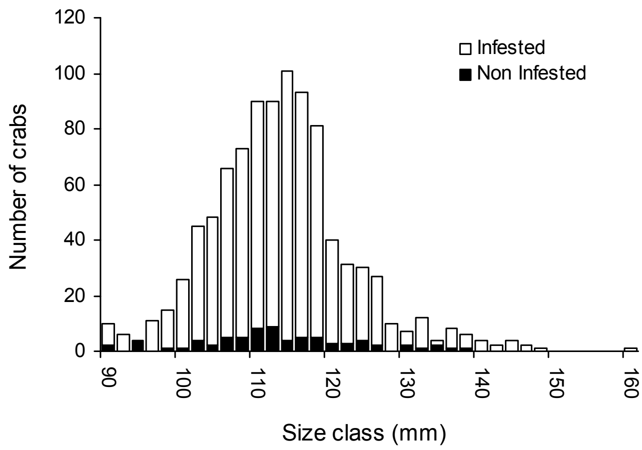


Figure 10.2 Carapace width frequency of *Portunus pelagicus* infested with barnacle symbionts (*Octolasmis spp.*) compared with non-infested crabs.

A total of 77, 273 *Octolasmis spp.* individuals were found inside the branchial chambers of sampled crabs, 73.7% on the gills, 23.3% on the branchial chamber under the gills and the remaining 3% on other surfaces within the branchial chamber. Only barnacles settling on surfaces of the gills and the branchial chamber under the gills were further analysed in this research. There was no significant difference (P>0.05) in the distribution of *Octolasmis spp.* under the gills compared with those on the gills (Figure 10.3) with gill 6 having the highest settlement (27.6%).

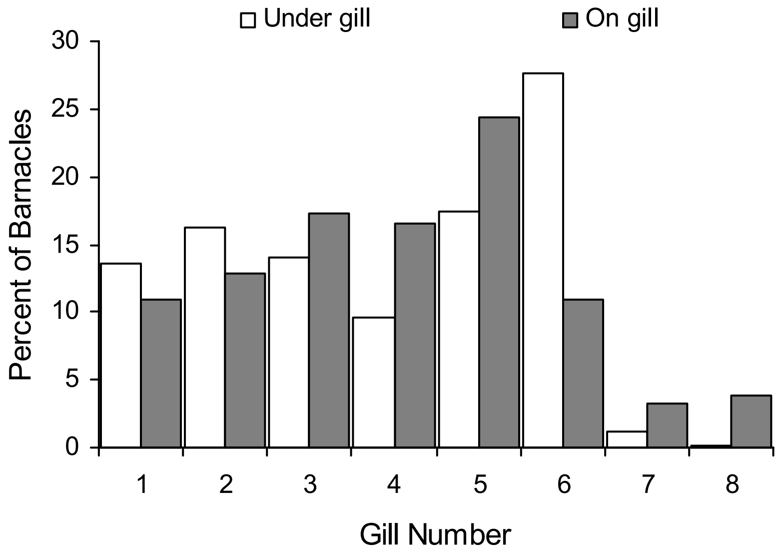


Figure 10.3 Percentage of total barnacles settling on and under each of the gills. (N=952). Gills numbered using the scheme of Walker (1974).

The area for each gill was calculated using the formula for a right cone ($A = \pi$ r h) with *Octolasmis spp.* abundance per gill found to be independent of gill area. (χ^2 = 36748.1, df = 5, P< 0.0001). Barnacles were found to be significantly (F=2343.7, df=3807, P<0.001) more abundant on the hyperbranchial side of gills than the hypobranchial side (Table 10.2). The proximal segments of the gills also displayed a significantly (F=66.1, df=3807, P<0.001) higher prevalence of *Octolasmis spp.* with 70.3% found on the proximal segments of the gills and only 29.7% on the distal segments.

Table 10.2 Percentage of *Octolasmis spp.* found on each segment of the gills of infested *Portunus pelagicus*.

	Proximal	Distal	Total
Hyperbranchial	1223 (2.4%)	1189 (2.3%)	2412 (4.7%)
Hypobranchial	34806 (67.9%)	14045 (27.4%)	48851 (95.3%)
Total	36029 (70.3%)	15234 (29.7%)	51263 (100 %)

The symbiotic barnacle, *Chelonibia patula* was found on the external surfaces of the carapace of 360 (37.8%) crabs. The occurrence of *Chelonibia patula* was strongly associated with the presence of *Octolasmis spp.* in the brancial chamber (χ^2= 32.784, df=1, P<0.0001). The occurrence of *Octolasmis warwickii* on external surfaces was also tested for independence with other *Octolasmis* species in the brancial chamber and also found to be dependent (χ^2= 29.442, df=1, P<.0001). In contrast the chi-square test for independence of the infestation of *C. patula* and *O. warwickii* showed that these species were independent. (χ^2 = 3.738, df=1, P=0.053).

Moult condition appeared to have an effect on the abundance of barnacles, however the low number of crabs captured in the premoult (D0 to D13) condition resulted in inflated variances and an inability to detect differences. This is most probably due to the crabs generally low catchability during ecdysis

(Sumpton *et al*. 1990). Figure 10.4 shows significantly higher abundances of juvenile *Octolasmis spp*. in the branchial chambers of post moult crabs (73.3±28), compared with crabs in the intermoult condition (36.5±5). In contrast, adult *Octolasmis spp*. were found in lower abundances in post moult crabs than intermoult, with 12.9±6 and 27.1±2 barnacles per gill chamber respectively.

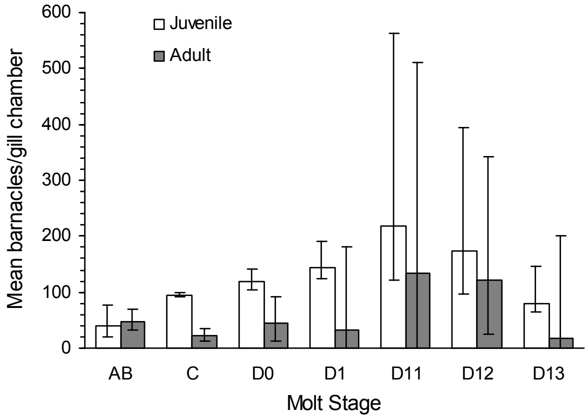


Figure 10.4 Prevalence (± standard error) of *Octolasmis spp.* in gill chambers of *Portunus pelagicus* of various moult stages.

Crabs in the intermoult stage and crabs not parasitised by *S. granifera* were analysed further using a GLM to identify any differences in infestation between areas, across seasons and between sexes. The model analysing the effect of various factors on the prevalence of "recently settled" *Octoloasmis spp.* in host gill chambers accounted for 69.8% of the variation in barnacle abundance (Table 10.3). All factors and second order interactions were found to significantly affect mean barnacle abundance (P<0.05). The covariate was also highly significant (P<0.001) with a positive relationship between carapace width and barnacle prevalence.

Table 10.3 Results of GLM analysing the effect of various factors on the prevalence of "recently settled" *Octolasmis spp*.

Factor	d.f.	s.s.	m.s.	v.r.	P.
Area	2	1808.273	904.136	621.22	<.001
Season	3	278.982	92.994	63.89	<.001
Sex	1	6.878	6.878	4.73	0.03
Area.Season	6	119.539	19.923	13.69	<.001
Area.Sex	2	9.108	4.554	3.13	0.044
Season.Sex	3	15.470	5.157	3.54	0.014
Area.Season.Sex	6	17.151	2.859	1.96	0.069
Carapace width (Covariate)	1	18.661	18.661	12.82	<.001
Residual	643	935.835	1.455		
Total	667	3209.895	4.812		

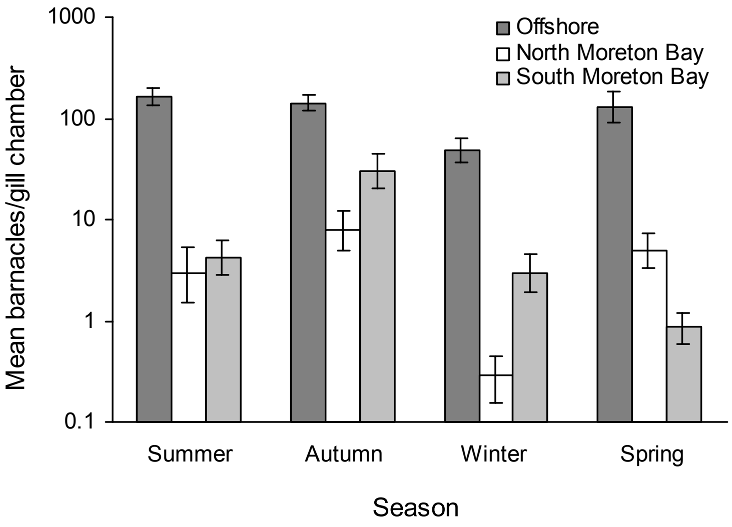
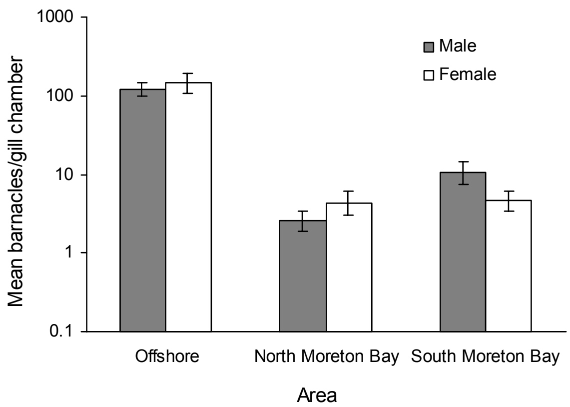


Figure 10.5 Seasonal variation in model predictions (± standard error) of "recently settled" *Octolasmis* prevalence in gill chambers of *Portunus pelagicus* from three areas in southern Queensland.

The offshore area was had significantly higher predicted mean barnacle abundances for all seasons, with the highest mean abundance of 167 (95%C.I. 203-137.0) barnacles per gill chamber occurring in summer (Figure 10.5). North and South Moreton Bay showed high intra-seasonal variation and no clear patterns, with mean abundances varying between 0.3 (95%C.I. 0.4-0.2) for North Moreton Bay in winter and 30 (95%C.I. 45.2-20.5) for South Moreton Bay in autumn. The North Moreton Bay sample for winter was significantly lower than all other seasons and areas (P>0.05) although this sample was obtained using trawl gear rather than baited pots.

Barnacle prevalence in gill chambers of male and female crabs in the offshore area was significantly higher (P<0.001) than all other areas, with 119.4 (95%C.I. 145.7-97.9) and 145.3 (95%C.I. 119.4-108.8) barnacles per gill chamber respectively (Figure 10.6a). South Moreton Bay was the only area where the symbiont prevalence between sexes was significantly different. The mean predicted barnacle abundances of recently settled *Octolasmis spp* in gill chambers by season and sex are shown in Figure 10.6b. Crabs sampled during summer and autumn had significantly higher barnacle loads than those sampled in winter. Differences between sexes were not significant (P>0.05) within any one season.

(a)



(b)

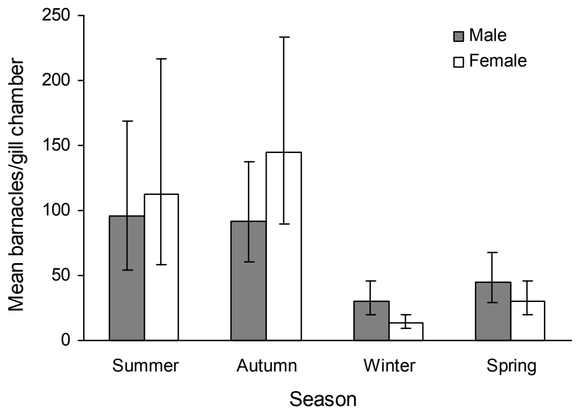


Figure 10.6 Model predictions (± standard error) of the spatial (a) and temporal (b) variation in recently settled *Octolasmis spp.* prevalence on male and female *Portunus pelagicus* in southern Queensland.

The analysis of variance table from the GLM for adult Octolasmids is displayed in Table 10.4. This model only accounted for 19.6% of the variation in barnacle abundance. Sex was the only factor which did not significantly account for variation in barnacle abundances, with all other factors and interactions significant at the 5% level of significance. The covariate was also significant with a positive relationship between carapace width and barnacle abundance existing (P<0.001).

There was a high degree of variation in adult barnacle abundances for both sexes by season and area (Figure 10.7). Males displayed a significantly lower (P<0.05) barnacle abundance in the offshore area during autumn. The North Moreton Bay area had the only significant difference within a season, with males having significantly higher (P<0.05) barnacle abundances. Females sampled in autumn displayed significantly higher abundances in the North Moreton Bay area, and males showed significantly lower (P<0.05) mean abundances during winter. Again it must be noted that this sample was obtained using trawl gear rather than baited pots. All other differences within each season were non significant. The high variation within each season precludes the detection any significant differences between seasons.

Table 10.4 Results of GLM analysing the effect of various factors on the prevalence of "adult" *Octolasmis spp*.

	d.f.	s.s.	m.s.	v.r.	F pr.
Area	2	40.198	20.099	8.81	<.001
Season	3	55.093	18.364	8.05	<.001
Sex	1	3.236	3.236	1.42	0.234
Area.Season	6	253.836	42.306	18.55	<.001
Area.Sex	2	32.193	16.097	7.06	<.001
Season.Sex	3	44.2	14.733	6.46	<.001
Area.Season.Sex	6	55.04	9.173	4.02	<.001
Carapace width (Covariate)	1	10.383	10.383	4.55	0.033
Residual	643	1466.286	2.28		
Total	667	1960.465	2.939		

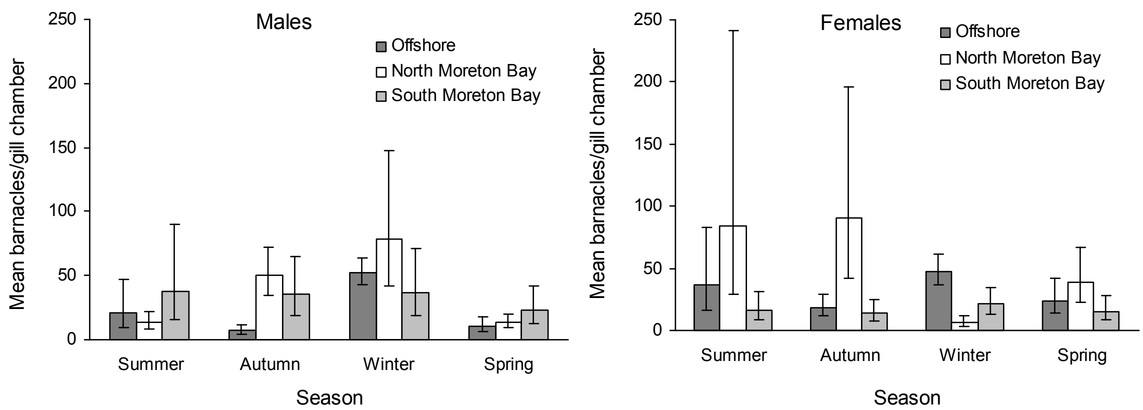


Figure 10.7 Model predictions (± standard error) of the spatial and temporal variation in adult *Octolasmis spp.* prevalence on male and female *Portunus pelagicus* in southern Queensland.

77 (12.3%) of the crabs examined were parasitised by the Rhizocephalan *Sacculina granifera.* These crabs were analysed to determine the effects of *S. granifera* on the abundance of other barnacle symbionts. Due to the lack *of S. granifera* infested crabs in offshore samples, only the crabs from North and South Moreton Bay were included in the analysis (Table 10.5). Season was not considered as a factor

in the analysis as parasitism by *S. granifera* was not represented across all seasons and areas. The statistical significances of factors from the GLMs for recently settled and adult octolasmids are shown in Table 10.6. As with prior analyses a significant relationship between carapace width and barnacle abundances exists. A significant 3 way interaction between area, sex and sacculina presence existed for recently settled octolasmids, with a two way interaction between sex and sacculina presence for adult Octolasmids.

Table 10.5 Number of *Portunus pelagicus* in samples that were infected by *Sacculina granifera*.

Area	*Sacculina* Stage	
	Not parasitised	Parasitised
Offshore	320	0
North Moreton Bay	269	43
South Moreton Bay	286	34

Table 10.6 Results of GLM analysing the effect of various factors on the prevalence of recently settled and adult *Octolasmis spp*. in branchial chambers of crabs parasitised by *Sacculina granifera*.

Factor	Recently settled	Adult
Area	**<.001**	**0.005**
Sex	0.503	0.169
Sacullina	**0.03**	**<.001**
Area.Sex	**0.047**	0.593
Area.Sacculina	0.904	0.096
Sex.Sacculina	**0.021**	**0.003**
Area.Sex.Sacculina	**0.001**	0.738
Carapace width (Covariate)	**0.029**	**0.026**

Males not parasitised by *S. granifera* displayed significantly higher adult barnacle abundances than females with 41.4 (95%C.I. 50.5-33.8) and 25.9 (95%C.I. 32.0-20.9) barnacles per gill chamber respectively (Figure 10.8). Differences between parasitised and non-parasitised females were non significant (P>0.05). Parasitised females showed the highest adult barnacle abundances with significantly higher (P<0.001) barnacle loads than both sexes unparasitised by *S. granifera* (130.0, 95%C.I. 214.9-78.8 barnacles per gill chamber).

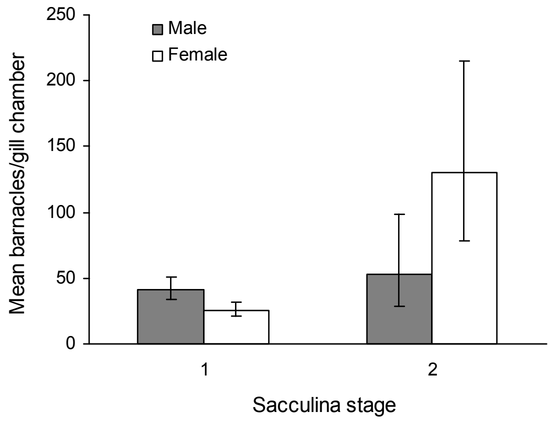


Figure 10.8 Prevalence (± standard error) of adult *Octolasmis spp.* in gill chambers of intermoult male and female *Portunus pelagicus* infested with *Sacculina granifera*. (1= not parasitised 2= parasitised).

Females in South Moreton Bay exhibited the only significant difference ($P<0.001$) between parasitised and unparasitised crabs from the same area (Figure 10.9). Parasitised females in this area had significantly higher recently settled *Octolasmis spp.* loads at 19.3 (95%C.I. 38.4-9.7) barnacles per gill chamber compared with a mean of 5.1 (95%C.I. 6.6-3.9) for unparasitised females.

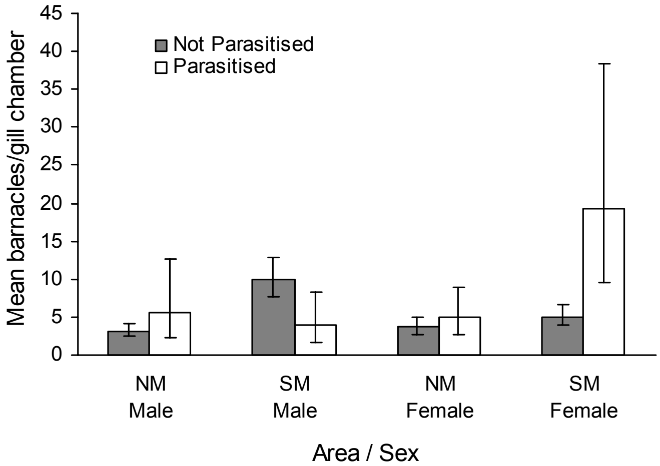


Figure 10.9 Spatial variation in the prevalence (± standard error) of recently settled *Octolasmis spp.* in gill chambers of parasitised and non-parasitised *Portunus pelagicus.* NM = Northern Moreton Bay, SM = Southern Moreton Bay.

Discussion

The blue swimmer crab *Portunus pelagicus* from areas around Moreton Bay, displayed a markedly higher prevalence (92%) of *Octolasmis spp.* than the rates reported by Gannon (1990) for the blue crab *Callinectes sapidus* (40%), Shields (1992) for *Portunus pelagicus* (70.2%) and Walker (2001) for the swimming crab *Charybdis callianassa* (63.5%). *Portunus pelagicus* exhibited comparable distributions within crabs to those reported for *Callinectes sapidus* by Walker (1974) and Jeffries and Voris (1983). In the present study *Octolasmis spp*. were more likely to settle in ventilated locations. In *Portunus pelagicus*, as with *Callinectes sapidus* higher concentrations were found on gills 3, 4 and 5. The proximal segment of the hypobranchial side of each gill displayed the highest concentration of barnacles, with the distal segment on hyperbranchial side having the lowest settlement. This distribution on each gill correlates well with the ventilatory flow through the branchial chamber. On entering the inhalant aperture, the water generally takes a U shaped route through the branchial chamber. This route starts at the inhalant aperture, moves posteriorly into the hypobranchial part of the chamber, then dorsally between the gill lamellae. Exhalent current flows anteriorly in the dorsal area of the branchial chamber to the exhalent aperture (Barnes, 1974).

The distribution of *Octolasmis spp.* in the branchial chambers of *P.pelagicus* is similar to that found in the blue crab *Callinectes sapidus* by Walker (1974). However, *Portunus pelagicus* displayed a higher relative frequency on gills 1 and 2, with 10.9% and 12.8% respectivley. This can be explained when one considers that Walker (1974) only included the barnacles on the ventral side of the gills. Walker (1974) states that due to the close opposition of gills, cyprid larvae are unlikely to be able to pass through the lamellae of the gills to the hyperbranchial side. Settlement on the hyperbranchial side of the gills can therefore only occur when respiratory flow is reversed. Reversal of flow is thought to occur during and after burrowing as a means of cleaning the gills and branchial chamber. (Barnes 1974)

The moult stage of crabs displayed trends of higher abundances in later moult stages similar to that found by Shields (1992) but the low number of crabs representing several moult stages precluded any conclusions being drawn. The presence of both juvenile and adult *Octolasmis spp.* in post moult crabs indicates a rapid settlement and growth rate of symbionts. This follows the settlement mechanism found by Jeffries *et al.* (1989) in which cyprids on the mud crab *Scylla serrata* were found to transfer from the exuviae to the newly moulted crab.

The symbionts *Chelonibia patula* and *Octolasmis warwickii* were found to have preference for the same hosts as the *Octolasmis spp*. found in the branchial chamber. These three symbionts do not share the same microhabitat, with *Chelonibia patula* and *Octolasmis warwickii* settling only on the external surfaces. Gannon (1990) identified 4 mechanisms that would make a crab an ideal host and possibly result in the co-occurrence of these species. Host infrequency of moulting, greater settlement area of the host, host reduced resistance to harmful effects after settlement by one species, and the planktonic larvae of the barnacle species completing development and settling in the same areas. It is unlikely that settlement by an external barnacle would result in a reduced resistance to settlement by *Octolasmis spp*.. Host infrequency of moulting and greater settlement area can not be treated as separate functions as they display a large degree of colinearity with larger crabs observed as having longer intermoult periods, thus moulting less frequently (Sumpton *et al.* 1994). The co-occurrence of these species is most likely a function of host size and the larval ecology of the barnacle species. The varied nature of host activity would account for settlement of larvae from more than one species, however it is improbable that the larvae complete development and settle in the same areas.

The abundance of *Octolasmis spp.* per branchial chamber displayed a marked spatial distribution. The offshore area was found to have significantly higher barnacle loads in all seasons for both sexes. This trend was only evident for newly settled Octolasmids, with adult Octolasmids not showing any marked patterns with respect to area, season or sex. Jeffries and Voris (1996) noted that markedly higher abundances of Octolasmids are found on crabs from areas that exhibit higher than natural densities. One might therefore hypothesise that variance in barnacle abundance may correlate with population densities at a given location. This study supports this hypothesis when one considers the generally higher catch rates in the offshore area compared to both the areas within Moreton Bay (Sumpton *et al.* 2000). The lack of any clear pattern with respect to the adult Octolasmids is perhaps due to the fact that only crabs with longer intermoult periods are likely to have high loads of adult symbionts.

Based on the results of this study, the potential for using symbiont load for stock discrimination in *Portunus pelagicus* is somewhat limited. The differences observed between offshore and Moreton Bay areas were significant, however the within area variance was high, reducing the accuracy of any predictions. Any further work in this area should consider the species composition between the areas, with at least 5 species from the genus *Octolasmis* known to settle on *Portunus pelagicus* (Jeffries *et al.,* 1982).

An infestation rate of 12% for *Sacculina granifera* was consistent with Shields (1992) and comparable with Sumpton *et al*. (1994) who found an infestation rate of 7% in males and 12.3% in females. The nature of *Sacculina granifera* whose infection inhibits moulting in *Portunus pelagicus* (Phillips and Cannon, 1978), subsequently increases the intermoult period, making infected crabs an ideal host for symbiotic barnacles. In the present study only female crabs infected by *Sacculina granifera* exhibited higher barnacle abundances. This higher barnacle abundance for females parasitised by *Sacculina granifera* may reflect the different habitat preferences of females (Sumpton *et al.* 1989). These results contrast with those of Phillips and Cannon (1978), who found noticeably more thoracic barnacles and slightly more stalked barnacles in crabs infected by *Sacculina granifera*.

The effects of infestation by *Octolasmis muelleri* on gas exchange in the blue crab *Callinectes sapidus* was assessed by Gannon and Wheatly (1992) who found that high infestation rates caused physiological stress on the host. Crabs with massive infestation did not survive the stress of experimental handling, and displayed a higher incidence of experimental mortality when subjected to aerial exposure and elevated temperatures. (Gannon and Wheatly, 1988). The prevalence of *Octolasmis* in the present study is higher than that of Shields (1992) who found a prevalence of 70.2% for crabs captured exclusively in the area adjacent to the North Moreton Bay region sampled in this study. Gannon (1990) found infestation rates of between 0 and 224 *Octolasmis muelleri*, and described heavy infestation as greater than 50 barnacles per crab. This contrasts with the present study in which over 64% of the crabs had more than 50 per barnacles per crab (25 per branchial chamber). Although the present study used larger experimental crabs than Gannon (1990), the high barnacle load on *Portunus pelagicus* may potentially cause high mortality for crabs that are stressed in other ways. This could be particularly relevant for commercially caught crabs harbouring heavy barnacle loads. Such crabs that are stressed during handling may suffer high rates of post discard mortality thereby adversely impacting on the fishery.

Parasitism of blue swimmer crabs by *Sacculina granifera* and *Ameson sp*

Introduction

As mentioned earlier there are a number of parasites that affect blue swimmer crabs in Queensland but the main two that impact on the population are the rhizocephalan barnacle *Sacculina granifera* and the microsporidian *Ameson sp*. Microsporidians have been known to cause mortalities of the portunid crab *Callinecthes sapidus* in North America (Overstreet, 1978) and have been recorded in *Portunus pelagicus* in Queensland (Shields 1992, Sumpton 1994) during the 1980's. Consumers of sand crabs often complain about "mushiness" of some cooked crabs that have dry, fibrous muscle tissue and are unpalatable. Cooked microsporidian infected crabs likewise have muscle tissue which is very dry and fibrous due to degeneration of muscle tissue caused by the microsporidian. Although mushiness has been linked to poor handling and cooking practises (Slattery *et al*. 1989) severe microsporidian infection can also cause this condition. Previous studies have shown that the prevalence of the microsporidian can be over 2% in some areas. Considering that over two million crabs are caught and marketed each year in Queensland, the infection prevalence is cause of some concern to fishers, processors and the general public, particularly since infection cannot be readily determined by external examination alone.

Sacculina granifera, infects the commercial sand crab, *Portunus pelagicus* in Australian waters and infection rates in some areas of Queensland can be as high as 30% (Thomson, 1951; Sumpton *et al.* 1994). Ecological studies on *S. granifera* in Australia have been generally limited to the waters of Moreton Bay and there are few reports of infection from elsewhere in Australia. Weng (1987) compared abdominal morphology and sex ratios of infected and uninfected crabs, and contrasted temporal infection patterns in central Moreton Bay and the Gulf of Carpentaria. He found large numbers of crabs bearing externae were found in both areas with no difference in prevalence between sexes. The parasite, in the later stages of its infection of a crab eventually causes sterilisation and there have been concerns about the impact of the parasite on egg production given the high prevalence of *Sacculina* in some areas. Unlike the microsporidian, later stage *Sacculina* infection is readily detectable and also does not have as great an influence on the marketability of the crab because it has little direct influence on the crab's flesh. It is only crabs that have been infected for a relatively long time and have therefore not moulted for an extended period which tend to have flesh that is distasteful.

Any increase in the prevalence of either parasite, however, clearly poses a significant risk both to the viability of the population and to the continued successful marketing of the product. This chapter examines changes in the rates of infestation of blue swimmer crabs by these parasites since research carried out during the 1980's. Additional information on the spatial distribution and prevalence of parasitic infestation from areas only recently fished is also highlighted and likely impacts of the parasite on the population are discussed.

Materials and Methods

Male and female crabs collected throughout the commercial fishery-sampling program were examined for externae of *Sacculina granifera*, which were defined as immature sacs (sacs < 25 mm breadth, mantle opening not fully developed) or mature sacs (sacs > 25 mm breadth, mantle opening well developed). Male crabs without an externa but with a modified abdominal flap indicating the presence of an interna were also noted. The prevalence of scarred individuals (i.e. from a dislodged externa) was also recorded.

Thoracic muscle tissue and internal organs of each sampled crab were also examined macroscopically for evidence of microsporidian infection. Externally, infected crabs appeared normal and displayed no signs of infection but flesh of microsporidian infected crabs lost its normal translucent appearance and took on a white grainy texture. Microscopic observation of this white muscle tissue revealed that numerous microsporidian spores had invaded striated muscle cells. In addition to this marked muscle necrosis, infection by *Ameson sp.* often caused the haemolymph to take on a milky appearance and lightened the colour of the hepatopancreas and female gonad. These were the main features used to distinguish microsporidian infected crabs from normal crabs.

Results

The prevalence of *Sacculina granifera* infection of female crabs caught by commercial pot fishers varied dramatically among areas and years (Figure 10.10). This analysis included all female crabs that were caught in pots and demonstrated that at times the rates of infection among females can be high (over 20%). Sampling of crabs was not undertaken in Hervey Bay until 1999 and there was incomplete sampling in all areas except south Moreton Bay during 2001. There was no significant difference (P>0.05) in the prevalence of the parasite in Hervey Bay and Moreton Bay but the offshore areas of Bribie to Fraser Island had a significantly lower prevalence of the parasite than either of the embayment fisheries. During 1985 and 1986 *Sacculina* was present in up to 3% of crabs in the Bribie to Fraser area but in none of the sampling periods in the 1990s did the prevalence exceed 1% in this area. North Moreton Bay was the only area that displayed a significant long-term temporal change in parasite prevalence with rates increasing dramatically in 1998 to over 15% of the catch.

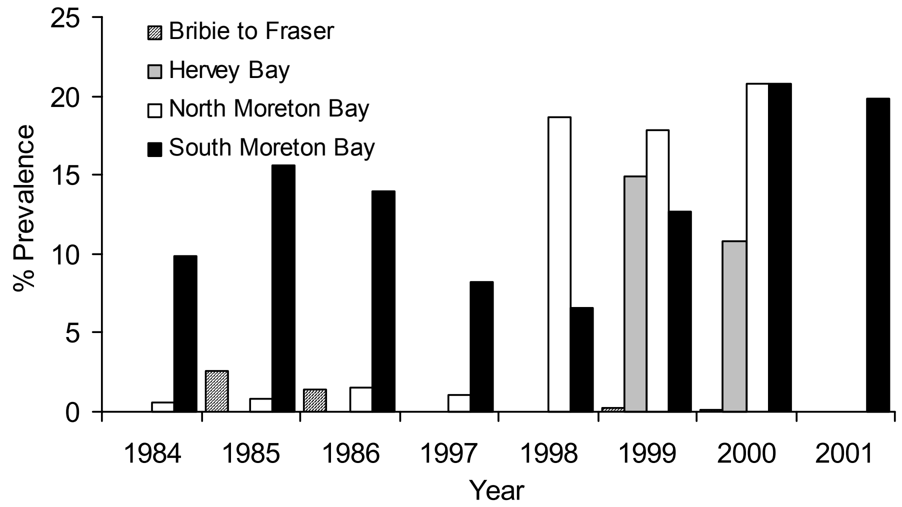


Figure 10.10 Change in prevalence of *Sacculina granifera* infecting female blue swimmer crabs caught in pots from several areas in SE Queensland.

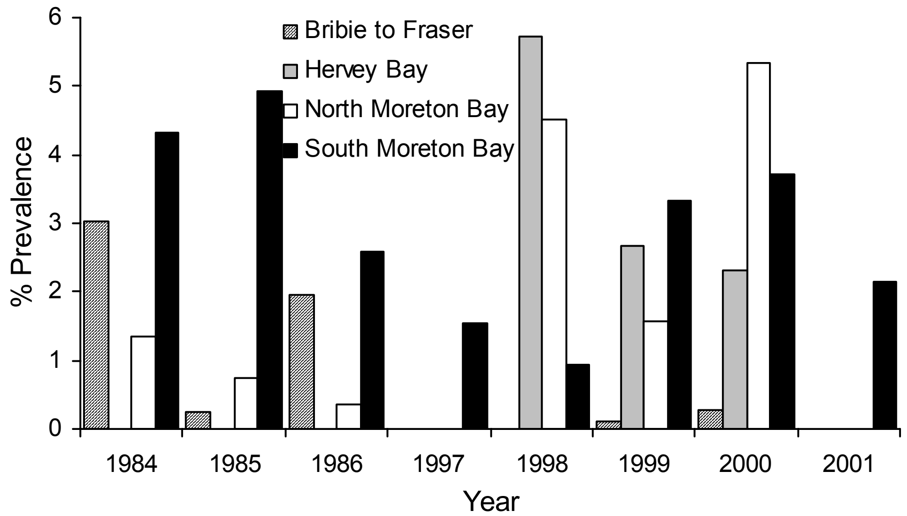


Figure 10.11 Change in prevalence of *Sacculina granifera* infecting male blue swimmer crabs caught in pots and marketed from several areas in SE Queensland.

The prevalence of *Sacculina granifera* in male crabs that were retained by commercial pot fishers was significantly less than for females with rates generally being half those of females (Figure 10.11). Like females, the spatial patterns of highest infection rates were in the embayments of Hervey Bay and Moreton Bay.

Microsporidian infection was still a feature of the crab population with *Ameson sp*. found in crabs from all areas and the overall infection rate was 0.84% for males and 0.64% for females.

Discussion

Sumpton (1994) noted 29 of a total 3189 (0.91%) adult males and 12 of 2295 (0.52%) adult females caught using trawls in Moreton Bay during 1985 and 1986 were infected with microsporidians. Infection prevalence appeared higher during summer and autumn although sample sizes were too small to enable statistical analysis of seasonality in prevalence. By comparison, 21 of 4278 (0.49%) adult females caught in commercial pots were infected. The similarity in female prevalence rates for pot caught and trawl caught crabs suggests that catchability is not affected by parasitic infection, that is, an infected female crab will have the same probability of capture in pots as an uninfected crab. The rates determined during the most recent period of sampling (1997 to 2001) are also similar to historic rates, although again there is considerable spatial and temporal variation. Shields (1992) also examined 205 *P. pelagicus* during March, April, May, September and November, 1989 and found 2.9% of these were infected with *Ameson sp.* The difference in prevalence rate between the different studies is within expected limits given the differences in sample sizes and temporal sampling regimes. For example, samples from some months during the present study and that of Sumpton (1994) had prevalence rates exceeding 2%.

The sampling of slightly different areas during the 1980s and more recently, may complicate the detection of long-term temporal changes in infection rates. The Bribie to Fraser samples collected during the 1980s were taken from the waters just outside Moreton Bay because the fishery had not expanded into more remote offshore waters further north. However, by the 1990s fishing effort had spread to the areas further north in more open ocean conditions. It is clear that *Sacculina* prefers estuarine conditions as demonstrated by the higher prevalence in southern Moreton Bay. Large-scale temporal differences in infection rates that appear also to be most noticeable for northern Moreton Bay probably also reflect small-scale spatial variations in sampling intensity. Parasitism by *Sacculina* is known to vary dramatically over both small temporal and spatial scales (Sumpton *et al.* 1994). Fishers targeting male crabs tend to avoid areas that have high rates of infection of these marketable crabs. During 1998, 1999 and 2000 some samples were obtained from fishers who were fishing in different areas than had previously been sampled thereby biasing some of the rates of infection.

The lack of large numbers of crabs parasitised by *Sacculina granifera* in oceanic waters may indicate that these areas are not heavily reliant on recruits from the embayment areas but it is equally likely that parasitised crabs may not migrate to these areas due to behavioural modification which may tend to keep individual within the Bays. Such a mechanism has been described for *Carcinus maenus* by Rasmussen (1959). Studies of parasites of the blue swimmer crab therefore do not provide definitive data for determining the importance of recruitment to offshore areas by embayment stocks. The data do however show that prevalence in the offshore fishery is lower, with less potential impact on the market than crabs caught from inshore areas.

11. FISHERY INDEPENDENT SURVEYS

Introduction

There are increased requirements to ensure ecological sustainability of fisheries and one of the aims of this current research was to develop a protocol for the long term monitoring of the blue swimmer crab resource. The fact that recreational pot fishers as well as trawl and commercial pot fishers harvest the resource complicates the use of fishery-dependent catch and effort data as a monitoring tool. This is partly because the accuracy of commercial catch and effort records has already been questioned (See Chapter 5). While there is regular assessment of the catch and effort in the recreational sector there is no information collected about size structure of the recreational catch, and effort estimates are imprecise because they rely on daily estimates of effort only. This fishery is also susceptible to changes in the catch share taken between sectors making it difficult on a long-term basis to get accurate estimates of total catch and effort for many areas of the fishery. The exception to this is in the offshore areas outside Moreton and Hervey Bays. In these areas the recreational catch of blue swimmer is insignificant as demonstrated by the lack of blue swimmer crabs in boat ramp surveys of offshore recreational fishers (Sumpton 1999).

This chapter describes the results of five fishery independent surveys of blue swimmer crab stocks. Each survey is used to address different issues about densities and relative abundance of either juvenile or adult blue swimmer crabs. Two of the surveys were designed specifically to address objectives relevant to blue swimmer crabs and were funded as part of this project. However, staff on this present project were involved in the development of two of the three other surveys.

Materials and Methods

Annual Trawl Survey of Scallop Fishery (1997 to 2000)

The scallop fishery survey uses trawl gear to sample a large number of sites (over 400) throughout an extensive area off the central Queensland coast where both scallops (*Amusium ballotti*) and blue swimmer crabs (*Portunus pelagicus*) are landed in large numbers by commercial trawlers. One of the objectives of the surveys is to provide an annual index of relative abundance.

Full methods of the first survey (conducted from 5 to 16 October 1997) can be found in Dichmont *et al*. 2000. Essentially over 400 randomly allocated sites are surveyed using 20-minute trawl shots over a ten-day period. The design in subsequent years has largely remained the same apart from two of the four vessels each year being replaced with other commercial vessels. Two of the four vessels used each year have thus been the same for all surveys and calibration experiments have been undertaken each year immediately prior to the survey to calibrate for differences in relative fishing power among vessels. Changes in vessels' relative fishing power during the survey period (usually 10 days) could not be investigated because the geographical extent of the survey meant that vessels were too widely separated (over 100 nautical miles in some cases) throughout most of the survey to allow for side-by-side calibration experiments. The same vessel (15m commercial trawler, *Sea King*) has been used each year in the southern end of the survey region, which is where catch rates of blue swimmer crabs are generally highest, and which is the major focus of the blue swimmer crab analysis. During these surveys all blue swimmer crabs were sexed, measured and ovigerous females noted.

Otter Trawl Survey of Inshore Habitat in Southern Queensland (October 1999)

A trawl survey was conducted as part of a research project investigating the recruitment of eastern king prawn recruits between October 1999 and November 1999. The survey was designed to sample the known spatial distribution of eastern king prawn recruits in southern Queensland and in doing so also covered a large part of the known habitat for juvenile blue swimmer crabs (See Sumpton *et al*. 1994). Five broad geographic areas were sampled; the Wide Bay Bar region off southern Fraser Island, Moreton Bay, and inshore waters adjacent to the east coast of Moreton Island, North Stradbroke Island and South Stradbroke Island (Figure 11.1). A commercial prawn otter trawler, (*Elizabeth G)* fitted with two 3.5-

fathom "Yankee Doodle" trawl nets made from 9-ply was used throughout the survey. The port side net had a mesh size of 1 ¼" while the starboard net mesh size was 1 ½". Sampling stations were 1 nautical mile long and their precise location was determined (using DGPS) prior to the survey commencing. Each of the five areas was stratified into two or three depth strata, with at least 5 sampling stations within each depth/area strata (Figure 11.1). Bottom water temperature, surface salinity and depth were recorded at each sampling station. Crabs were sorted from the catch and frozen prior to being returned to the laboratory where the sex, moult stage and carapace width of blue swimmer crabs and three spot crabs (*Portunus sanguinolentus*) were recorded.

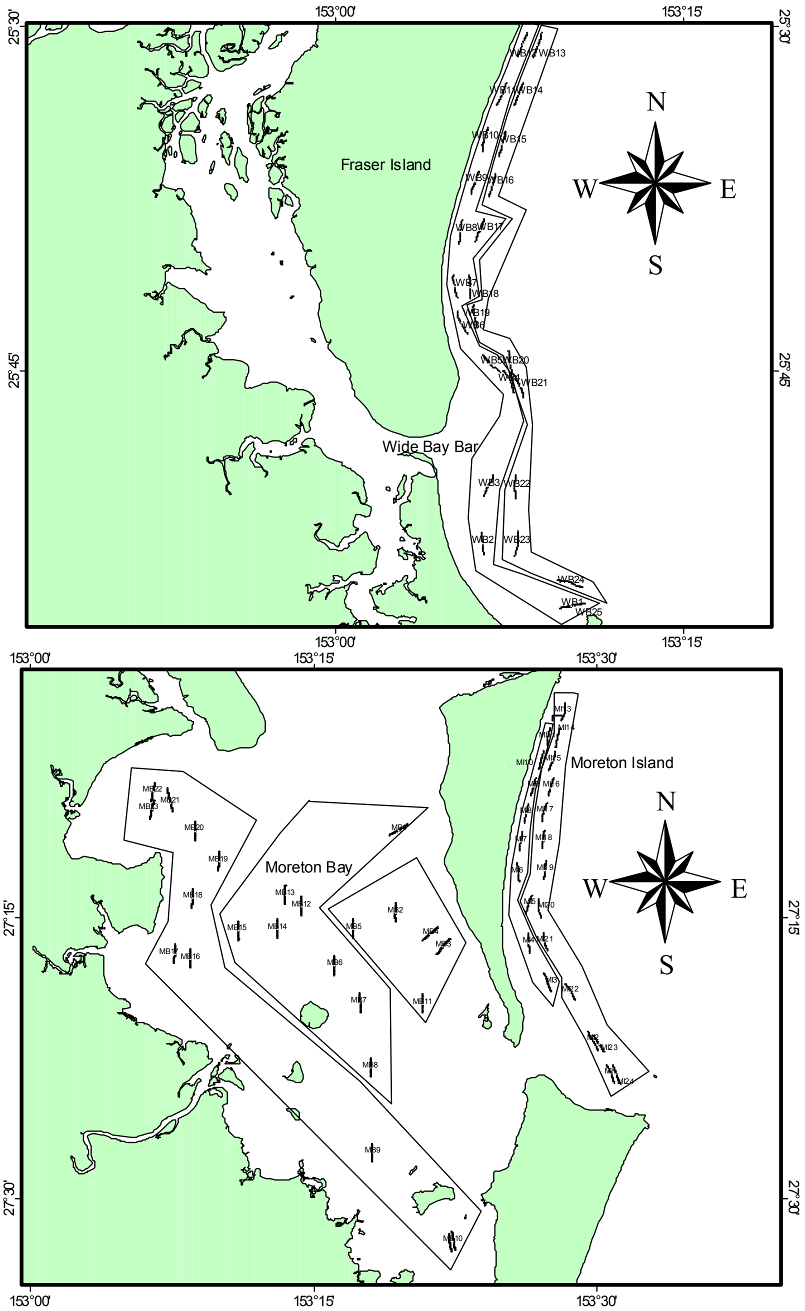


Figure 11.1 Location of 115 one-nautical mile transects along the southeast Queensland coast. The 5 areas sampled were the Wide Bay Bar, Moreton Bay and areas east of Moreton Island, North Stradbroke Island and South Stradbroke Island. (Cont'd next page)

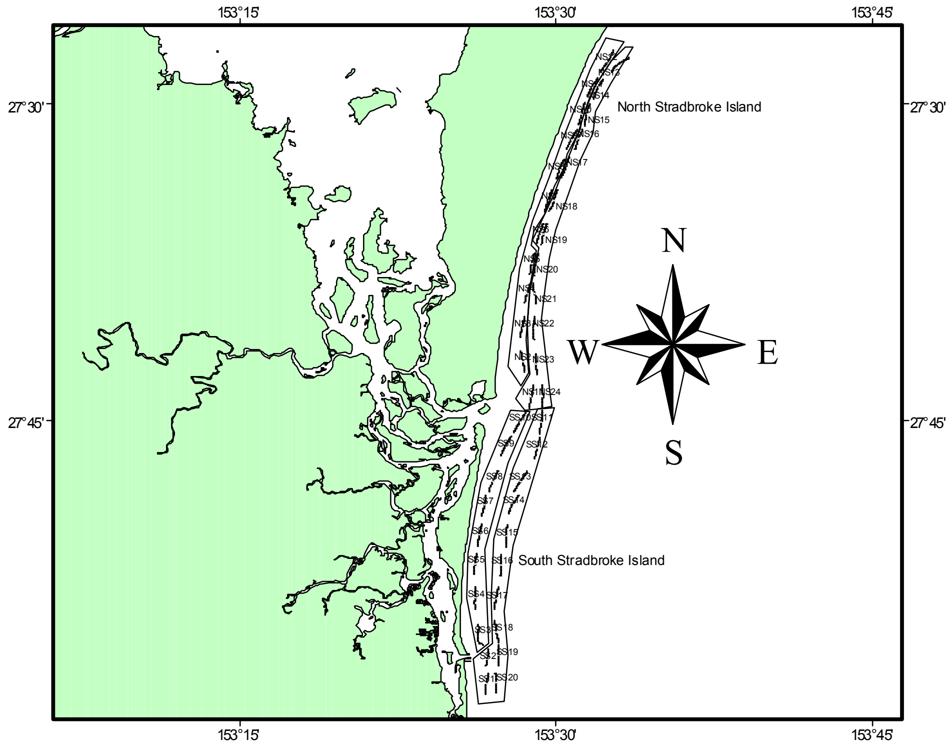


Figure 11.1 (Continued from previous page).

Beam Trawl Surveys of Peel Island, Deception Bay and Great Sandy Straits

Monthly samples of blue swimmer crabs were obtained from 24 one-nautical transects in the Great Sandy Straits (a narrow stretch of water between Fraser Island and the mainland) and Moreton Bay (Figure 11.2). Each transect was sampled at night once each lunar month as close as possible to the new moon phase for two consecutive years (1997 and 1998). Sampling gear consisted of a 5 m beam trawl with a 3.5 fathom "Yankee Doodle" net with 1¼" mesh towed behind a 6 m outboard-powered vessel (*RV Nautilus)*. A bycatch reduction grid was fitted to the net to reduce retention of large rays, sharks, turtles and jellyfish. Each transect was located and sampled using a differential global positing system (DGPS) to maximise the precision of the trawl. Surface water temperature, salinity and depth were recorded for each trawl.

Survey of Moreton Bay for Juveniles (February 2000 and 2001)

The surveys of juveniles in Moreton Bay were intended to provide information on the spatial variation in juvenile blue swimmer crab abundance within the Bay.

Two surveys were conducted in Moreton Bay during February 2000 and 2001. Each year a total of 100 randomly selected sites in Moreton Bay were sampled using beam trawls towed behind a 14m research vessel RV Warrego. Trawl gear consisted of a 9-ply polyethylene 3.5 fathom "Yankee Doodle" net with 1" mesh attached to a 5m-beam trawl. Surveys were conducted at a time when juvenile crabs were known to be most abundant in the trawl catch (Sumpton *et al.* 1994). All trawling was conducted at night over a fixed distance (1 nautical mile) at a speed of approximately 2 knots. No attempt was made to assess catchability of crabs to the gear and thus density estimates are relative density estimates only. At the completion of each trawl blue swimmer crabs were sexed, measured and assessed for maturity, parasitism and molt stage.

Fortnightly Beam Trawl Survey of Juveniles

In order to assess the short-term temporal variability in the relative abundance of blue swimmer crab juveniles, a beam trawl survey of the shallow western areas of Moreton Bay was undertaken between December 1999 and January 2001. Initially 12 stations were sampled in pairs both inside and outside permanent trawl closures. However, as there were no significant differences in relative abundance inside and outside of the closures, six of the sites were deleted after 6 months and a further 6 sites covering deeper areas of Moreton Bay were included. Sampling gear and protocols were identical to those used during the large-scale spatial surveys in February 2000 and 2001 (see previous section).

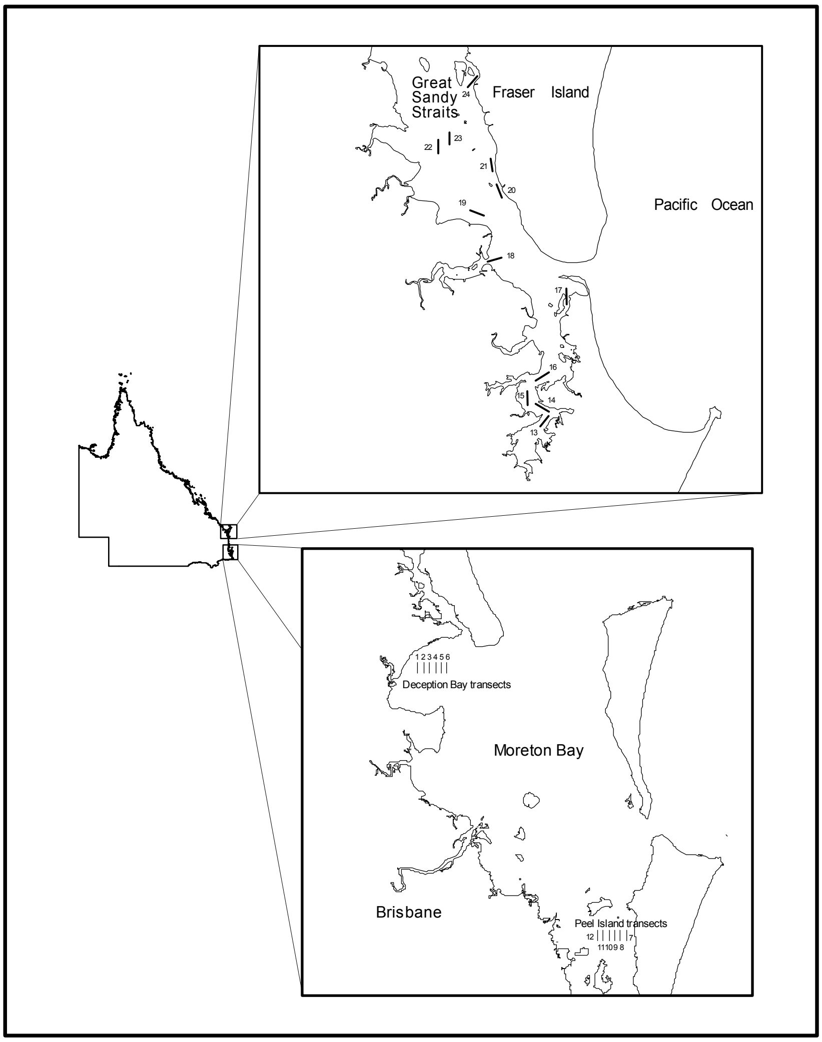


Figure 11.2 Transects surveyed monthly for blue swimmer crabs using beam trawl during 1998 and 1999.

Results

Annual Trawl Survey of Scallop Fishery (1997 to 2000)

A post hoc power analysis on crab density data collected from four years of scallop survey data was performed on catches in Grid V32 as this was the area with the highest densities of blue swimmer crabs and was the area with the largest reported trawl catch. Survey catch data consisted of the number of crabs caught per trawl. This was standardised to a relative density estimate as the number of crabs per square metre (i.e number of crabs/(net width (m)*trawl distance(m)).

Densities were transformed [Log(x+0.0001)] to normalise the data and the following response variables were included:- females (non-gravid), females (gravid), females (combined), males, and all crabs. One-way ANOVAs with year as a treatment effect were performed to obtain an estimate of variance (Table 11.1).

Table 11.1 Variance estimates of different response variables based on one-way ANOVA.

Response variable	Variance estimate	Transformed mean (original)	Error d.f
Females	0.3147	-8.095 (0.000266)	168
Females (gravid)	0.2241	-8.614 (0.000123)	168
Females (combined)	0.3727	-7.851 (0.000389)	168
Males	0.3354	-8.114 (0.000263)	168
All crabs	0.4419	-7.445 (0.000652)	168

Table 11.2 Number of samples required to detect a decline in relative abundance with 80% power at the 5% significance level. Two-sample test with one-tail significance. Standard deviation is based on stratified estimate of variance taken from a one-way ANOVA with year as treatment effect.

% change	Females (gravid)	Females (non-gravid)	All Females	Males	Males and Females
5	1054	1480	1752	1577	2077
10	250	351	416	374	493
20	57	79	94	85	111
25	35	48	57	51	67
30	23	32	37	33	44
variance	0.4734	0.5610	0.6105	0.5791	0.6648

The number of samples required to achieve the stated power assumes that the variance remains unchanged (i.e. that sample variance is a reasonable estimate of the population variance) (Table 11.2). Caution should be exercised when noting the low numbers of samples required to detect changes greater than 20%, as variance estimates may vary. Also note that the power test assumes that there are equal replicates in both samples.

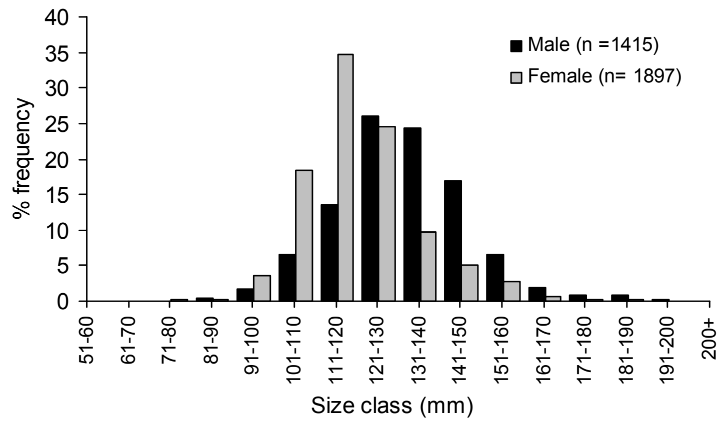


Figure 11.3 Size frequency of male and female blue swimmer crabs sampled during the 1999 scallop survey.

The small mesh size used during the survey would have normally sampled very small juvenile blue swimmer crabs (<50 mm CW) if they were present on the grounds but in no year were large numbers of immature crabs (< 110mm CW) sampled (Figure 11.3). Overall the results indicate that the current design (which samples approximately 70 sites in grid V32) would be able to detect between a 25% and 30% decline in relative abundance.

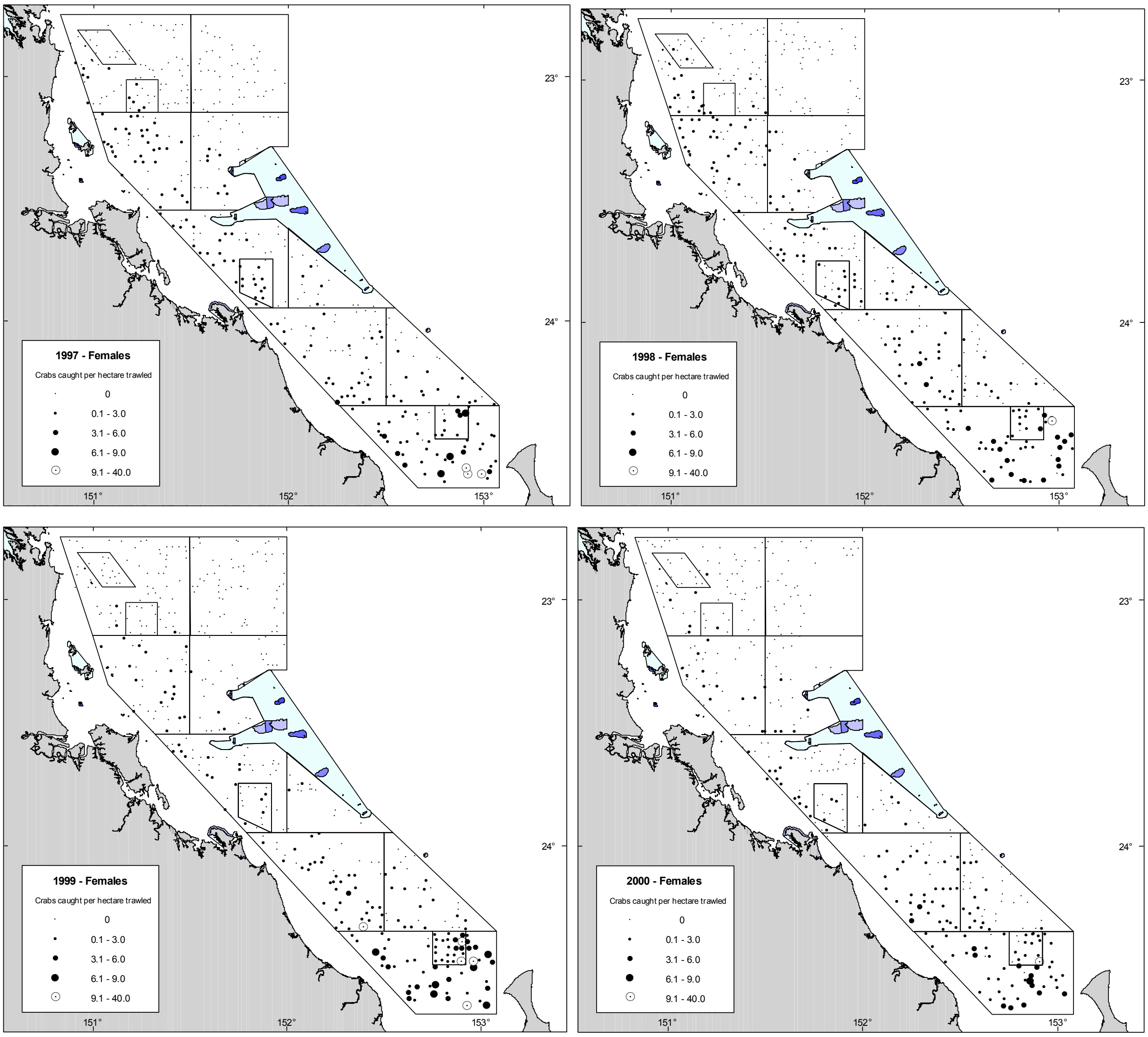


Figure 11.4 Relative density of female blue swimmer crabs (*Portunus pelagicus*) during annual surveys of scallops between October 1997 and 2000.

Densities of female *Portunus pelagicus* were found predominantly in the southern grids of the survey area and were rarely sampled in deep water in the north-eastern grid in any year (Figure 11.4). The spatial patterns were consistent from year to year although density was lowest during the 2000 survey. The pattern for ovigerous females (Figure 11.5) was similar to that of all females suggesting that there may be no unique spawning grounds in this region.

Males were likewise most abundant in the southern end of the survey region in all years sampled (Figure 11.6).

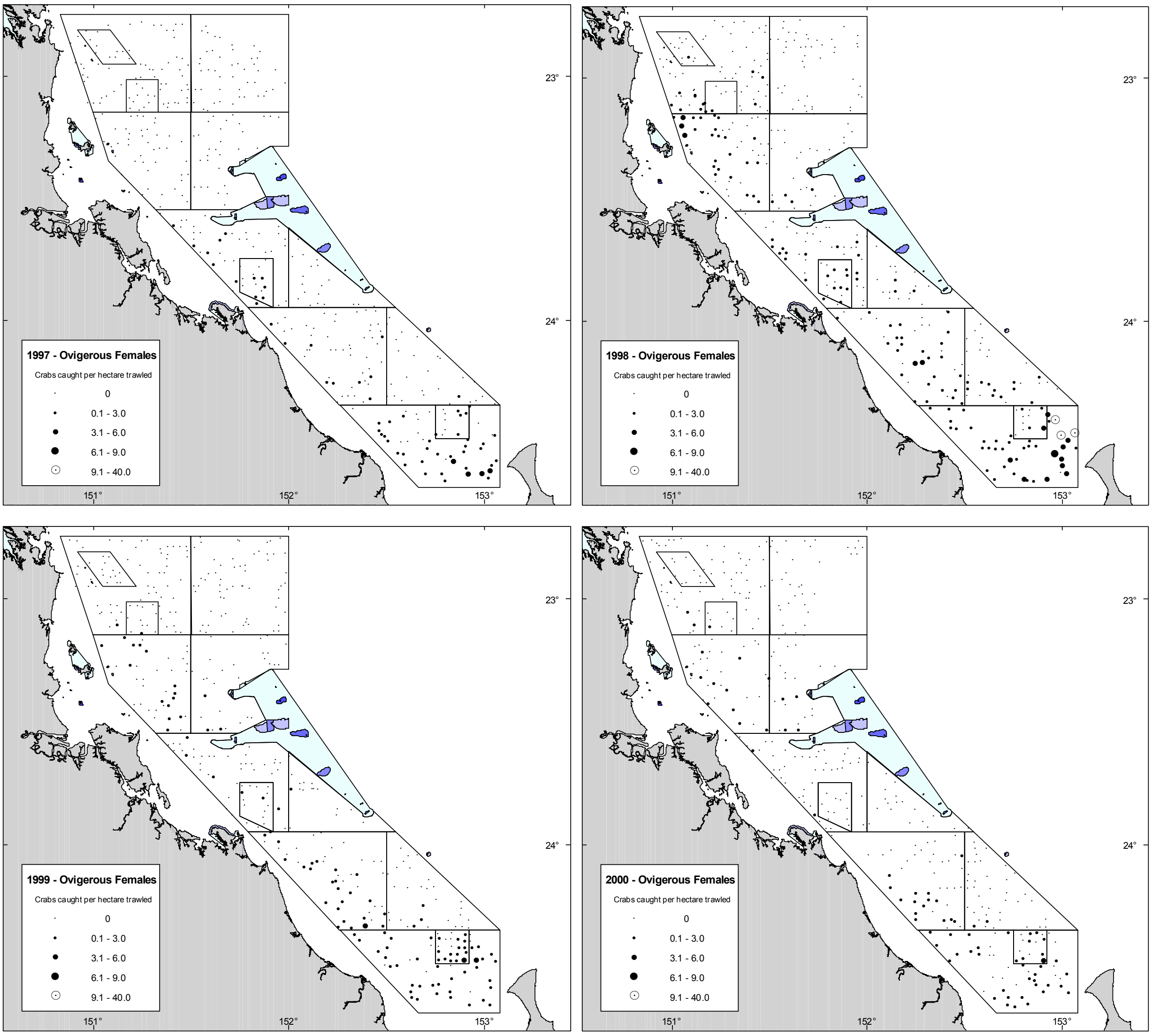


Figure 11.5 Relative density of ovigerous female blue swimmer crabs (*Portunus pelagicus*) during annual surveys of scallops between October 1997 and 2000.

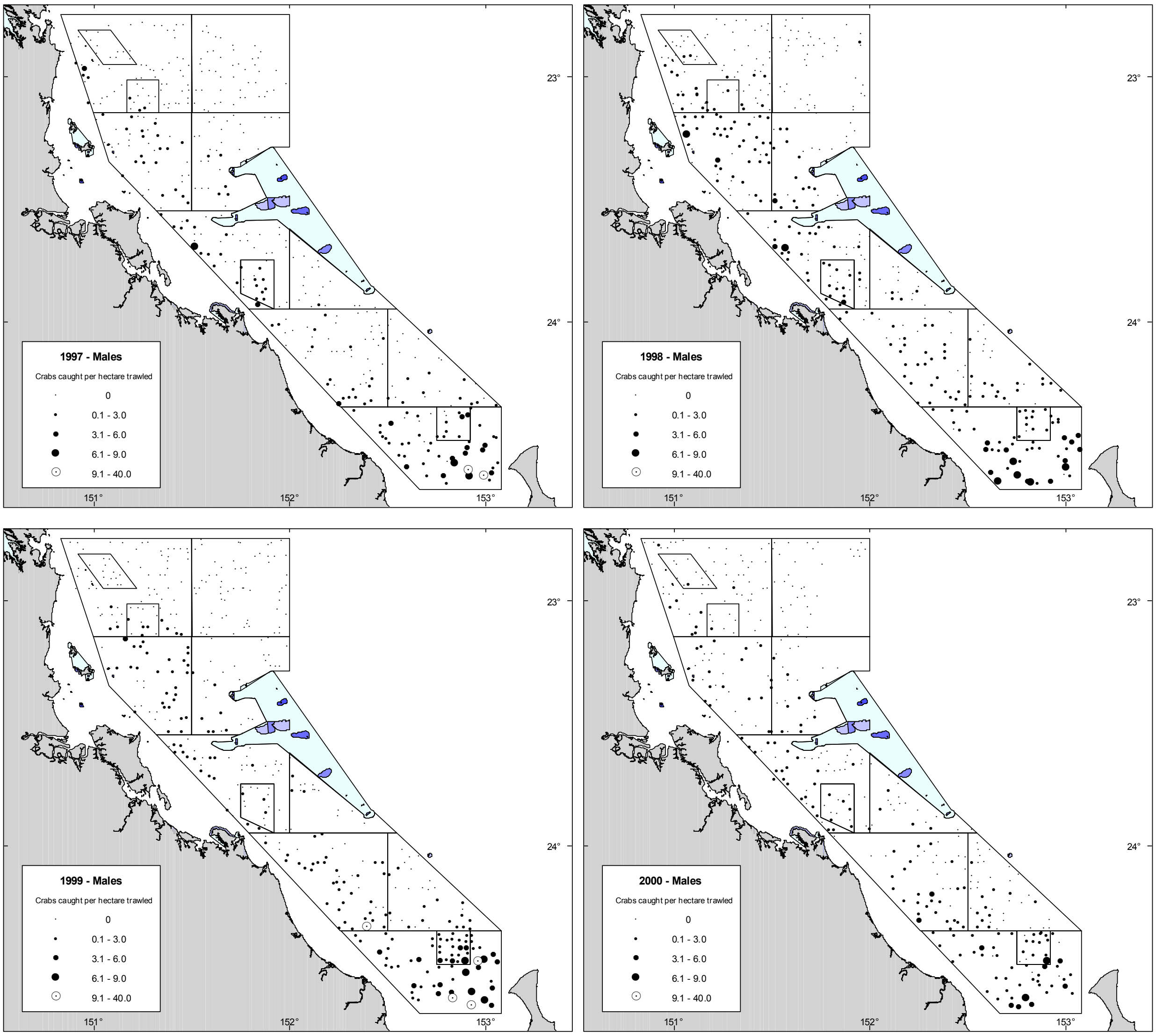


Figure 11.6 Relative density of male blue swimmer crabs (*Portunus pelagicus*) during annual surveys of scallops between October 1997 and 2000.

Otter Trawl Survey of Shallow Habitat in Southern Queensland (October 1999)

Females of both species (*P. pelagicus* and *P. sanguinolentus*) outnumbered males in the catch in most areas sampled apart from Moreton Bay where the sample size of *P. sanguinolentus* was very small (9 crabs). Overall the ratio was more biased towards females for *P. pelagicus*.

Table 11.3 Sex ratios (ratio of males to total crabs) of blue swimmer crabs and 3 spot crabs sampled from shallow water habitat in southern Queensland. (NR – 3 spot crabs not recorded)

Species	North Stradbroke	South Stradbroke	Moreton Island	Moreton Bay	Wide Bay
P.pelagicus	0.43	0.35	0.26	0.43	0.50
P. sanguinolentus	0.25	0.44	0.45	1.00	NR

The two species had a contrasting distribution pattern with blue swimmer crabs the most abundant of the two in the estuarine environment of Moreton Bay. Three spot crabs were the most abundant species in the oceanic environment outside Moreton Bay, particularly at the southern end of the survey region (Figure 11.7).

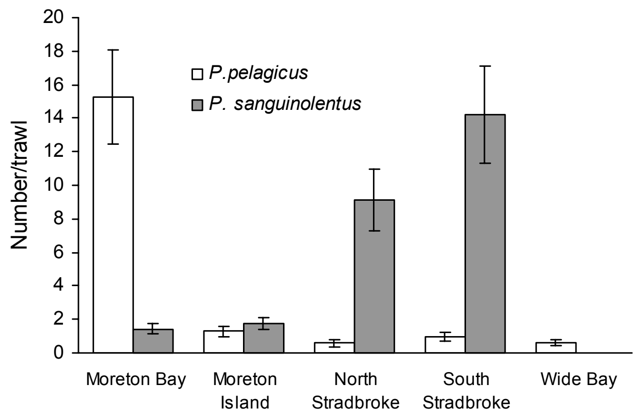


Figure 11.7 Abundance of blue simmer crabs and three spot crabs caught from five regions in southern Queensland during fishery-independent trawl sampling in October 1999.

When the four sampled areas outside Moreton Bay were pooled the main size trends were for a significantly higher proportion of juvenile (<110 mm) blue swimmer crabs to be sampled in Moreton Bay compared with more oceanic conditions outside the Bay (Figure 11.8). There were too few juvenile or adult three spot crabs sampled in Moreton Bay to draw comparisons but the fact that they were sampled in low numbers suggests that estuarine areas may not be important juvenile habitat for *P. sanguinolentus*. Likewise ovigerous females were found throughout the sampled area apart from *P sanguinolentus* in Moreton Bay (Figure 11.9).

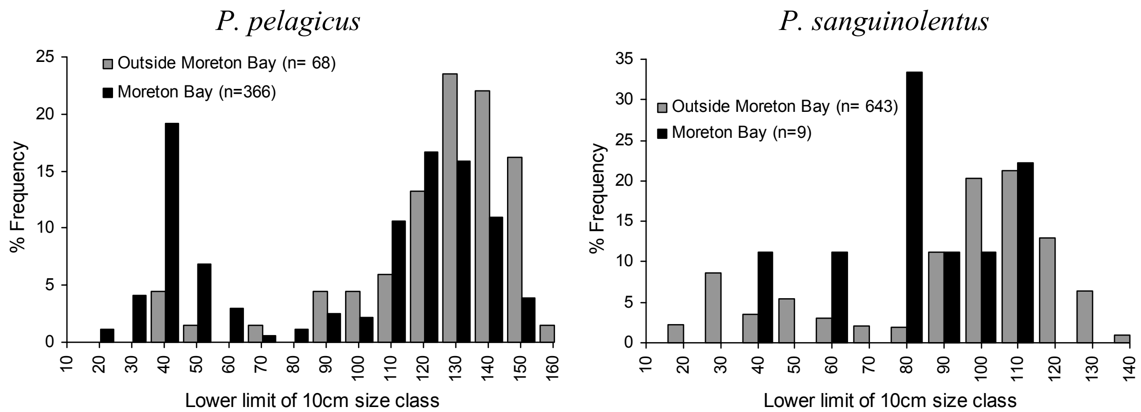


Figure 11.8 Size frequency of *Portunus pelagicus* and *Portunus sanguinolentus* from fishery-independent survey of southern Queensland waters using prawn otter trawls.

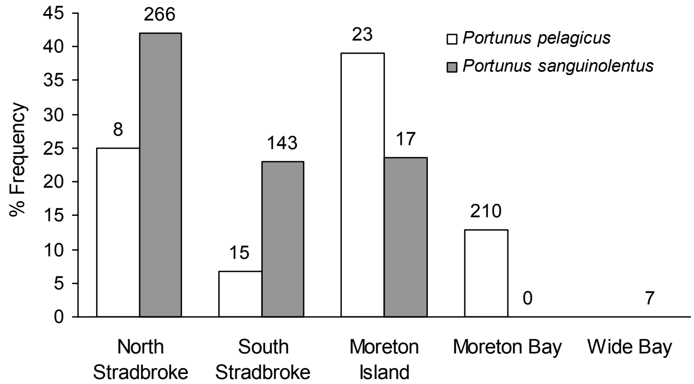


Figure 11.9 Percentage of adult *P. pelagicus* and *P. sanguinolentus* that were ovigerous from different regions in southern Queensland. Total numbers of adult females sampled are shown above each bar. No data were collected for *P. sanguinolentus* at Wide Bay.

Beam Trawl Surveys of Peel Island, Deception Bay and Great Sandy Straits

Numbers of blue swimmer crabs caught during the sampling of Deception Bay, Peel Island and Great Sandy Straits were too few to enable the derivation of growth curves for each region (Figure 11.10) but they do demonstrate the general trend of juveniles and adults being available in the shallow areas of both Moreton Bay and Great Sandy Straits.

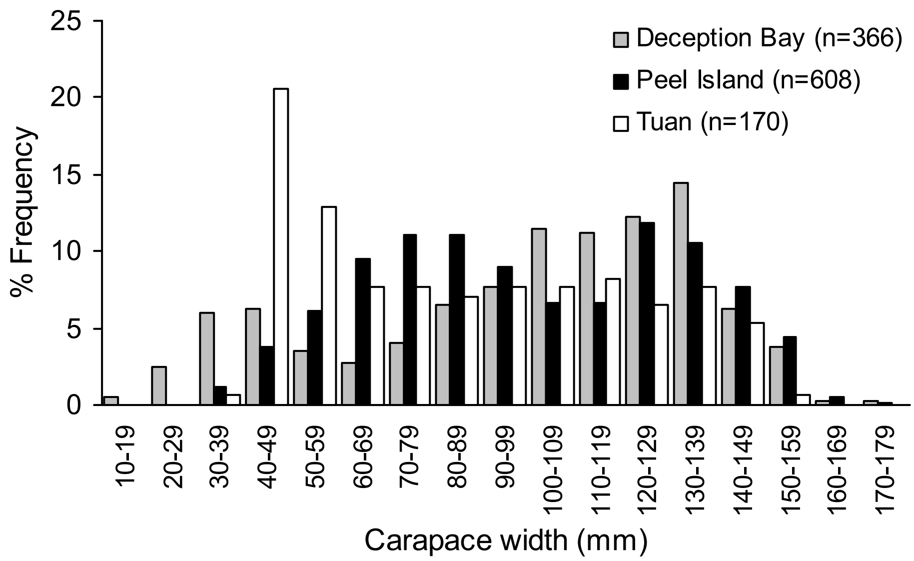


Figure 11.10 Size frequency of blue swimmer crabs sampled using beam trawls in Moreton Bay and Great Sandy Straits (Tuan).

Table 11.4 Total numbers of male and female blue swimmer crabs sampled in estaurine areas of southern Queensland.

Area	Male	Female
Deception Bay	177	189
Peel	289	319
Great Sandy Straits	100	70

Sex ratios in all these regions were closer to 1:1 than for other surveys. This was largely due to the gear selecting for smaller juvenile crabs that are not retained by the fishery and therefore sex ratios would not be expected to be biased towards females.

Juvenile Survey of Moreton Bay (February 2000 and 2001).

The relative distribution pattern of adult male and female blue swimmer crabs as well as immature crabs is shown in Figures 11.11 to 11.13. There were very few trawls in Moreton Bay that failed to catch any blue swimmer crabs. Adult males and females were more abundant in the western and southern Bay in both years. Juveniles, however, were more abundant in the central western Bay. There was no significant difference in the abundance of blue swimmer crabs caught in the survey between years with 4279 crabs sampled in 2000 compared with 4066 during 2001. At the time of preparation of this report not all 2001 data were available in the CFISH database but from the data available it appeared that the 2001 commercial catch in Moreton Bay was greater than 2000. This does not suggest that the survey is not a good indicator of future year class success as the juveniles sampled in 2001 are more likely to contribute to the 2002 catch. It is only after a few years data are collected that the predictive value of these surveys will be able to be assessed.

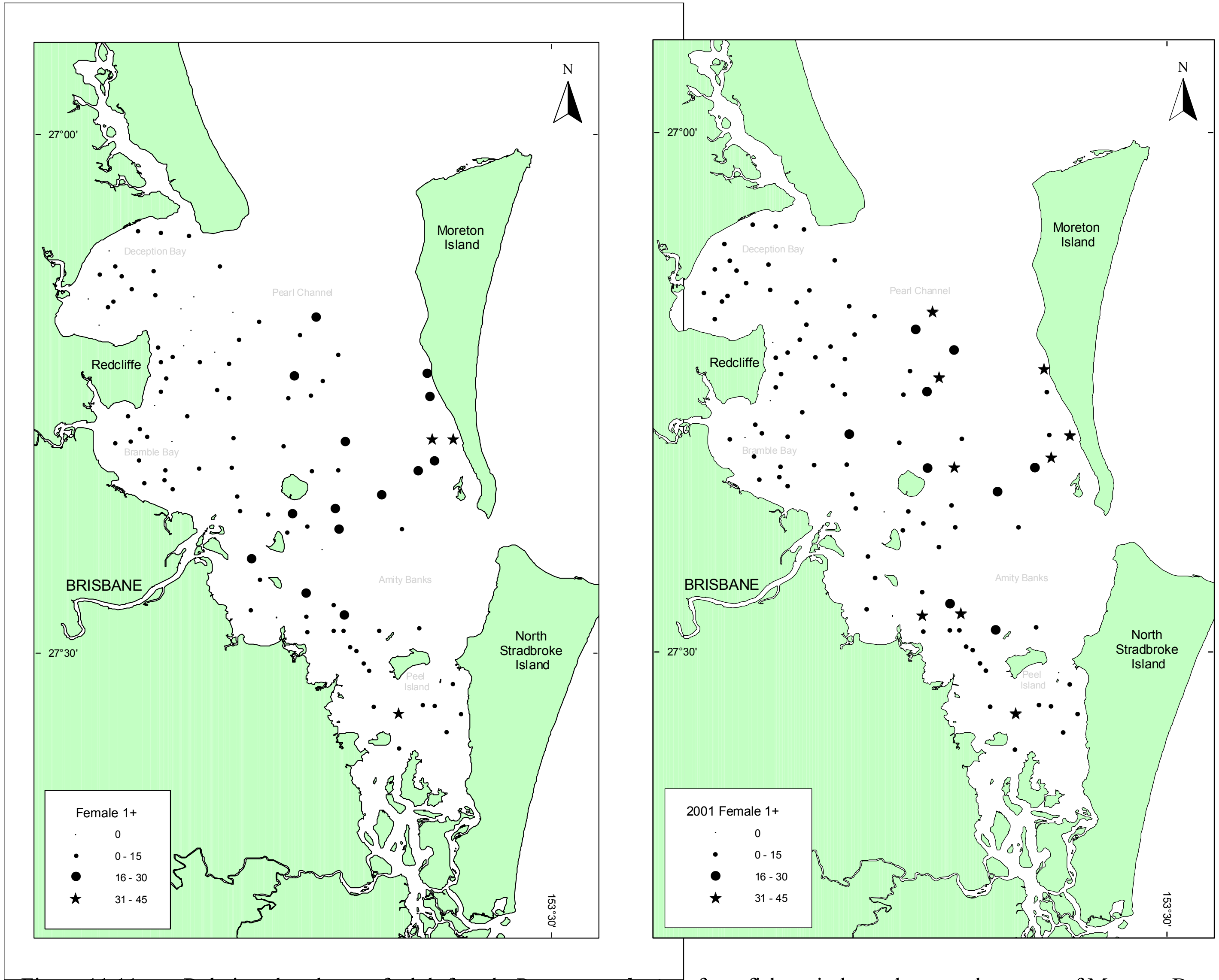


Figure 11.11 Relative abundance of adult female *Portunus pelagicus* from fishery independent trawl surveys of Moreton Bay during February 2000 and February 2001.

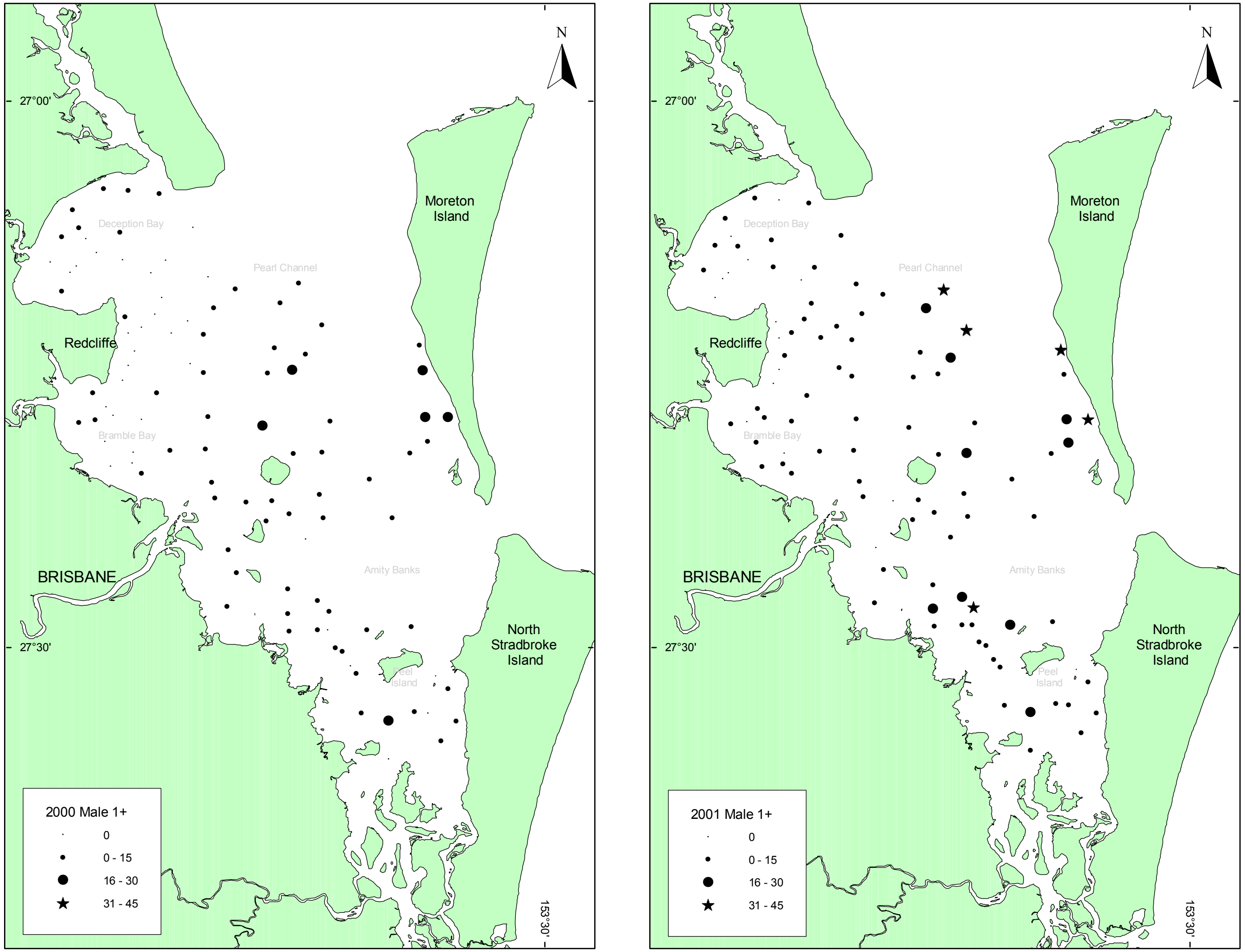


Figure 11.12 Relative abundance of adult male *Portunus pelagicus* from fishery independent trawl surveys of Moreton Bay during February 2000 and February 2001.

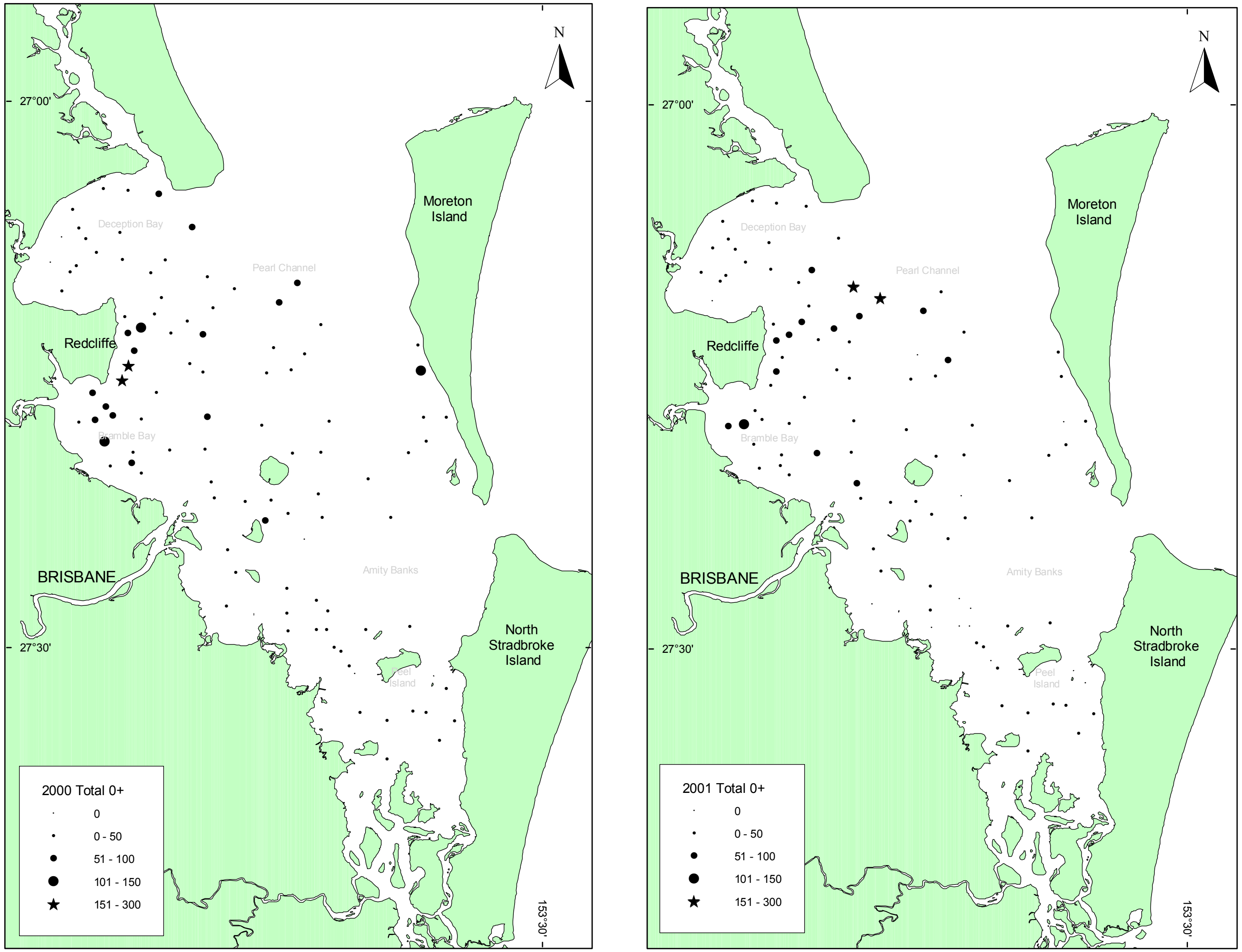


Figure 11.13 Relative abundance of juvenile (0+) *Portunus pelagicus* from fishery independent trawl surveys of Moreton Bay during February 2000 and February 2001.

Power analysis was undertaken to estimate the number of samples required to detect a change in average relative abundance of crabs (number of crabs caught in a one nautical mile trawl of approximately 25 minutes duration) of approximately 5% over time –usually a year. A number of similar indices were explored, namely 0+ year old, 1+ All, Male 1+, Female 1+, Total. Power was set at 80% and probability of detecting a "decline" was 95%.

Data were stratified by depth (0-4 m, 5-8 m, 9-12 m and 13-16 m) to reduce variance as there were trends for larger numbers of juveniles to be found in shallower water, particularly on the western side of the Bay. In order to optimise residual error, we endeavoured to obtain as similar variances within each strata as possible.

Source	Df
Time	1
Depth	3
Time X Depth	3
Residual error	192
Total	199

A number of data transformations were tested with log data providing the best fit. Residual error was used as an estimate of variance with the grand mean of the Time factor used to calculate an amount that constitutes 5% of mean. These parameters were then used in the following power equation.

$$\Phi = \sqrt{\frac{n'\delta^2}{2k's^2}}$$

where
Φ- non-centrality parameter
δ- minimal detectable difference
n'-number of data in each level of Time
k-number of levels in Time factor
s^2- residual error mean square (variance).

Table 11.5 Mean number of crabs of various categories caught in 1 nautical mile beam trawls during recruitment surveys in Moreton Bay.

Year	All Males	Juvenile males	Adult males
2000	19.16	14.73	4.25
2001	19.65	12.65	7.01
Combined	19.41	13.69	5.62
	All Females	Juvenile females	Adult females
2000	23.55	15.66	7.54
2001	21.39	11.30	10.08
Combined	22.48	13.49	8.80
	M/F ratio		
2000	0.9087		
2001	0.8955		
Combined	0.902		

Power analysis (Table 11.6) indicated that at the current intensity of sampling (approximately 100 sites), between a 25% and 30% change in relative abundance of males and females will be able to be detected. The value of these surveys as predictors of future years class strength will not be fully known until the 2002 catch data from the commercial fishery are available.

Table 11.6 Number of samples required to detect a decline in relative abundance of various categories of crabs with 80% power at the 5% significance level. Two-sample test with one-tail significance. Standard deviations used are based on stratified estimate of variance taken from a two-way ANOVA with depth strata and year as treatment effects

% change	All Males	All Females	Both sexes	Adult Female	Adult Male
5	4380	3778	4183	3715	4065
10	1037	896	992	881	964
20	232	200	222	198	217
30	92	79	88	78	85
40	45	39	43	39	42
σ	0.9649	0.8967	0.9434	0.8890	0.9300

Fortnightly Beam Trawl Survey of Juveniles.

Table 11.7 Numbers of crabs (both sexes) caught during a fortnightly survey of western Moreton Bay from December 1999 to January 2000.

Size Class (mm)	16-Dec	23-Dec	29-Dec	6-Jan	16-Jan	20-Jan	28-Jan	5-Feb	11-Feb	20-Feb	26-Feb	7-Mar	20-Mar	5-Apr
10-19	0	0	2	5	2	4	1	0	8	50	0	3	1	0
20-29	28	48	28	50	84	50	17	35	29	85	26	46	30	6
30-39	152	208	99	109	163	214	62	69	23	30	38	147	76	56
40-49	58	173	63	80	109	184	59	64	32	13	13	68	55	17
50-59	27	50	20	21	33	30	32	28	15	10	10	24	12	9
60-69	6	13	5	4	8	9	16	20	15	8	3	10	4	2
70-79	7	6	4	5	4	8	3	4	7	5	2	4	12	3
80-89	4	3	2	1	3	1	2	5	6	10	1	6	8	2
90-99	3	4	1	4	2	3	4	6	2	6	2	1	10	2
100-109	2	5	1	1	6	7	1	5	5	6	1	7	14	6
110-119	3	2	2	6	4	7	5	5	6	8	4	7	22	2
120-129	2	7	2	2	7	5	2	5	2	7	1	11	24	2
130-139	2	10	5	6	5	5	5	2	3	8	3	3	15	3
140-149	7	6	2		1	3	3	2	0	3	1	7	4	2
150-159	2	1	0	2	2	1	0	0	1	2	1	1	1	0
160-169	0	0	1	0	0	1	0	0	0	0	0	0	0	0
170+	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Size Class (mm)	18-Apr	4-May	1-Jun	16-Jun	14-Jul	15-Aug	14-Sep	15-Oct	2-Nov	10-Nov	24-Nov	14-Dec	20-Dec	8-Jan
10-19	0	2	0	0	0	0	1	0	0	0	0	0	0	3
20-29	10	50	4	13	10	3	1	1	0	0	1	7	7	6
30-39	27	74	8	89	52	30	8	24	1	2	7	17	17	126
40-49	27	44	7	60	79	43	27	11	2	6	11	53	53	129
50-59	31	25	4	46	66	42	70	13	7	6	25	63	63	28
60-69	11	9	6	12	35	18	90	5	8	10	23	38	38	14
70-79	11	10	2	6	24	16	79	6	1	3	8	24	24	17
80-89	3	7	1	7	10	20	56	5	7	8	13	20	20	24
90-99	12	12	0	10	13	37	52	12	9	6	15	11	11	17
100-109	14	9	1	12	15	49	53	18	10	11	15	17	17	15
110-119	15	13	2	16	16	34	41	10	13	11	23	11	11	23
120-129	15	16	11	16	20	37	43	19	18	24	25	19	19	28
130-139	12	21	12	26	17	28	17	13	19	9	22	14	14	19
140-149	3	8	4	3	5	13	15	13	8	17	11	16	16	13
150-159	1	4	1	4	2	7	3	5	7	3	3	2	2	4
160-169	0	0	0	0	1	0	2	2	1	0	1	0	0	3
170+	0	0	0	0	0	0	0	0	0	0	0	0	0	0

This survey was mainly designed to gather size modal progression information that could be used to estimate blue swimmer crab growth (see Chapter 9). There was considerable data collected for crabs less than 120mm carapace width but modal separation was difficult once the smaller crabs had reached around 90 mm CW. At this point there was marked overlap of the 0+ and 1+ year old size modes.

Discussion

A number of consistent findings have emerged from the results of these surveys. Firstly, juvenile blue swimmer crabs were most abundant in shallow waters inside Moreton Bay and were rarely taken in offshore oceanic areas. By comparison, in offshore waters juveniles of *P. pelagicus* appeared to be replaced by juveniles of the closely related *P. sanguinolentus*. However, adults of the latter species were also uncommon in the more estuarine conditions of Moreton Bay.

The distribution of adults relative to distance from the more estuarine conditions of Hervey Bay during the scallop surveys suggest that blue swimmer crabs make their way into deeper water as they develop supporting the findings of earlier research in Moreton Bay (Sumpton *et al*. 1994). The extent to which juveniles in Moreton Bay and Hervey Bay contribute to the offshore fisheries is yet to be fully established. Tagging work carried out in the 1980’s (Potter *et al*. 1994) suggested that adults remained inside Moreton Bay. However, as there was little fishing effort in offshore waters during that time the conclusion that most of the Moreton Bay stock remains in Moreton Bay must now be questioned. The contribution that blue swimmer crabs spawned in Moreton Bay and Hervey Bay make to the offshore population can best be determined using a tagging experiment, now that there is now considerable fishing effort in offshore waters. Unfortunately methods of tagging blue swimmer crabs are currently not well developed since studies have shown a high rate of tag mortality and the retention of tags at the moult is poor (Potter *et al*. 1994). The problem of successful tag retention following moulting would have to be addressed before a large-scale tagging program could be successfully undertaken. Research conducted elsewhere as part of the national strategy on research into this fishery attempted to address the issue of an optimal tagging strategy for blue swimmer crabs, however, there has been little progress towards developing an appropriate tag for the species.

The large-scale spatial survey of blue swimmer crabs in Moreton Bay provided results that could be useful in future monitoring of blue swimmer crab stocks. The survey also collected useful data on juvenile snapper (*Pagrus auratus*), winter whiting (*Sillago maculata*) and bycatch suggesting they may form part of a worthwhile monitoring program. Benefits of future blue swimmer crab surveys should include the additional benefits gained in the monitoring of other fisheries resources. In addition, the prawns and other bycatch species were not analysed, but these could be kept and subsequently analysed in the laboratory at a later date. All the data collection activities for snapper, winter whiting and blue swimmer crabs can be conducted during the surveys apart from data entry and analysis that would normally require approximately 10 person days. The costs of these surveys (not including analysis and reporting costs) are shown in Table 11.8. The analysis of the prawn and bycatch data would also require additional laboratory resources and no estimate has been made for this in the following table.

Table 11.8 Costs (as at 30/6/2002) associated with undertaking an annual fishery independent survey of Moreton Bay (TO3(4) = Technician classification scale, TOIL = Time off in lieu of overtime).

Item	Justification	Cost
Charter of research vessel	10 days @ $600.00 per day	$6000.00
Fishing gear and consumables	Allowance to periodically replace fishing nets and other consumables	$500.00
Research assistants (30 days)	TO3(4) Salary and on-costs for 2 staff during survey and consequent TOIL	$7000.00
Travel allowances (3 staff @10 days)	Travel allowance for skipper and 2 technicians (30 days @ $45.00 per night)	$1350.00
TOTAL		$14,850.00

If a commercial vessel were to be chartered for this purpose the vessel costs would approximately double and there would be additional difficulties associated with standardisation of the program from year to year if different vessels were being used.

The true value of the Moreton Bay recruitment surveys can be best determined when their accuracy for predicting the catch of blue swimmer crabs is established. At present this is not possible as only the full 2000-calender year catch and effort data series is available. At the time of preparation of this report the complete 2001 crab season catch and effort data was not fully available and therefore comparisons of survey relative abundance and fisheries production was not possible. The correlation of survey density estimates of juveniles and subsequent fisheries production would be an added bonus of the survey, as it would provide an indication of the magnitude of future catches at the height of the season (2 or 14 months after the survey).

Estimates of power to detect CPUE and size changes in the commercial pot fishery

We also determined the number of samples required to detect declines in both size and catch rates (CPUE) of blue swimmer crabs in the Queensland commercial pot fishery. The data were collected over a four-year period from late 1997 to early 2001. Most analyses were confined to 1997-2000, apart from the CPUE analysis that examined catch rates in the March to May period during 1998-2001.

The predictor variables were-

Zone	North Moreton Bay, Offshore, Hervey Bay, South Moreton Bay
Pot Group	1,2,3,4 (Referring to different pot designs)
Month	Jan - Dec
Year	1997 - 2001
Crabber	Data from 20 fishers were used

One objective of this exercise was to enable sampling to be conducted using as few crabbers as possible. Therefore data from only one crabber was originally used to conduct power analysis. Where the number of samples required became unrealistic then all crabbers were included in modelling response variables.

The variance from the output of generalised linear models was used as a basis for power calculations. As the data did not come from any orthogonal design the number of samples proposed to detect a decline from the power analysis must be treated with a degree of caution. Therefore two sets of output are given. One set assumes that the design is orthogonal, therefore the number of samples given may be considered optimistic. The second set are either produced from a reduced model which gives a higher variance estimate or the variance estimates have been manually inflated. These estimates of sample size may be considered the pessimistic scenario. The number of samples required are based on a future design and not from the current design. Where it was possible (usually when we can use two-sample tests only) the number of samples required for future sampling using current data are provided. Power was set at 80% with 95% confidence (one-tail).

Female Crab CPUE Power Analysis (single crabber)

Optimistic scenario

Model used: Log CPUE= Mean + Year + Month + error
Variance = 0.09963, Standard Deviation = 0.3156, error d.f =25

Percent decline	N(within)	Absolute change	N(per year)
5	40	0.0513	480
10	10	0.1054	120
20	3	0.2230	36

Pessimistic scenario

Model used: Log CPUE = Mean + Year + error
Variance = 0.189, Standard Deviation = 0.4347, error df = 25

Percent decline	Absolute change	N(per year)	N(25 in year 1)
5	0.0513	889	α
10	0.1054	211	α
20	0.2230	48	5500

Male Crab CPUE Power Analysis (single crabber)

Optimistic scenario

Model used: Log CPUE= Mean + Year + error
Variance = 0.3833, Standard Deviation = 0.6191, error d.f =32

Percent decline	N(per year)	Absolute change	N(32 in year 1)
5	1801	0.0513	2010
10	427	0.1054	477
20	96	0.2230	107
25	58	0.2877	65

Pessimistic scenario

Model used: Log CPUE = Mean + Year + error
Variance = 0.428, Standard Deviation = 0.654, error df = 32

Percent decline	N(per year)	Absolute change	N(25 in year 1)
5	2010	0.0513	α
10	477	0.1054	α
20	107	0.2230	α
25	65	0.2877	α

Male Crab CPUE Power Analysis (all crabbers, March to May only)

Optimistic scenario

Model used: Log CPUE= Mean + Year + Zone.Year + Month + error
Variance = 0.2560, Standard Deviation = 0.5060, error d.f =50

Percent decline	Absolute change	N(reps)	N(per year)
5	0.0513	300	1200
10	0.1054	72	288
15	0.1625	31	124
20	0.2230	17	68

Pessimistic scenario

Model used: Log CPUE= Mean + Year + Zone.Year + error
Variance = 0.2832, Standard Deviation = 0.5322, error df = 50

Percent decline	Absolute change	N(reps)	N(per year)
5	0.0513	333	1332
10	0.1054	79	316
15	0.1625	34	136
20	0.2230	18	72

Male Crab Size Power Analysis

The variance estimates have been artificailly inflated in the last two columns of the remaining two tables

Model: Carapace width = Mean + Month + Year + error
Variance = 71.03, Standard Deviation = 8.425, error df = 6804
Mean size in 2000 = 149.3 mm

Percent decline	Absolute change	N(reps)	N(per year)	N (reps) $\sigma = 144$	N (reps) $\sigma = 400$
5	7.47	2	24	3	8
10	14.93	-	-	-	2

Female Crab Size Power Analysis

Model: Carapace width = Mean + Month + Year + error
Variance = 136.8, Standard Deviation = 11.696, error df = 1531
Mean size in 2000 = 139.06

Percent decline	Absolute change	N(reps)	N(per year)	N (reps) $\sigma = 215$	N (reps) $\sigma = 400$
5	76.95	3	36	5	9
10	13.91	1	12	2	3

The power analyses suggested that relatively few replicates were required to detect a change in the average size of crabs in the pot fishery. Even with artificially inflated variance less than 60 catches needed to be measured in order to detect a 5% reduction in size. The larger variance in catch per unit effort data however resulted in a large number (and generally unrealistic number) of samples being required in order to detect a change. Even when the analysis was restricted to the peak of the fishery the wide variation in catch rates suggested that over 1200 catches need to be monitored to detect a 5% reduction in CPUE.

12. BYCATCH OF THE QUEENSLAND BLUE SWIMMER CRAB POT FISHERY

Introduction

In 1998 the Queensland commercial pot fishery produced just over 350 tonnes from an estimated 450,000 commercial pot lifts. The recreational catch is believed to be around 200 tonnes (Williams 2002) and a large proportion of this is also landed using pots. Given this level of effort, there exists the potential for the commercial and recreational pot fishery to impact on bycatch species and also for bycatch species to perhaps have a negative impact on the target species due to interactions and mortalities within the pot.

Economic considerations such as the time taken to sort the catch, damaged product and decreased value of by-product have caused commercial fishers to address bycatch since the fishery first developed. However in recent years the influence of environmental groups and the general increase in community concern over bycatch has resulted in government action through the formulation and implementation of policies addressing the issue of ecological sustainability, which includes sustainability of both the target and non-target species.

In the 1990s bycatch became a major issue in world fisheries with estimates of as much as 40 percent of the world's catch being discarded or under utilised species (Buxton 1998). During a peak period of international concern for the environment *The Fisheries Management Act 1991* was developed by the Fisheries Management Authority (FMA) to ensure ecological sustainable development and conservation of biological diversity. The Australian Fisheries Management Authority (AFMA) in line with these objectives implemented the *Commonwealth Endangered Species Protection Act 1992*, and worked to develop the Commonwealth Bycatch Policy. More recently there have been steps to remove the blanket exemption of marine species from wildlife export controls by the Australian Government to exempt only those marine species harvested in accordance with sustainable and ecologically based management arrangements. In light of this push to ecologically manage fisheries by assessing and regulating fishing impacts, there is relevance in describing the bycatch associated with the Queensland blue swimmer crab pot fishery. In this report 'bycatch' refers to the animals discarded that are not the undersized or females of the target species, blue swimmer crabs.

This chapter describes the bycatch associated with the commercial Queensland blue swimmer crab pot fishery, in the four most productive regions of the state (see chapter 5). These include Northern Moreton Bay, Southern Moreton Bay, offshore Bribie Island to Fraser Island and Hervey Bay. Total catch of these bycatch species is also estimated using the information catch rates and effort estimates from logbook information. Finally, suggestions are made about ways in which fishing practises can be altered to reduce the capture of non-target species.

Materials and Methods

From October 1997 to May 2001 QDPI research observers accompanied commercial pot fishers from Hervey Bay, Moreton Bay and offshore from Mooloolaba and Bribie Island and recorded their catch on a pot by pot basis. As well as biological information (see Chapter 9) relating to blue swimmer crabs, bycatch was also recorded for each pot lifted. Bycatch was classified by common name. At a latter stage these common names were converted to species if possible, alternatively a genus or family classification was used. Other information recorded included pot type (whether it was wire or mesh), time of pot lift, time the pot was last baited and environmental factors such as salinity, water temperature, percentage cloud cover, wind direction and wind strength. For the purpose of this discussion the following regions were defined and include the fishing grounds recognised by commercial fishers that are enclosed in brackets.

1) Hervey Bay
2) Offshore (Mooloolabah, Caloundra, Bribie - >30m depth)
3) Nth Moreton Bay (Deception Bay, Crab Paddock, North Moreton, M4 Moreton Bay, Bribie Island, Scarborough, Pearl Channel)
4) Sth Moreton Bay (Chain Banks, Wynnum, Green Is, Rous Channel, Peel Is, Coochiemudlo)

The pots used by commercial fishermen are cylindrical in shape (approximately 1.0m in diameter and 0.3m high), and usually either galvanised wire mesh or trawl mesh placed over a mild steel/plastic frame. The wire mesh normally has a mesh size of approximately 70mm at its widest aperture compared with 45mm for the trawl mesh. There are usually two diametrically opposing entrance funnels, each with a gradual upward incline into the pot. Despite some variations to these basic designs, pot type was broadly categorised into wire pots or trawl mesh pots for analysis. Trip bycatch catch rates were calculated by dividing the number of fish or invertebrate species captured per trip by the number of pot lifts for that trip. Commercial logbook effort information was used in conjunction with trip bycatch catch rates to provide an estimate of the total number of individuals caught for each bycatch species per region as the intensity of sampling was generally consistent with the total commercial effort expended in each region.

Factors affecting the catch rates of bycatch were analysed using a binomial regression model with the capture of a bycatch species by a commercial crab fisher modelled according to the probabilities P(caught) = π and P(not caught) = 1 - π. The probability π was modelled using a logistic transformation with log (π/ (1-π)) being a linear function of $X^T{}_\beta$ of the covariates: season, region, pot type, depth*region and time last baited. Here, $X^T{}_\beta$ represents a vector of these covariates and β a vector of parameters to be estimated from which the significance of the contributions of each covariate can be assessed. This component of the model was fitted using the procedure for binomial regression in Genstat.

Table 12.1 Parameter estimates and standard errors from the binary regression analysis of the probability of a commercial blue crab fisher catching any bycatch species, a fish species or a crab species.

Parameter	All by-catch Estimate (se)	Fish Estimate (se)	Crabs Estimate (se)
Region			
North Moreton	B - 2.04 (0.899)	B - 5.38 (1.31)	B + 4.53 (1.02)
South Moreton	B - 6.28 (1.3)	B - 4.88 (1.85)	A - 2.11(1.60)
Offshore	A +1.17 (1.06)	A - 2.74 (1.44)	B + 7.08 (1.16)
Hervey Bay	A 0	A 0	A 0
Pot Type			
Wire	A + 2.036 (0.22)	B +1.44 (0.37)	A +1.97 (0.25)
Mesh	B 0	B 0	B 0
Covariates			
Depth*region (HB)	- 0.134 (0.043)	- 0.257 (0.065)	+0.12 (0.049)
Depth*region (NM)	- 0.046 (0.018)	+0.073 (0.022)	- 0.081 (0.018)
Depth*region (OFF)	- 0.051 (0.01)	- 0.02 (0.01)	- 0.049 (0.009)
Depth*region (SM)	+ 0.774 (0.157)	+0.002 (0.001)	+1.188 (0.212)
Time pot last baited	0	0	0

The letters A and B denote groupings with significant differences in the probability of catching any bycatch, fish and crabs ($p<0.05$); letters that are the same indicate no significant difference. The symbols +, - and 0 respectively denote an increasing, decreasing or non-significant effect on the probability of catching bycatch. HB = Hervey Bay, NM = North Moreton Bay, SM = Southern Moreton Bay and OFF = Offshore Bribie Island to Fraser Island.

Results

The regression analysis indicates that in terms of capturing a bycatch species in a pot, there was no significant difference between Hervey Bay and Offshore (Table 12.1). However there is a significantly reduced chance of bycatch capture in the Moreton Bay (both north and south regions) compared with both Hervey Bay and Offshore (Bribie to Fraser Island). Similar results were found with the analysis that examined fish bycatch only. Once again the probability of catching fish was not significantly different between Hervey Bay and Offshore. However there was a significantly reduced chance of catching fish in Moreton Bay compared with Offshore and Hervey Bay.

The same pattern did not exist with the probability of catching non-target crab species. The probability of catching crab bycatch was not significantly different between Hervey Bay and southern Moreton Bay. However there was a significantly higher chance of catching non-target crabs in northern Moreton Bay and offshore regions compared with Hervey Bay and southern Moreton Bay. The factors that were identified as having a significant effect on the occurrence of bycatch included season, region, pot type, time since pot was last baited and an interaction between depth and region.

Fishers using trawl mesh pots had a significantly greater probability of capturing bycatch than did fishers using the more traditional wire pots. The effect of depth was not consistent across all regions. In Moreton Bay increasing depth tended to increase the probability of catching fish bycatch but this pattern was reversed for the two offshore areas.

Commercial pots used to capture blue swimmer crabs, catch numerous invertebrate and finfish species (Table 12.2 and 12.3), with invertebrates comprising approximately 65% and finfish almost 35% of the total bycatch caught for all regions of the fishery.

Table 12.2 List of taxa of non-fish bycatch caught in 7136 commercial crab pot lifts from Oct 1997 to May 2001. The total number of each taxon likely to be caught in pots each year can be calculated by multiplying the number recorded during the observer trips (N) by 63 since there are currently about 450,000 pot lifts per annum. Percentages represent the contribution to the total bycatch (including fish).

Bycatch Common Name	Species Name	Family	N	%
Crustaceans				
Spanner Crab	*Ranina ranina*	Raniniidae	1459	21.86
3 Spot Crab	*Portunus sanguinolentus*		1265	18.95
Rock Crab	*Charybdis natator*	Portunidae	607	9.09
Mud Crab	*Scylla serrata*	Portunidae	263	3.94
Coral Crab	*Charybdis feriatus*	Portunidae	68	1.02
Granular Bay Crab	*Galene bispinosa*		60	0.90
Trawl Crab	*Charybdis callianassa*	Portunidae	44	0.66
Hermit Crab		Paguridae	39	0.58
Slipper Lobster	*Scyllarides squammossus*		11	0.16
Surf Crab	*Matuta victor*	Calappidae	1	0.03
Red & White-spotted Reef Crab	*Lophozozymus erinnyes*	Xanthidae	1	0.03
Painted Crayfish	*Panulirus ornatus*		1	0.01
Red spotted box crab	*Calappa philargius*	Calappidae	1	0.01
Decorator crab	*Hyastenus spp.*	Majidae	1	0.01
Eastern king prawn	*Penaeus plebejus*	Penaeidae	1	0.01
Xanthid crab		Xanthidae	2	0.01
Crab unspecified			2	0.01
Other invertebrates				
Starfish	*Pentacerasta spp.*		311	4.66
Octopus	*Octopus spp.*		110	1.65
Sea Urchin			52	0.78
Cuttlefish	*Sepia spp.*		20	0.30
sea cucumber			8	0.11
Saucer scallop	*Amusium japonicum balloti*		5	0.07
Turtle unsp			2	0.03
Bailer Shell			1	0.01
mollusc			1	0.01
Birds				
Cormorant	*Phalacrocorax spp.*		3	0.04

Table 12.3 Taxonomic list of fish bycatch caught in 7136 commercial crab pots from Oct 1997 to May 2001. The total number of each species likely to be caught in pots each year can be calculated by multiplying the number recorded during the observer trips (N) by 63 since there are currently about 450,000 pot lifts per annum. Percentages represent the contribution to the total bycatch (including invertebrates and birds).

Bycatch Common Name	Species Name	Family	N	%
Leatheriacket	*Monocanthid sp.*	Monocanthidae	282	4.23
Bar-faced Weever	*Parapercis nebulosa*	Mugiloididae	237	3.55
2 eyed cardinal fish	*Apogon nigripinnis*	Apagonidae	205	3.07
Red Emperor	*Lutjanus sebae*	Lutjanidae	185	2.77
Grunter	*Pelates spp.*	Teraponidae	185	2.77
Whiptail	*Pentapodus spp.*	Nemipteridae	123	1.84
Squire	*Pagrus auratus*	Sparidae	104	1.56
Sweetlip	*Lethrinus spp.*	Lethrinidae	95	1.42
Grass sweetlip	*Lethrinus laticaudis*	Lethrinidae	94	1.41
Pearl Perch	*Glaucosoma scapulare*	Glaucosomatidae	89	1.33
Pinky	*Nemipterus spp.*	Nemipteridae	86	1.29
Bullseye	*Priacanthus spp.*	Pricanthidae	73	1.09
Gulf Damsel	*Pristosis jerdoni*	Pomacentridae	71	1.06
Cardinal fish	*Apogon spp.*	Apagonidae	62	0.93
Venus Tusk-fish	*Choerodon venustus*	Labridae	51	0.76
Purple Tusk-fish	*Choerodon cephalotes*	Labridae	45	0.67
Bream	*Acanthopagrus australis*	Sparidae	39	0.58
Goatfish	*Parupeneus spp.*	Mullidae	27	0.40
Stripey	*Microcanthus strigatus*		26	0.39
Toadfish		Tetraodontidae	25	0.37
Banded toadfish	*Marylina pleurostictus*	Tetraodontidae	18	0.27
Wobbegong shark	*Orectolobus ornatus*	Orectolobidae	18	0.27
Parrot fish unspecified		Scaridae	13	0.19
Skate (Shovelnose Ray)		Rajidae	13	0.19
Stingray unspecified		Dasyatididae	13	0.19
Remora	*Remora remora*		12	0.18
Scorpaenid unspecified		Scorpaenidae	12	0.18
Shark unspec			19	0.28
Flathead	*Platycephalus caeruleopunctatus*	Platycephalidae	11	0.16
Catfish unspec		Ariidae	10	0.15
Happy moments	*Siganus spp.*	Siganidae	9	0.13
Colcloughs Shark	*Brachaelurus colcloughi*	Brachaeluridae	7	0.10
Scad unspecified.	*Decapterus spp.*	Carangidae	7	0.10
Blind Shark	*Brachaelurus waddi*	Brachaeluridae	6	0.09
Magpie Morwong	*Cheilodactylus vestitus*		5	0.07
Stonefish	*Synanceja horrida*	Scorpaenidae	5	0.07
Threadfin Sweetlip	*Lethrinus gennivittatus*	Lethrinidae	5	0.07
Silver Biddy	*Gerres oyena*	Gerreidae	4	0.06
Spangled Sweetlip	*Lethrinus nebulosus*	Lethrinidae	4	0.06
Tusk fish unspecified	*Choerodon spp.*	Labridae	4	0.06
Flathead - Sand	*Platycephalus arenarius*	Platycephalidae	3	0.04
Blue spotted ray	*Amphotistius kuhlii*	Dasyatididae	2	0.03
Butterflyfish unspecified	*Chaetodon spp.*	Chaetodontidae	2	0.03
Callionomys	*Callionomys spp.*	Callionymidae	2	0.03
Cod	*Epinephelus spp.*	Serranidae	2	0.03
Flounder unspecified		Bothidae	2	0.03
Hairtail	*Trichiurus lepturus*	Trichiuridae	2	0.03
Porcupine fish	*Dicotylichthys myersi*	Diodontidae	2	0.03
Port Jackson shark	*Heterodontus portusjacksoni*	Heterodontidae	2	0.03
Schooling bannerfish	*Heniochus diphreutes*	Chaetodontidae	2	0.03
Tawny nurse shark	*Nebrius ferrugenius*	Ginglymostomatidae	2	0.03
Black banded kingfish	*Seriolina nigrofasciata*	Carangidae	1	0.01
Black-Tipped cardinalfish	*Apogon semilineatus*	Apagonidae	1	0.01
Little jew	*Johnius vogleri*	Sciaenidae	1	0.01
Maori cod	*Epinephelus undulostriatus*	Serranidae	1	0.01
Moray eel	*Gymnothorax spp.*	Muraenidae	1	0.01
pineapple fish	*Cleidopus gloriamaris*	Monocentrididae	1	0.01
shovelnose ray		Rhinobatidae	1	0.01
Silver toadfish	*Lagocephalus scleratus*	Tetraodontidae	1	0.01
Sole	*Cynoglossus spp.*	Cynoglossidae	1	0.01
Starry Triggerfish	*Abalistes stellatus*	Balistidae	1	0.01
Tarwhine	*Rhabdosargus sarba*	Sparidae	1	0.01
Winter whiting	*Sillago maculata*	Sillaganidae	1	0.01
Zebra Lionfish	*Dendrochirus zebra*	Scorpaenidae	1	0.01

Crustacea represent about 57% of the invertebrate bycatch. The Portunidae family is represented by 6 species and comprise about 34% of the bycatch. Of this family, the three spot crab (*Portunus sanguinolentus*) is the most abundant (19%). Overall spanner crabs are the most abundant bycatch species (21.86%) associated with the fishery and these are caught almost exclusively outside Moreton Bay.

Forty families of fish represented by 55 species were captured in crab pots. Of these, the leatherjackets were the most abundant and represented 4.2% of all bycatch species over the entire region. The bar faced weever was the second most abundant at 3.6% of the bycatch. There are also several species of recreational and commercial importance that are caught in the pots. Of these red emperor, squire, pearl perch, sweetlip and venus tusk fish were the most dominant. Red emperor was in fact the fourth most abundant fish bycatch species found in pots. The classification of the bycatch into sexually mature and immature components was beyond the scope of this study but most of the commercially and recreationally important fish species caught in pots appeared to be juveniles.

Neither spanner crabs nor three spot crabs were found in the sampled bycatch from Moreton or Hervey Bays (Table 12.4). Both these are important commercial species and three spot crabs are a very important marketable by-product of this fishery in some areas. Apart from squire that were more common in southern Moreton Bay, most of the other commercially or recreationally important fish species were taken from the offshore areas outside Moreton Bay.

Table 12.4 Breakdown of bycatch species as a percentage from all regions and separately for each region.

Common name	Scientific name	All regions	Nth Moreton	Sth Moreton	Offshore	Hervey Bay
Crabs						
Spanner Crab	*Ranina ranina*	21.9	*	*	31.5	*
3 spot crab	*Portunus sanguinolentus*	19.0	22.3	*	21.6	*
Rock Crab	*Charybdis natator*	9.1	6.3	21.7	6.8	27.3
Mud Crab	*Scylla serrata*	3.9	20.8	4.3	<1	*
Coral Crab	*Charybdis feriatus*	1.0	3.9	*	<1	<1
Other						
Starfish	*Pentacerasta spp.*	4.7	<1	3.7	1.5	42.6
Octopus	*Octopus spp.*	1.6	<1	1.9	2.2	*
Fish						
Leatherjacket	*Paramonocanthus otisensis*	4.2	4.6	20.7	2.6	7.3
Bar-faced Weever	*Parapercis nebulosa*	3.6	6.9	*	3.4	*
2 eyed cardinal fish	*Apogon nigripinnis*	3.1	2.1	*	3.9	<1
Red Emperor	*Lutjanus sebae*	2.8	<1	*	4	<1
Trumpeter	*Pelates spp.*	2.8	2.8	2.8	3.1	*
Whiptail	*Pentapodus spp.*	1.8	5.8	*	<1	5.8
Squire	*Pagrus auratus*	1.6	3.4	12.1	<1	*
Tusk fish	*Choerodon spp.*	1.5	<1	1.9	<1	7.7
Sweetlip	*Lethrinus spp.*	1.4	<1	*	1.8	1.9
Grass sweetlip	*Lethrinus laticaudis*	1.4	*	2.5	1.8	<1
Pearl Perch	*Glaucosoma scapulare*	1.3	*	*	1.9	*
Pinky	*Nemipterus theodori*	1.3	*	*	1.9	*
Bullseye	*Priacanthus macracanthus*	1.1	*	*	1.6	*
Gulf Damsel	*Prisdosis jerdoni*	1.1	*	*	1.5	<1
Sharks and Rays		1.1				

Discussion

As noted previously there is a requirement for Australian fisheries to be managed in an ecologically sustainable manner. Since the introduction of the *Commonwealth Fisheries Management Act* 1991 and the *Endangered Species Protection Act* 1992 Australian prawn trawling industries have been closely scrutinised primarily because it is recognised as the most destructive form of fishing in terms of bycatch capture and physical damage to the environment. Australia's Northern Prawn Fishery (NPF) catches an average of 8,000- 10,000 tonnes of prawns per year. However, it also takes roughly 8- 10 times that amount in unwanted bycatch, much of which dies. From 1993 to 1998 several Fisheries Research and Development Corporation (FRDC) funded projects focussed on describing this bycatch, developing and testing devices to reduce the amount of bycatch caught and assisting fishers to begin using some of these devices. More recently, FRDC have helped to fund research to describe and quantify trawl bycatch in Queensland and the preliminary effects of bycatch reduction devices (BRD's). Descriptions of the impact of non-trawl fishing operations is relatively limited. However, several fisheries (including pot and trap fisheries) have been identified as having the potential to impact on sensitive megafauna in particular.

Seabird bycatch

The most important seabird bycatch issue in Australia is the incidental mortality of seabirds, especially the number of vulnerable or endangered species of albatross caught in the tuna fishery. Data collected from 1991-1996 by fishery observers in the Japanese Southern Blue Fin Tuna fishery in the Australian Fishing Zone have produced estimates that range from 900- 3,700 seabirds killed per year, of which about 75% are albatross. Over this time the effort in this fishery varied from 6-26 million hooks, and the bycatch rate varied from 0.07- 0.18 birds per thousand hooks. Mitigation measures and gear, such as the use of bird scaring lines, night setting, weighting of lines, bait casting and thawing, have been developed in recent years. Bird capture rates in the blue swimmer crab fishery however appears far lower with less than 1 bird (cormorant) caught per 2000 pot lifts. The issue of bird mortality is also highly area specific and limited to the shallow areas on the western side of Moreton Bay. Very few fishers in fact reported ever catching cormorants or other sea birds and the three birds observed during this study came from a single fisher fishing in shallow water. Using the rate of about 1 bird per 2000 pot lifts and then multiplying up to the total pot lifts would overestimate the number of birds caught due to the limited bird bycatch in the deeper areas where most of the fishery is conducted.

Bycatch of megafauna

The annual reports to the International Whaling Commision from the Commonwealth have been the only consistent source of information regarding the incidental capture of dolphins in other fisheries around Australia. Recent reports indicate that dolphins are caught occasionally in the shark gill-net fishery in Western Australia and in the inshore gill-net fishery for barramundi and threadfin salmon in northern Queensland (Anderson, 1995). There have also been reports of incidental captures of dolphins in a pilchard purse-seine fishery in Western Australia (1994) and in a developmental pilchard purse-seine fishery in southern Queensland (1997-1998) in which 9 dolphins died. As a result of these reported deaths and despite efforts to develop contingences to minimise dolphin mortalities, the developmental fishery was closed. During none of the observer trips were interactions of crabbing apparatus with marine mammals observed and fishers who have been fishing for many years have never witnessed dolphins or whales caught in crab apparatus.

On only one observer trip was a marine turtle found entangled in the rope of crabbing apparatus. This turtle was eventually freed unharmed. Despite this, crabbing apparatus is known to snare turtles and cause mortalities (see Chapter 15). Steps to mitigate this problem are highlighted elsewhere in the report (Chapter 15).

General pot bycatch

In Australia, only one other study has described the bycatch associated with a pot fishery. Frusher and Gibson (1998) investigated the bycatch rates associated with the Tasmanian rock lobster fishery with reference to the effect of pots with and without escape gaps. In this fishery nearly 2 million pot lifts are recorded each year. In fact according to Brown and Phillips (1994), fisheries for rock lobsters throughout southern and western Australia account for over 16 million pot lifts per year.

From the number of pot lifts mentioned above, it is obvious that there is the potential for pot fisheries to capture large quantities of bycatch. Therefore it is surprising, that in the current climate of ecologically sustainable fisheries management, that so little has been done to examine the impacts of pot fisheries on bycatch species. A reason for a lack of research in this area relates to the fact that these fisheries are seen as target specific in comparison with trawl, longline and gill net fishing. The results of this study support this view with the level of fish bycatch being relatively insignificant compared with trawl and net fisheries.

The impact of barotrauma in fish species caught in offshore waters is an area that needs further investigation. Not all species are equally able to cope with the effects of barotrauma. There is little published information on the ability of species to survive barotrauma. Observer data indicated that short-term survival of most species was high as there were few occasions when fish removed undamaged from pots did not swim away. Placing fish and crabs in the sorting tray often resulted in further damage to the fish. There are several features of pot fishing that serve to lessen the impact of operations on bycatch. Firstly, pots are normally hauled to the surface relatively slowly allowing time for barometric compensation, the soft trawl mesh covering of pots also causes less damage than the more solid metal wire pots and sorting times are often short. Even when fishers may not immediately sort the crab catch most were observed promptly returning fish bycatch to the water.

The observed regional differences in bycatch catch rates and species composition occur largely because of substrate differences among the regions. When pots are placed near to reefs and rubble areas, bycatch is increased compared with the more open sandy/mud areas of Moreton Bay. Some of the offshore crabbing areas are close to juvenile habitat for a number of rocky reef species such as red emperor and pearl perch and that is why they are sometimes a significant part of the bycatch. Mesh size is also an important factor in determining the amount of bycatch retained in pots. It is noteworthy that larger mesh sizes usually result in less bycatch and it is recommended that fishers use a mesh size larger than the prawn mesh that is common in some areas. This both reduces the fish bycatch and minimises sorting of undersized target species that are able to escape through the mesh.

13. GHOST FISHING IN THE QUEENSLAND BLUE SWIMMER CRAB POT FISHERY

Introduction

Most of the blue swimmer crab pot catch is taken in baited pots that are left to fish in the water continuously. These pots are commonly cleared and rebaited daily although weather conditions can sometimes result in pots not being checked for more than 7 days. This is particularly the case in more open water, offshore areas outside Moreton Bay that are more prone to the effects of adverse weather.

Commercial fishers are licensed to use 50 pots and are restricted to taking only male crabs with a carapace width greater than, or equal to, 150 mm. Traditionally, over the past few decades, crabbers used rigid pots constructed from a steel rod frame, covered by wire meshing. In the late 1980s, however, some fishers began using collapsible pots constructed of polyethylene trawl mesh on a steel and/or plastic frame. Over 95% of fishers operating in the Moreton Bay area now use these trawl mesh pots (see Chapter 15). This trend occurred for a number of reasons. Firstly, trawl mesh pots are less prone to corrosion, thereby prolonging the effective working life of the gear. Secondly, many of the designs are collapsible and allow for easy storage aboard small vessels enabling fishers to work more efficiently further from port. Fishers also believe that they are less prone to turtle interactions and actually fish better than the wire pots.

A survey of commercial crabbers conducted in early 2001, showed that significant pot loss occurred during a fishing season (see Chapter 15). Of the respondents, the vast majority stated that they had lost pots during the previous 12 months with an average loss of about 35 pots per annum (range 0 to 400). According to the crabbers, pot loss occurred for several reasons including the accidental or intentional removal of marker floats and pots by other vessels, heavy weather moving pots into deeper water and incidental removal of floats by large animals including sharks.

This pot loss no doubt gives rise to ghost fishing, a phenomenon described by Smolowitz (1978) as the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman. Theoretically, ghost fishing occurs when the contents of a lost pot (both target species and bycatch) die and attract more animals into the pot. These animals then die and attract more, with this process continuing until the pot breaks down and can no longer fish.

Historically, a lost wire mesh pot would corrode and cease fishing in a relatively short space of time. Fishers usually have to rewire the frame of their pots with new wire mesh at least once per fishing season. However, a consequence of the more durable nature of a trawl mesh pot is that, if lost, it will remain viable for a greater period of time and may continue to ghost fish for both crabs and other species long after the more traditional designs would have corroded away. The smaller mesh size of the trawl mesh pots also causes smaller fish species to be retained than was traditionally the case with wire pots (see Chapter 12).

Several authors in the United States, Europe and Canada have examined ghost fishing by pots in crab fisheries. Ghost fishing in the Dungeness crab *Cancer magister* fishery has been investigated by Breen (1987), who recorded a steady increase in the cumulative catch of crabs with an overall catch rate of 16.9 crabs per pot per year. Guillory (1993) investigated the potential impact of ghost fishing on the blue crab *Callinectes sapidus* fishery in a Louisiana estuary and observed an increase in cumulative catch throughout the study, with an average of 34.9 crabs per pot per year being recruited despite the lack of bait.

This chapter examines the ghost fishing characteristics of the three main pot types used by commercial blue swimmer crabs fishers in Queensland. Specifically the rates of entrance, escapement and mortality are assessed and the composition of other by-catch components are described. The overall pot loss in the fishery is then quantified and the fishery and ecological impacts of ghost fishing are described.

Materials and Methods

Two ghost fishing experiments were conducted in Deception Bay, Queensland (27° 11'S 153° 03'E). This area was chosen for the experiment as it is easily accessible in most weather conditions and there is a substantial *P. pelagicus* population that is fished throughout the year by both recreational and commercial fishers. Three pot designs as commonly used by commercial fishers were used in the experiments (see Table 13.1). Each pot had two diametrically opposed, slightly inclined entrance funnels and were attached via five metres of polyethylene rope to a 15cm spherical float. Five of each pot design were deployed alternatively in approximately 3 m of water in the study area.

The first experiment was conducted over a period of 46 days starting on the 15th of May, 2000. Pots were checked daily for the first four days, twice weekly for the following two weeks and weekly thereafter. The second experiment was conducted over 78 days and started on the 19th of October, 2000. During the second experiment, the pots were checked daily for three days, twice the following week and weekly for the remainder of the experiment. In both experiments, the pots were baited once only at the beginning of the experiment with a single sea mullet (*Mugil cephalus*) weighing approximately 600 grams. When pots were checked they were removed from the water and all *P. pelagicus* were measured and fitted with a tag. The tags consisted of a numbered, 15 mm diameter, stainless steel disc that was attached across the lateral spines of the crab using stainless steel wire. The tag number and carapace width of each *P. pelagicus* was noted, as was bycatch abundance and composition, before all animals were returned to the pots that were then returned to the water, unbaited. On subsequent lifts, all tagged crabs and bycatch species were noted, while new crabs were tagged and measured. All captured animals, alive and dead, were left in the pots. Any mud crabs, *Scylla serrata*, were measured and released due to the detrimental effect they have on other captured animals. All *P. pelagicus* were classified as 'new', 'escaped' or 'dead'. The live *P. pelagicus* tagged on previous lifts were classified as 'static'. The crabs were assumed to have entered the pots on the day they were first tagged, while dead crabs were assumed to have died the day they were first discovered dead.

A general linear regression model was used to predict catch rates for each pot type using various combinations of known factors. A step forward regression model using binomial distribution and logit link function was used to analyse the effects of various factors on ghost fishing mortalities. Various temporal states of the pot in relation to the state of the bait were defined as follows. "Fresh" bait was defined as the first 2 days after the pot was first set, "Stale" was from day 2 to 7 when there was commonly some bait remaining in the pot and "None" referred to day 7 onward when the bait originally placed in the pot was exhausted. During the second experiment a further state was described as "None + SE" which was defined as the period after which the bait was exhausted but immediately following a prolonged period of strong (>25 knots) south-easterly winds which occurred during this experiment.

The potential number of crabs caught by lost pots in the southeast Queensland *P. pelagicus* fishery was estimated using information gathered during a survey of commercial crabbers in the area. The results of this survey provided a conservative estimate of the number of pots that are lost throughout a season and the type of pot lost. The number of pots lost per annum was then multiplied by the ghost fishing rates achieved by each pot type in this experiment to estimate the impact of pot loss on the fishery.

Table 13.1 Characteristics of the three pot types used in the experiments.

Frame Material	Mesh Type	Dimensions (cm)
Gal. steel rod, plastic uprights	50mm polyethylene trawl mesh – diamond shape	100 x 30
Galvanised steel rod	50mm polyethylene trawl mesh – diamond shape	90 x 33
Galvanised steel rod	60mm wire mesh – hexagonal shape	93 x 30

Results

The traditional wire pots caught significantly less blue swimmer crabs than either of the pots constructed using trawl mesh (Figures 13.1 and 13.2). Although it was expected that the smaller mesh size of the trawl mesh pots would retain smaller crabs and therefore bias the estimates of catch rate there was no significant differences (P>0.05) in the mean size of crabs caught among the various pot designs. During the second experiment (Figure 13.2) both trawl mesh pots clearly out fished the wire pot.

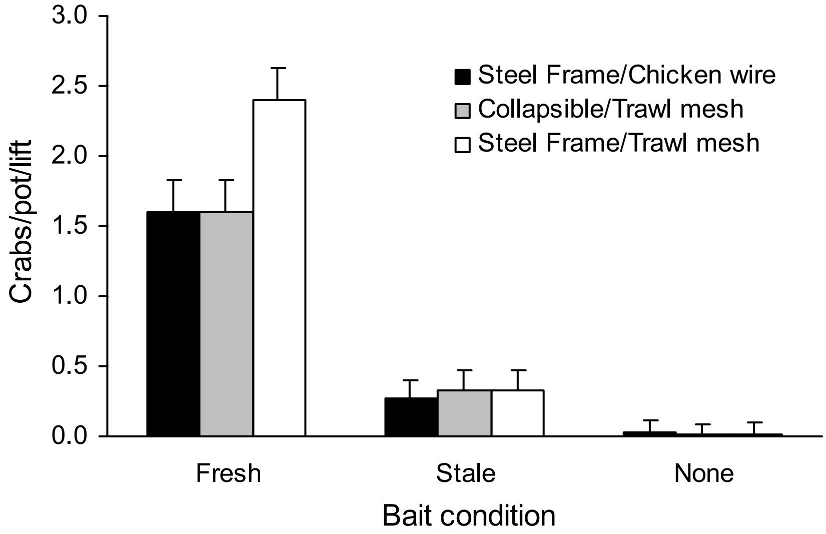


Figure 13.1 Number of blue swimmer crabs caught per pot lift for 3 different pot designs used in Moreton Bay during May to June 2000 (Experiment 1).

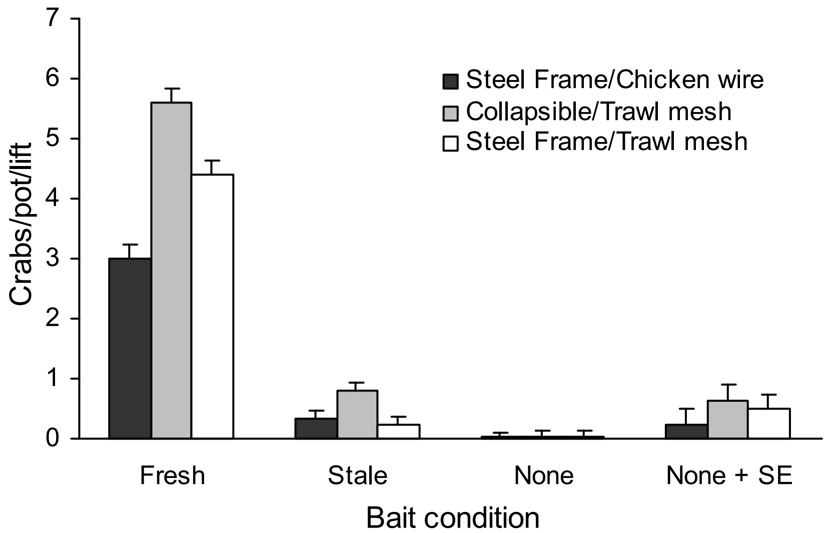


Figure 13.2 Number of blue swimmer crabs caught per pot lift for 3 different pot designs used in Moreton Bay during October and November 2000 (Experiment 2).

The period of strong south-easterly wind resulted in additional entrances of crabs to pots where the bait had been exhausted for some time. This pattern was observed in all pot types. The rate at which crabs entered pots also increased after this period. For both the trawl mesh pots an additional 5 or 6 crabs entered the pots following the period of strong winds. During this period there was not an apparent increase in the amount of fish bycatch in the pots and no noticeable change in the numbers of dead fish in the pots. In fact most pots had no dead fish evident when the increase was observed.

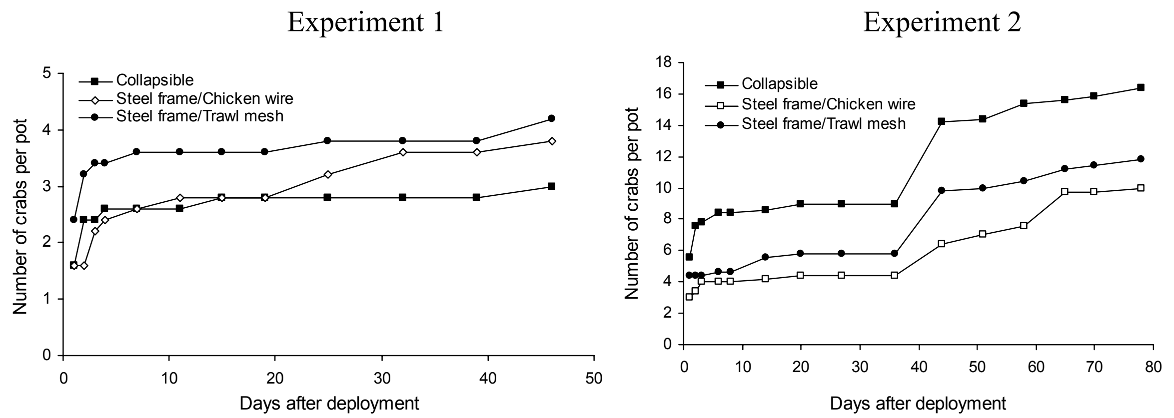


Figure 13.3 Cumulative number of crabs in each pot for two ghost fishing experiments in Moreton Bay using different pot designs.

It was often difficult to determine whether crabs had escaped or whether they had died and been consumed, but generally crabs that died and were eaten had their carapace remaining that had the tag attached to it. However, only the tag was found in the bottom of the pot on one occasion. Despite these difficulties, crab mortalities were observed in both experiments (Figure 13.4).

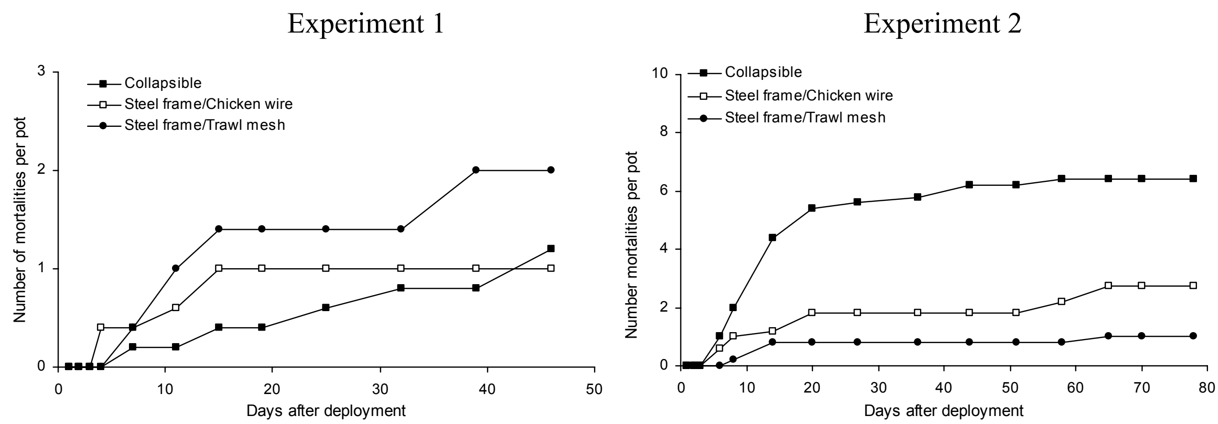


Figure 13.4 Cumulative number of crab mortalities per pot for two ghost fishing experiments in Moreton Bay using different pot designs.

Once crabs died they quickly decayed or were eaten, typically within the first week (Figure 13.5). During the second experiment when water temperatures were warmer the rate of removal was even greater.

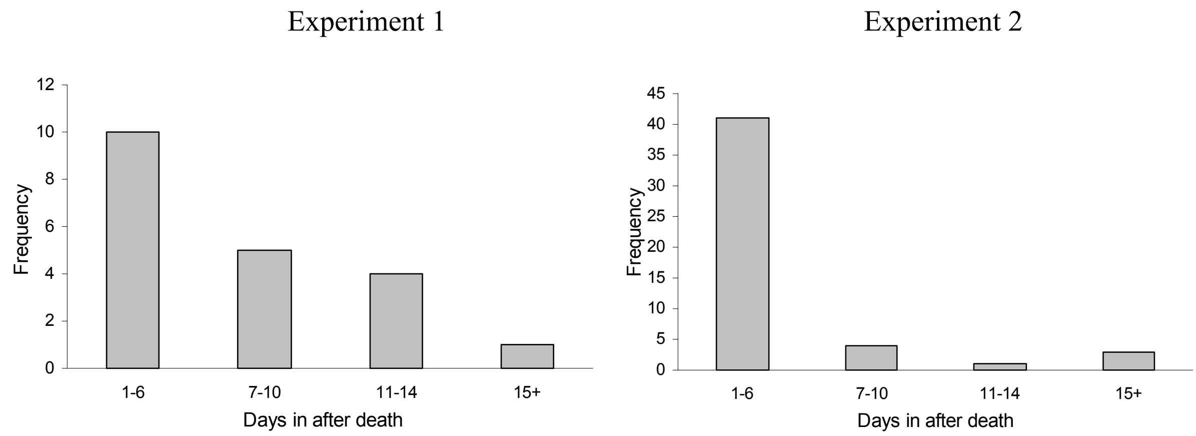


Figure 13.5 The number of days that dead crabs persisted in pots before they were totally removed.

Over the course of the two experiments relatively few non-crab bycatch species were found in any of the pot designs (Table 13.2 and 13.3) but during both experiments the trawl mesh pots retained significantly more fish bycatch than either of the other designs.

Table 13.2 The average number of individual bycatch components caught per pot lift in three different pot designs during experiment 1. Standard errors are shown in brackets. Species of recreational or commercial importance are also highlighted.

Genus/ species	Collapsible Trawl Mesh	Steel Frame/ Trawl Mesh	Steel Frame/ Chicken Wire	Rec./Comm. Importance
Portunus pelagicus	2.367 (0.092)	2.317 (0.224)	1.581 (0.199)	Rec/Comm
Apogon	0.033 (0.023)	0.017 (0.017)	0	-
Charybdis	0.217 (0.079)	0	0	Comm
Dasyatis	0	0	0.016 (0.016)	-
Lutjanus	0.133 (0.044)	0	0	Rec/Comm
Maraliner	0.350 (0.078)	0.100 (0.046)	0.016 (0.016)	-
Paramonocanthus	0.450 (0.096)	0.050 (0.028)	0	-
Pelates	0.350 (0.096)	0.183 (0.077)	0	-
Portunus sanguinolentus	0.267 (0.075)	0	0	Comm
Psuedorhombus	0.050 (0.028)	0	0	-
Scylla	0.233 (0.084)	0.133 (0.060)	0.194 (0.073)	Rec/Comm
Terapon	0.033 (0.033)	0	0	-
Tripodichthys	0	0.050 (0.050)	0.242 (0.101)	
Orectolobus	0	0	0.016 (0.016)	-

Table 13.3 The average number of individual bycatch components caught per pot lift in three different pot designs during experiment 2. Standard errors are shown in brackets. Species of recreational or commercial importance are also highlighted.

Genus/species	Collapsible/ Trawl Mesh	Steel Frame/ Trawl Mesh	Steel Frame/ Chicken Wire	Rec./Comm. Importance
Portunus pelagicus	5.683 (0.305)	4.090 (0.243)	2.282 (0.156)	Rec/Comm
Charybdis	0.061 (0.027)	0.119 (0.037)	0.028 (0.019)	Comm
Dasyatis	0	0.045 (0.041)	0.070 (0.068)	-
Euristhmus	0.073 (0.029)	0	0	-
Maraliner	2.744 (0.491)	0.478 (0.146)	0.127 (0.024)	-
Microcanthus	0.012 (0.012)	0	0	-
Paramonocanthus	0.171 (0.063)	0	0.014 (0.014)	-
Pelates	0.073 (0.029)	0	0	-
Scylla serrata	0.110 (0.035)	0.149 (0.052)	0.085 (0.042)	Rec/Comm
Sepia	0.012 (0.012)	0	0	Comm
Orectolobus	0	0	0.014 (0.014)	-

Discussion

There are currently no management regulations to reduce ghost fishing by blue swimmer crab pots in either the commercial or recreational fishery. During a recent survey of recreational fishing 7.9 % of all recreational anglers interviewed survey targeted blue swimmer crabs, 38% of whom used pots to capture the crabs. The remainder used dillies that are also likely to have a marked ghost fishing potential although this was not quantified as part of this research. The concentration of recreational effort in embayment areas such as Moreton Bay and Hervey Bay indicates that ghost fishing by recreational fishing gear may be of a similar magnitude to that of the commercial fishery given that over 200 tonnes of blue swimmer crabs are caught annually by recreational fishers whose CPUE is considerably less than the commercial fishery (Sumpton 1999). Generally, however recreational blue swimmer crab potting apparatus is not left overnight and therefore is less likely to be lost than is commercial apparatus. Results of the commercial pot fisher questionnaire (see Chapter 15) suggest that commercial pot crabbers lose on average 35 pots per year. Based on the fact that crabbers report a large proportion of their pot losses are due to theft probably about 50% of these pots remain in the environment. There are about 180 boats reporting pot catches of blue swimmer crabs but many of these are only small operators who may not fish for more than a few weeks a year. The actual numbers of pots lost in the environment therefore could range from approximately 1000 to 6000 per year (although the higher figure assumes that all crabbers pot losses remain in the environment). Estimates of the life of pots are limited by the life of the metal frame that supports the trawl mesh, as the trawl mesh persists for a considerably longer period than the metal components. Depending on the thickness of the rod used for construction, pots may continue to ghost fish for more than 4 years before the frame rusts and the pot collapses. Based on the average rate of entrance of crabs determined by the current experiments a lost blue swimmer crab trap will catch 22 crabs per annum (range 8 to 54 crabs). However there is considerable variation in this estimate as seasonal factors, pot type as well as weather conditions appear to exert a considerable influence on the entrance of crabs to lost pots.

There is a range of construction alternatives that could minimise the ghost fishing potential of trawl mesh pots. Firstly, an increase in the mesh size as is commonly used in Hervey Bay would limit the number of small animals that are trapped in lost pots. The use of rubber and thin mild steel to construct the support mechanisms of funnels would also be a sound practise as the rubber quickly weathers and breaks, thus collapsing the funnel and preventing the entrance of animals. While the pot would still persist in the environment its potential to ghost fish would be greatly reduced. Many designs used by fishers do incorporate funnel designs that will collapse within 12 months of pots being lost.

There are some limitations in the analysis conducted in this study. The fact that pots are lifted and checked regularly has a marked influence on the ghost fishing potential, as repeated handling may cause mortality of some species. Crabs have also been observed escaping from pots but this experiment was unable to accurately quantify this due to difficulties in delineating escapes from mortalities where the crabs were eaten in total or the remains had fallen through the mesh of the pot. It is also clear that a number of factors can influence the ghost fishing characteristics of lost pots. Crabs enter pots regardless off whether they are baited or not. Whether this is due to the crabs seeking a refuge, or an attraction to residual odours on the pots themselves in unclear. The period of unusually strong winds that occurred during the second experiment resulted in additional entrapment of crabs in the pots and an elevated rate of attraction. Similar future events may further increase the rate of entrance of crabs thereby causing the rates estimated in these experiments to be underestimated.

The shape and size of entrance funnels also has a major influence on the quantity of both crabs and fish bycatch that is retained in each design. In these experiments the two trawl mesh pots that had the same mesh size had slightly different funnel designs that tended to retain significantly different quantities of fish bycatch in particular. In these experiments we were not so much concerned with determining the factors that affected the ghost fishing of lost pots but more on describing the magnitude of the problem. That is why unmodified designs as used in the fishery were tested. A better comparison may have involved the altering of single factors such as mesh size while keeping funnel shape and size as well as other design factors consistent. This would have required significantly more effort and as such was not progressed.

14. FISHERIES STOCK ASSESSMENT AND MODELLING

There are a number of specific issues related to the fishery that can be addressed by some form of fisheries modelling. The most simplistic models that are applicable to this fishery are yield per recruit models, as the main method of management relates to minimum legal size. In order to apply these models all that is required is estimates of growth and natural mortality. The former is often easy to obtain, but deriving appropriate levels of natural mortality is more problematic. In the case of the blue swimmer crab growth estimates are available from this and previous studies based on modal progression of length frequency distributions (using seasonal and non-seasonal growth models), laboratory rearing as well as tagging studies. There is still however, considerable uncertainty about the precision of some of these growth parameter estimates, particularly as they relate to growth after the size at which crabs recruit to the pot fishery.

Biomass dynamics models may also be an appropriate tool to assess the status of the blue swimmer crab stock, particularly given that a 12-year history of commercial catch and effort data is now available. Limitations of this type of analysis are related to the paucity of information on the magnitude of the recreational catch, as well as uncertainty in the catch and effort estimates of the commercial sector (See Chapters 5). Nevertheless this chapter describes the application of yield per recruit and biomass dynamics models in the Queensland blue swimmer crab fishery.

Growth and Mortality information derived from laboratory and tagging studies

During the mid 1980's almost 7000 male sand crabs greater than 140 mm carapace width were tagged and released in a range of areas in Moreton Bay (Potter *et al*. 1994). Recapture rates ranged from 2% to 60% depending on area with an overall average of approximately 15% of released crabs being recaptured. Of the 1003 recaptures only 26 had moulted. These data are important for a couple of reasons. Firstly, high recapture rates confirm that the fishing mortality of male crabs is high and the resource is heavily exploited. Secondly, the general lack of moulting between release and recapture confirms the infrequency of moulting for mature crabs and indicates that natural mortality could be responsible for a considerable proportion of total mortality of crabs between one moult and the next. This time lag between successive moults of mature crabs was further confirmed in laboratory holding trials where fewer than 10% of crabs greater than 140 mm C.W. moulted over a 4-month holding period. The relatively short life history coupled with the decreased moulting frequency of mature crabs suggests that crabs should be fished shortly after reaching their final moult, before the effects of natural mortality can impact on the population (See later discussion also).

Unlike fish, whose growth can be described by a single continuous growth function, the growth of crabs is discontinuous because crabs must shed their exoskeleton in order to grow (the process known as moulting). Moulting occurs fairly regularly at first but then declines in frequency as the crabs get older. A mature crab may stay approximately the same size and weight for many months but then increase in size and weight by more than 25% over a period of a couple of weeks as the crab moults.

Male blue swimmer crabs are believed to have only 3 "maturity moults"; that is, once they reach sexual maturity they will only moult another 2 times. There is only limited information available on the size of sand crabs at the various maturity moults although the information is vital when discussing size limits. Campbell (1984) kept over 50 mature and immature sand crabs in the laboratory for 2 years and documented the changes in size at each successive moult. The results of these observations are shown in Table 14.1.

Table 14.1 Size of male blue crabs held in the laboratory for 2 years, during different maturity moults (after Campbell, 1984)

Maturity Moult	Average Carapace Width (mm)	Range of Carapace Widths (mm)	Number of Crabs
1	93	72 - 120	61
2	126	108 - 158	42
3	164	144 - 210	27

Log normal distributions were fitted to these data with the resulting distributions weighted by the number of observations. The most critical observations involving these data are that at the present legal size limit of 150 mm only approximately 82% of terminal moult crabs can be legally marketed. In other words there is a proportion of the population that may never reach legal size. At a size limit of 140 mm. over 95% of terminal moult crabs are available for capture and 14% of 2nd moult crabs are also available. At both size limits (150 mm and 140 mm) crabs will have a full maturity moult (usually extending over several months) when they will be protected and able to mate. At a size limit of 140 mm over 85% of 2nd moult crabs would also be protected. The three moult size distributions were used to model the expected catch under a range of fishing and natural mortalities using the following equation for a 10 cm drop in size (i.e. 150 → 140 mm).

$$y = f\,[ppn_2 + ppn_3\,(1-m)(1-f \cdot ppn_2)]$$

Where y = relative catch
f = fishing mortality (proportion of crabs of a particular moult being caught)
m = natural mortality (proportion crabs of that moult that die from natural causes)
ppn_2 = proportion of legal crabs in moult 2.
ppn_3 = proportion of legal crabs in moult 3.

***NB** These mortalities are not instantaneous mortalities*

Some of the results of this analysis are summarised in Table 14.2. It is clear from these data that a lowering of the present size limit to 140 mm would result in at least a sustainable 25% increase in catch in (numbers) over a wide range of fishing and natural mortalities. Available evidence suggests that proportional fishing mortality for moults 2 and 3 would be somewhere between 0.1 and 0.2 (based on tagging results discussed earlier). Natural mortality is more difficult to estimate but a proportional natural mortality of 0.1 for moults 2 and 3 would appear to be conservative. Particularly since a laboratory study (Campbell, 1984) 30% of crabs died between moults 2 and 3. Even if natural mortality is higher than 0.1 the model predicts increasing catches for increasing levels of natural mortality.

Table 14.2 Change in catch numbers expected by a lowering of size limit from 150 mm to 140 mm for a range of expected fishing and natural mortalities.

Natural Mortality (Proportional)	Percentage increase in catch (numbers) for 10mm lowering of size limit(150 mm → 140 mm) for various proportional fishing mortality values between 0.1 and 0.5				
	0.1	0.2	0.3	0.4	0.5
.1	26.7	25.6	24.5	23.4	22.3
.2	28.1	27.0	26.0	24.9	23.8
.3	30.0	28.9	27.9	26.8	25.7
.4	32.4	31.4	30.3	29.3	28.2

To date the discussion of the impact of lowering the minimum legal size has revolved around yield expressed as number of crabs. Yield as expressed in weight is probably not as critical for this fishery as it is for some others where there can be over a 20-fold difference in the weight of the smallest exploitable animal and the largest. By comparison at the present legal size of 150 mm the average weight of a blue swimmer crab is approximately 300g while at 140 mm it only reduces by 10% to an average of 270g. The majority of individuals in the present catch weighs less than 400g and it is rare (<0.1%) to catch a crab exceeding 800g.

Lowering the size to 140 mm would result in a reduction in the number of very large crabs caught. The impact of this on the yield per recruit in terms of weight would obviously vary depending on the level of fishing and natural mortality experienced. During maturity moults 2 and 3, however, it is not likely to impact markedly because 13.7% of 2nd moult crabs exceed 140 mm while 3% exceed 150 mm. Crabs are also often not marketed by weight but by "bodies" so weight considerations may not be as critical.

A further computer model (YPERSIM) was used to estimate the effects of varying the minimum legal size on relative yield per recruit (expressed as weight). Details of the model can be found in Restrepo and Fox (1988) but it is essentially a simple stochastic model utilising the Beverton and Holt 3-parameter yield per recruit method. The parameters used in this model are shown in Table 14.3. Values of K and $L\infty$ were obtained from monthly length frequency distributions of trawl catches (Potter and Sumpton, 1986) using the program MULTIFAN (Sparre, 1987). Since these parameters were estimated without error, a range of parameters spanning the likely range either side of these values were used in the model. The mortality rates used in this simulation were instantaneous estimates in comparison to the estimates used in the previous model which were estimated for a larger time interval over only 1 or 2 maturity moults. The model simulated the changes in yield for a wide range of exploitation rates and natural mortalities assuming a uniform distribution of all parameters.

Table 14.3 Parameters used in YPERSIM simulation of change in relative yield for blue crabs at different legal sizes.

PARAMETER	RANGE	DISTRIBUTION
C	0.60 - 0.85	UNIFORM
E	0.20 - 0.70	UNIFORM
$^{M}/_{K}$	0.22 - 1.36	UNIFORM
$L\infty$	180 - 205	UNIFORM
K	1.4 – 1.8	UNIFORM

C: Ratio of the size at first capture (Lc) and the largest average carapace width reached by the stock (L_D)
E: Exploitation ratio (rate of fishing to total mortality)
$^{M}/_{K}$ Ratio of the instantaneous natural mortality and the Von Bertalanffy growth constant

While there are also limitations in using a model which utilises the continuous Von Bertalanffy growth function to model the essentially "stepwise" crab growth pattern, the results provide an indication of the effects of varying the minimum legal size. The simulation showed that yield per recruit would be maximised between 100 - 120 mm carapace width although the risks of actually lowering yield become significantly greater when sizes are lower than about 130 mm (Figure 14.1). A lowering of the minimum legal size to 140 mm should cause on average a 10% increase in yield with virtually no risk of yield reduction. Any increase in minimum legal size from the current 150mm would cause substantial reductions in yield.

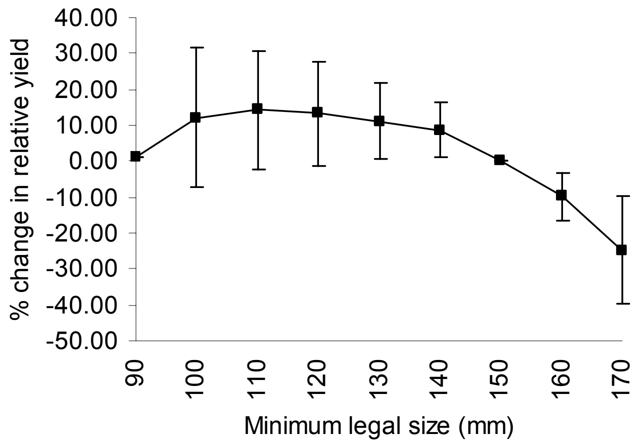


Figure 14.1 Percentage change in relative yield per recruit for a range of different minimum legal sizes. Standard deviations are shown as vertical bars.

No attempt was made to model the value per recruit because marketers confirmed the subjectivity in pricing policy with gradings such as small, medium and large being inconsistent across the market. Despite this both simulations showed an increase in "yield" for a reduction in size. This is significant because both models employed very different methods and data and yet both indicated considerable scope for a reduction in size limit.

There is a further important qualitative observation relevant to this discussion. When pairs of blue crabs are seen copulating or courting, the male crab is usually significantly larger than the female. Under the present management regime, as mentioned earlier, research in the mid-1980's and this current research showed that all females capable of reproduction had been mated. Male crabs are also on average larger than females so a modest reduction in size limit would be unlikely to have a dramatic impact on the size structure of the male population. However, it needs to be pointed out that the attainment of sexual maturity by a male may not necessarily ensure his reproductive success since behavioural factors also play a part in successful mating as small males are unlikely to mate with larger females.

Both analyses performed, did not accommodate reproductive information, nor stock size/recruitment information (the latter is unknown for blue crabs). While both analyses provided evidence for a substantial reduction in size limit it would be unwise to consider reductions to a level around the attainment of sexual maturity (i.e. 120 mm) as the impact of this on mating and egg fertilisation rates is unknown. However, as mentioned earlier, reductions of 10 to 20 mm are sustainable and even highly beneficial in terms of increasing yield.

Other studies have likewise confirmed the desirability for harvesting blue swimmer crabs at a relatively small size. Melville-Smith *et al*. (2001) who have recently completed a study of the Western Australian blue swimmer crab fishery have presented models showing that yield is maximised if the minimum legal size is less than 100mm. Unfortunately, yield per recruit models which utilise continuous growth models may not be entirely appropriate for analysing crabs, particularly blue swimmer crabs. While there is good information of the growth of crabs during the first 12 –18 months of life, there is little precision in growth rates when crabs are greater than about 130mm in carapace width due to the difficulty in discriminating between early 1+ age and older crabs. Blue swimmer crabs are known to reach sizes in excess of 220 mm and in the offshore areas of the fishery in Queensland the majority of the catch is in excess of 160mm. The fact that crabs have an incremental increase in size means that when they moult they can increase in size and weight by more than 25% in a relatively short period of time. The examination of growth of crabs larger than about 130mm in terms of moult increment and duration of inter-moult period is vital if fishery yields are to maximised. This is particularly the case if natural mortality of larger crabs is very low. Unfortunately tagging methods for this species appear to affect moulting and can also cause high levels of mortality (Potter *et al*. 1994). The development of tagging methods that have minimal impacts on moulting and growth of blue swimmer crabs is an important area for further research.

Biomass Dynamic Modelling

In an effort to provide some form of basic stock assessment of the blue swimmer crab fishery such as the derivation of maximum sustainable yield, biomass dynamics models were fitted to the commercial catch and effort data. The Schaefer form of the Butterworth-Andrew observation-error biomass dynamic model (Butterworth and Andrew 1984) was used to provide estimates of model parameters and derived management variables.

The deterministic form of this model assumes that the fishery can be modelled by the equations:

$$\boldsymbol{B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t} \qquad \text{and} \qquad \boldsymbol{\left(\frac{C}{E}\right)_t = \left(\frac{1}{2}q_t\left[B_t + B_{t+1}\right]\right)}$$

where

B_t is the biomass at time t,	q is the catchability coefficient.
C_t is the catch at time t,	K is the theoretical carrying capacity
E_t is the fishing effort, and	r is the intrinsic rate of increase

In all cases a linear relationship between catch rate and biomass is assumed. Other models including the Pella-Tomolinson and the Fox models were also fitted to data. Subsets of data were modelled under two different assumptions. The first assumption was that the first year of the catch data series represents an unexploited population and therefore B_0=K and implicitly that there is no recruitment variability. The second assumption was that $B_0 \neq$K and therefore B_0 does not represent an unexploited resource. The latter case is certainly the most likely scenario as all areas are fished, particularly Moreton Bay, where blue swimmer crabs have been under heavy fishing pressure for the last 50 years in particular, both from the commercial trawl and pot sectors. The Bribie to Fraser area more closely resembles an area of lower exploitation rates because of the fairly recent exploitation of certain offshore areas.

There are, however, a number of problems with the application of surplus production models in this fishery. The fact that there is a substantial recreational component for which there is little long term data on either catch and effort is a severe limitation since changes in recreational CPUE are not known. Therefore the models do not take into account the considerable impact that the recreational sector has on the resource. This is more relevant in areas such as Moreton Bay that support large recreational fisheries. In the offshore areas of Hervey Bay and Bribie to Fraser the recreational fishery is very small and the models should provide a better fit with the commercial catch and effort data from these areas. In addition to the lack of information on the recreational catch, the difference in catchability of the trawl and pot fisheries is also unknown and can therefore not be segregated in the models. Despite this limitation, the incompatibility of the two methods (Trawl and pot capture) often results in the two fisheries targeting crabs in essentially different areas, although there is a certain degree of overlap. This means that it may be possible to model the data from each fishery separately to avoid the problems with catchability. Finally, due to the relatively short life cycle of blue swimmer crab, annual variations in recruitment have a greater degree of influence on the total biomass than in species that have a longer life cycle. Despite these limitations the models may be useful if they provide a reasonable fit to the observed catch and effort data and if there is sufficient contrast in the data to adequately fit the models. In these cases they may give an indication of sustainable harvest under a range of chosen management strategies. Figures 14.2 to 14.show the results of the application of these models to the commercial CFISH data. In all these figures the values in the upper left-hand corner of the predicted yield graphs represent r - the intrinsic rate of increase, q – the catchability coefficient K – carrying capacity. The forth figure is the value of B_0 when the modelled scenario was unconstrained (i.e. when $B_0 \neq$K).

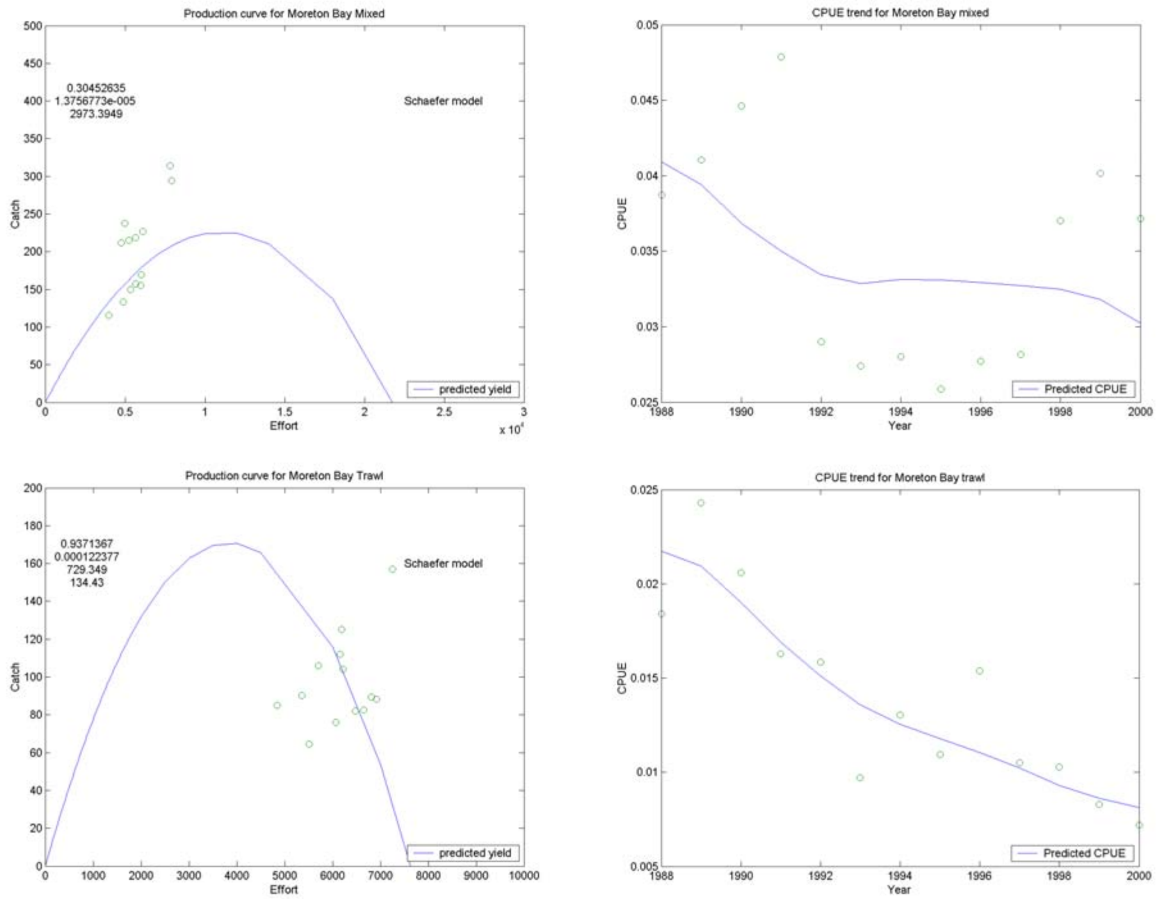


Figure 14.2 Schaefer surplus production models based on commercial catch and effort data for the Moreton Bay Fishery.

The surplus production models for the mixed fishery (Figure 14.2) had a poor fit with the observed CPUE data due mainly to unusually high CPUEs during both the early and later periods over which commercial catch data have been collected. In contrast the trawl CPUE data provided a good model fit. This model suggested that there was too much effort in the Moreton Bay trawl fishery which resulting in less than optimal catches. Caution needs to be exercised with this interpretation due to the problems of accurately describing trawl effort (see General Discussion, Chapter 17).

The models for the Bribie to Fraser region (Mixed fishery) suggested that the resource was currently under-exploited as CPUE trends were still increasing and the models were not properly constrained (Figure 14.3). It is highly unlikely that the actual MSY is as high as that predicted by these models. Like the Moreton Bay trawl model the Bribie to Fraser trawl model also produced a good model fit with declining CPUE trends evident.

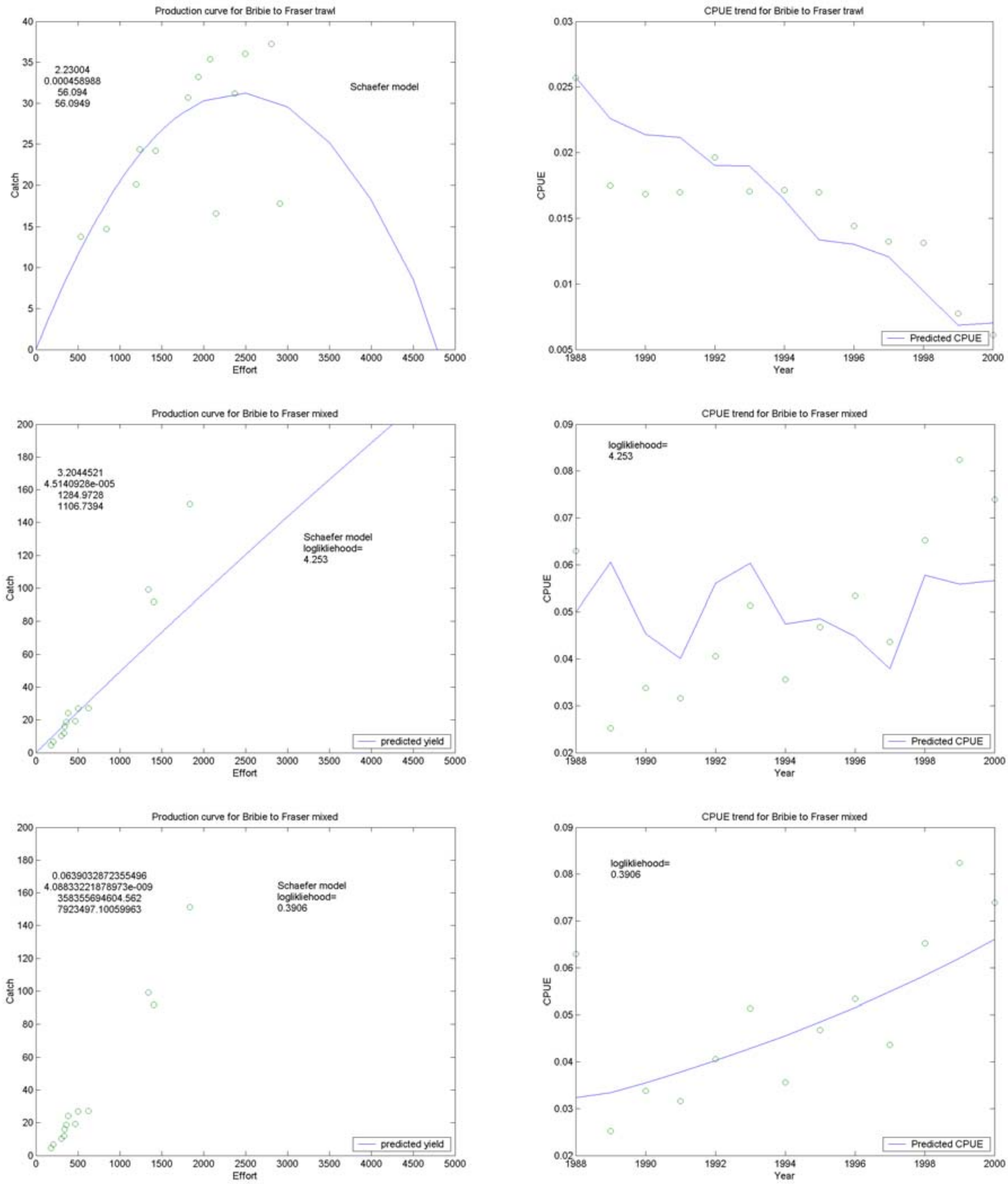


Figure 14.3 Schaefer surplus production models based on commercial catch and effort data for the Bribie to Fraser offshore fishery region.

The models for the Hervey Bay region (Figure 14.4) had the worst fit of any region. Both trawl and mixed CPUE were highly variable. Once again the carrying capacity estimates and consequent estimates of MSY are overoptimistic for this region.

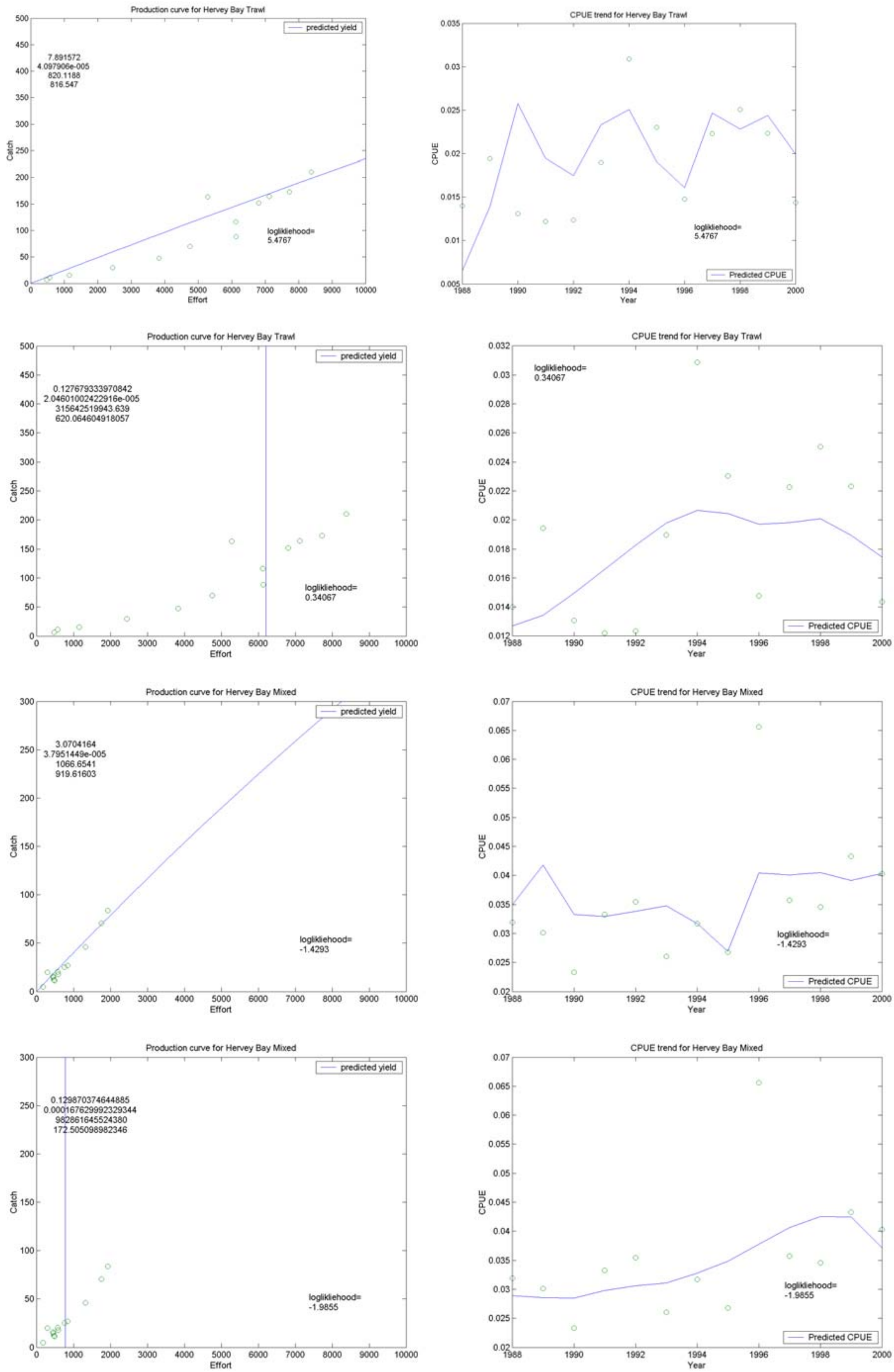


Figure 14.4 Schaefer surplus production models based on commercial catch and effort data for the Hervey Bay fishery region.

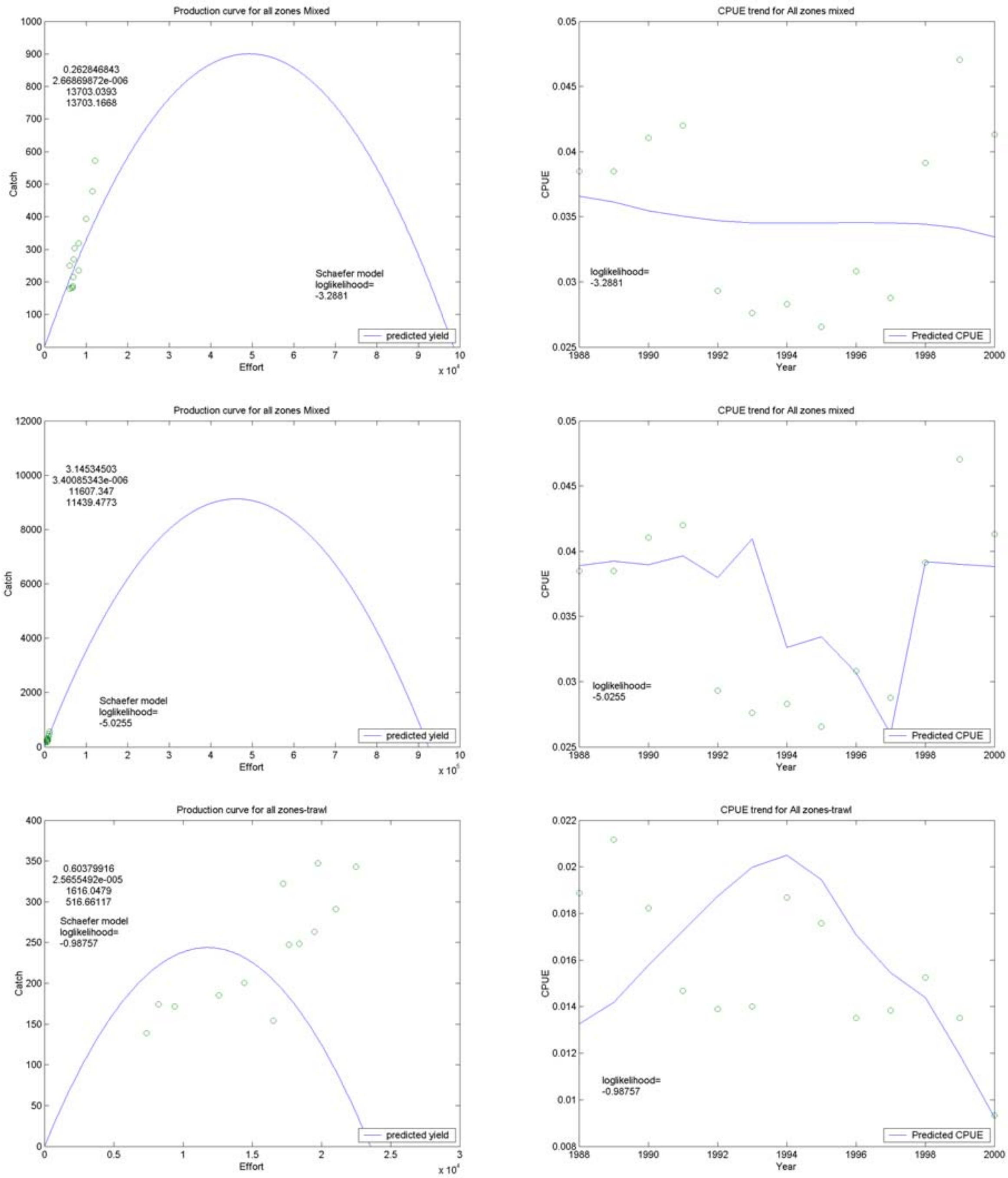


Figure 14.5 Surplus production models for commercial trawl and mixed catch and effort for all areas combined.

When models were constructed for all catch and effort throughout the state the mixed fishery models (Figure 14.5) were impacted by high values of CPUE during the early and later part of the time period. Once again none of the models provided a reliable fit to the data. Even when mixed effort data was converted to pot lifts rather than days the overall model fit was still poor.

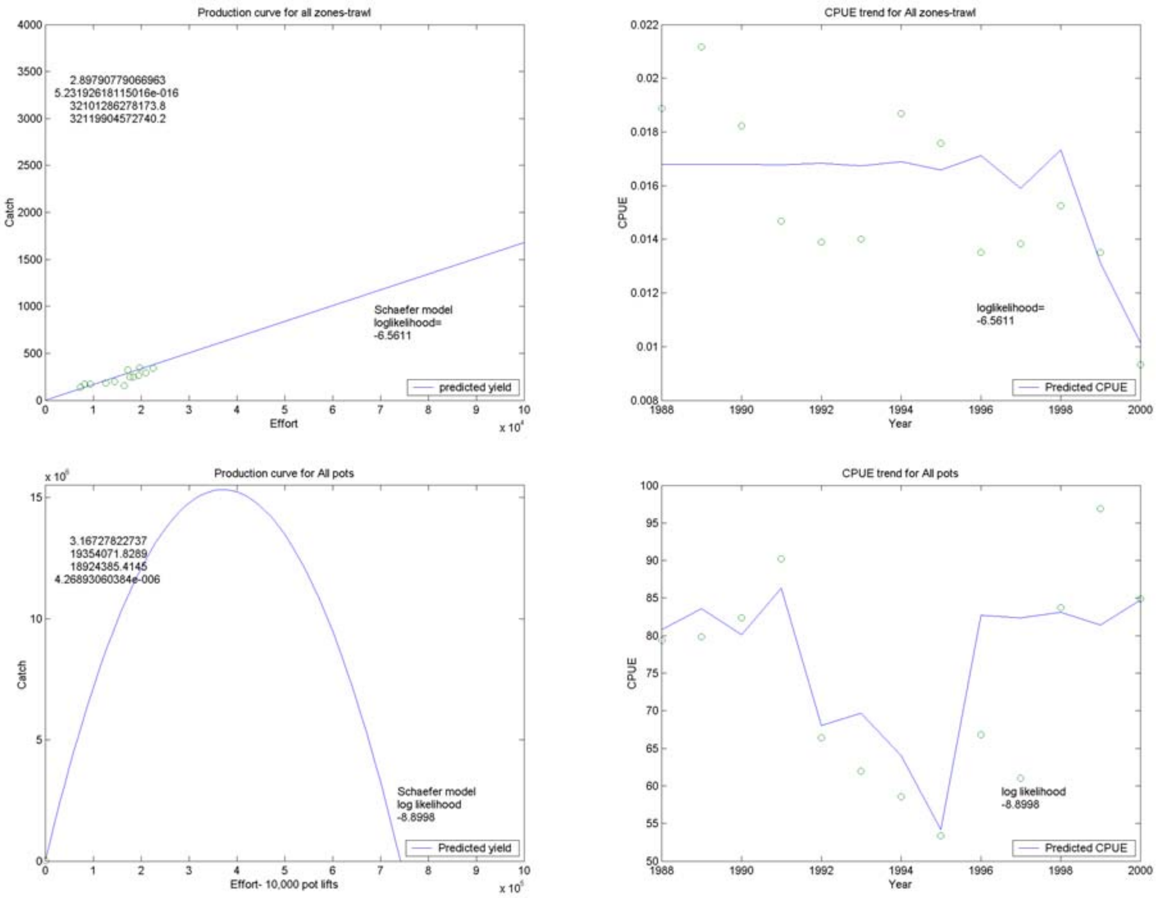


Figure 14.6 Production curves for all regions combined trawl data and pot data. (Effort for the pot data was recorded as the number of pot lifts).

It is clear that data in many occasions violate a number of assumptions implicit in the applications of the models and therefore the results in all cases must be viewed as unreliable. There was insufficient contrast in the data to adequately constrain many of the models. In many cases most of the contrast has occurred only in 1999 and 2000, which were unusually productive years. Many of the problems with the CFISH data highlighted in Chapters 5 and 6 also contributed to the poor model fit with observed data. In one or two of the models the model predictions of CPUE fit quite well with the observed figures. In particular Moreton Bay trawl and Bribie to Fraser mixed fit the data well. Overall, however, what can be said is that the lack of clearly defined equilibrium conditions in the offshore fisheries and the fact that in many cases the CPUE is still increasing in many areas means that these models may not be appropriate. We would certainly not recommend using these types of models to determine maximum sustainable yield even though this parameter is easy to calculate from these models.

15. SURVEY OF COMMERCIAL BLUE SWIMMER CRAB POT FISHERS

Introduction

One of the major problems with utilising commercial catch and effort data derived from logbooks filled out by commercial fishers is that much of the information cannot be validated. A number of concerns about the accuracy and precision of the logbook records have previously been raised (see Chapter 5). In addition changes in the fishing power of fishing fleets (effectively an increase in fishing effort) may not be detectable from logbook records as technological developments in fishing gear, vessels, electronics amongst other things can impact on the effective effort exerted by a fishery.

A further general concern of the commercial fishing industry at present relates to environmental issues and the need to minimise the impacts of fishing on both the abiotic and biotic environment. In particular minimising the interaction of fishing gears on by-catch and non-target species. It has been recognised for some time that fishing gear used by both commercial and recreational crabbers can cause entrapment and death of marine turtles which may get caught up in ropes and fishing gear. Whilst observers were used to determine the incidence of this in the commercial fishery it was recognised that broader discussions with fishers may lead to a greater appreciation of the problem and also possibly lead to the formulation of solutions. As well as the impact of gear on by-catch there are the environmental problems caused by the loss of pots and other crabbing apparatus. In pot fisheries this may include ghost fishing (see Chapter 13) by lost pots but it is also important to consider that lost gear (particular pots constructed of plastic) may persist in the environment for some time before they are degraded.

This chapter presents information, gathered by way of questionnaire, on various topical issues in the blue swimmer crab pot fishery. These included accuracy and precision of logbook records, characteristics of fishing gear and operations as well as environmental impacts.

Materials and Methods

A questionnaire was designed to gather information (See end of chapter) from all crab endorsement holders who fished for blue swimmer crabs using pots or traps. We did not survey trawl operators who retained blue swimmer crabs as by-product for a number of reasons. Firstly, the problems with the recording of fishing effort in the pot fishery are very different to those of the trawl fishery and other differences meant that the survey results were not directly comparable between sectors. Secondly, there were a number of logistic problems in interviewing a widespread group of trawl fishers many of whom caught very few blue swimmer crabs. Finally, initial contacts with trawl fishers resulted in considerable antagonism towards the questionnaire largely because of management changes and restructuring of the trawl industry that was taking place at the time. Information was therefore sought on 5 broad areas pertaining to particular fishing activities of blue swimmer crab pot fishers. These included:-

- Characteristics of the vessel
- Characteristics of the fishing gear
- Information on by-catch including by-catch of marine turtles
- Information on the accuracy and precision of log book recording practises
- Other information including general comments

In an effort to maximise the response rate of commercial operators we sought to individually contact and survey all crab endorsement holders rather than mailing questionnaires that in that past have had poor response rates. The survey was carried out by Questionnaire during the period August 2000 to June 2001 with predominantly face-to-face interviews being used to collect information. Fishers who could not be contacted in person were phone interviewed. Only fishers that were currently actively fishing were interviewed and those licensed holders that were contacted, but who fished fewer than 10 days in the previous 12 months were not included in the analysis. Of the current licence holders in the fishery the data from 66 fishers were analysed, representing about half of the license holders in the fishery.

Results and Discussion

Vessel Characteristics

Hull Length

Vessels in the fishery ranged in size from 4.2 to 12.7 metres, with the largest proportion (37%) in the 5.2 to 6.2 metre range (Fig. 15.1) and only 10% of vessels greater than 9.2 metres in length. To examine spatial differences in vessel size, vessels operating from Moreton Bay to inside Bribie were grouped into Moreton Bay; southern Bribie to Sandy Cape were grouped into Sunshine Coast; Hervey Bay and the Sandy Straits were grouped into Hervey Bay; north of the latitude intersecting Sandy Cape into Nth of Fraser, and the data re-analysed. Two vessels operating from the Gold Coast were omitted from the analysis. The majority of vessels operating in Moreton Bay were from 4.2 to 6.2 metres while vessels operating in Hervey Bay were on average larger than those of Moreton Bay, and more evenly distributed across the 5.2 to 8.2 metre range. Most of the vessels larger than 9.2 metres operated off the Sunshine Coast and Nth of Fraser.

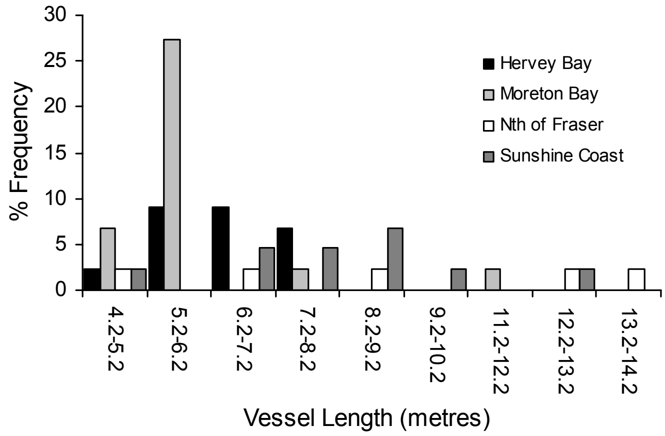


Figure 15.1 Comparison of size of vessels in the commercial pot fleet sample from Hervey Bay, Moreton Bay, Sunshine Coast and Nth of Fraser.

Cruising Speed

The majority of vessels in the blue swimmer crab fleet have cruising speeds of between 15 and 22 knots (Fig. 15.2). There are also a small number of very high-speed vessels, capable of travelling 30 knots or more, and vessels (probably displacement hulls) with cruising speeds of less than 9 knots.

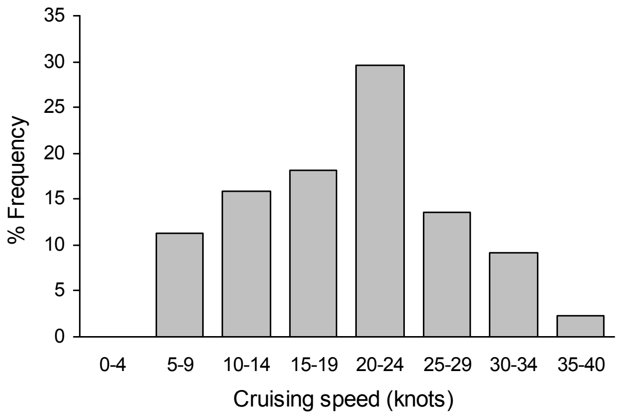


Figure 15.2 Frequency distribution of cruising speed of vessels within the fleet sample of blue swimmer crab boats.

Holding Facilities

Twenty seven percent of fishers interviewed did not respond adequately to the question of on board product holding facilities (Fig. 15.3) but it is probable that most of these maintained their product in bins without further processing. Forty-six percent of the fishers interviewed kept their product chilled, with bins and ice the preferred method. Seven percent of fishers kept their product live with mist sprays while 25% preferred to keep their product in bins, with some using wet bags to cover the product. It was clear from the results of the survey that many fishers handled their product comparatively poorly, however, none of the fishers or processors who were contacted by the research team had problems with product quality of pot caught crabs. Generally, even crabs that are just kept in bins are returned to shore within 5 hours of capture and at that stage many are still alive. The practise of most pot crabbers is to cook their crabs immediately they return to port. Historically this practise has resulted in a good quality product being maintained. Many see no advantage in increasing their overheads by using ice or other methods to improve product quality. Some fishers however did note that during the summer additional measures were required to maintain product quality because of the influence of elevated temperature on mortality.

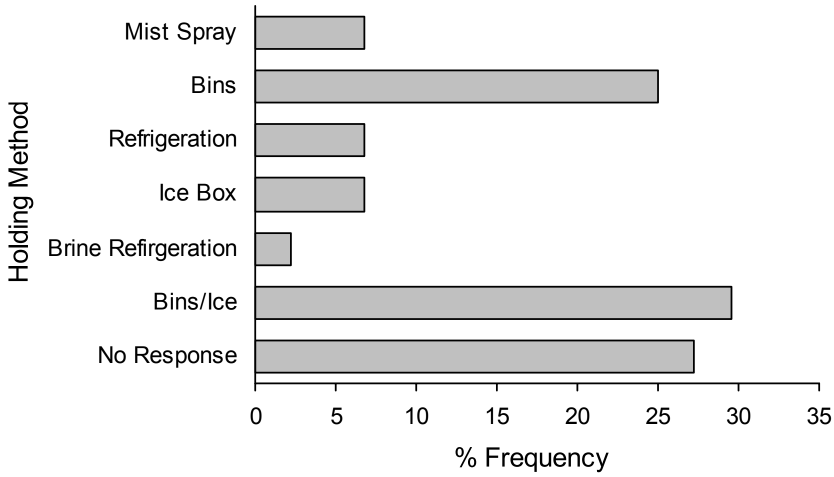


Figure 15.3 Percentage of commercial blue swimmer crab pot boats using various holding methods.

Skipper Experience

A wealth of experience is evident in the blue swimmer crab fishery, with 37% of skippers having been in the fishery for in excess of 19 years and 33% of skippers with between 10 and 15 years experience (Figure 15.4). There are relatively few skippers new to the fishery, with 9% of fishers having 2 to 3 years' experience. Responses show that 83% of fishers are owner skippers while the remaining 17% are employed skippers or skippers leasing the licence.

Figure 15.4 Level of experience (years) for owner skippers and skippers in the blue swimmer crab fishery.

Gear Characteristics

Gear Type

Seventy percent of fishers interviewed were using trawl mesh pots as the preferred gear type while 7% used a combination of trawl mesh and wire pots (Figure 15.5). Twenty percent were exclusively using the conventional wire pots and 4% used dillies.

There were a number of location specific trends in gear type used. In southern Moreton Bay there were still fishers who used the older traditional style wire pot although in almost all other areas these had been replaced by the various designs of trawl mesh pots stretched over a wire frame. Many of these pots were also collapsible although a small proportion of fishers used trawl mesh over a rigid wire frame. There was a general consensus that these pots were more efficient at catching crabs than the more traditional designs but the main reasons for using these designs were related to cost and logistics associated with transporting more gear on board vessels. Fishers stated that the life of a pot was at least doubled by using trawl mesh in preference to the wire pots that tended to rust away after a season and required rewiring. In contrast the trawl mesh pots only required cleaning and it was the wire frame of the pot which was the limiting factor of the life of a pot. Almost all pots were cylindrical with 2 entrance funnels but heights and diameters of pots varied. Most fishers claimed that they had moved towards more collapsible designs in the last 5 – 10 years.

Typically those fishers operating in Moreton and Hervey Bay tended to have their gear set as individually buoyed pots while those operating in offshore (deeper) waters usually set up their gear in “trot lines” of about 10 pots per line (see later). The trotline consists of pots attached to each other but with only a buoyed line at either end of the line.

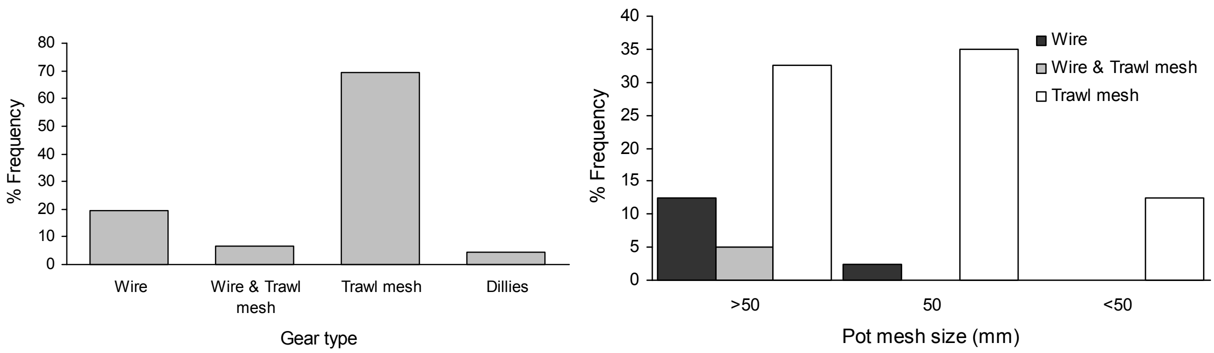


Figure 15.5 Proportion of fishers using different gear types and mesh sizes in the blue swimmer crab fishery.

Mesh sizes used on the trawl mesh pots were predominantly 50mm or greater with only 13% of fishers using mesh sizes less than 50mm (Figure 15.5). The majority of wire pots used by fishers also had mesh sizes greater than 50mm. No data was recorded for dillies as commercial fishers comparatively rarely used these. Data were originally recorded in inches and subsequently converted to the equivalent metric measurement. The majority of pots, both wire and trawl mesh pots, were between 0.9 and 1 metre in diameter and of 0.3 to 0.4 metres in height (Figure 15.6). A small number of fishers used larger pots from between 1.1 to 1.5 metres in diameter. These fishers tended to work in deeper offshore areas of the fishery, more prone to the effects of currents. In these areas larger heavier pots are preferable, as they are less likely to be moved by the current.

Direct observation and discussions with fishers showed a greater diversity in pot type used at present than was common in the fishery when the last research was undertaken in the mid 1980s. At that time pots differed slightly in overall dimensions but they were generally all cylindrical and constructed of wire over a cylindrical frame. Nowadays fishers utilise a wide diversity of apparatus with more plastics and other less biodegradable material used. An examination of the different designs available on the market to recreational fishers suggested an even greater variety of designs and material used but commercial fishers did not use most of these designs. A further recent trend was the smaller mesh size of the pots used.

While there was a range of different netting mesh sizes used, many fishers used standard trawl mesh that had a smaller opening than the more traditional wire designs. The smaller mesh size has the potential of retaining smaller fish by-catch species as well as smaller juvenile crabs. While smaller fish were clearly more common in these pots (see Chapter 12), smaller crabs were not significantly more abundant in them.

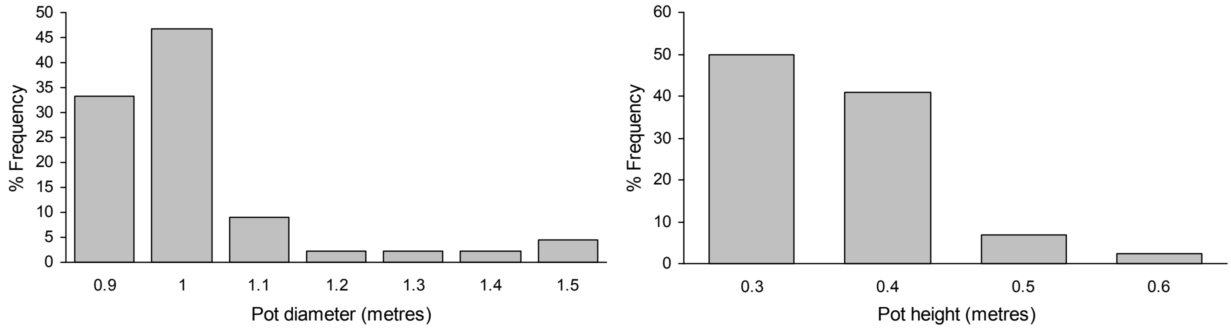


Figure 15.6 Frequency distribution of pot diameter and height (metres) for both mesh and trawl mesh pots.

Gear Configuration

The majority of the fishers in all areas set individual pots and dillies while 3 fishers on the Sunshine Coast and one in Hervey Bay used a combination of individual pots and trot lines (Figure 15.7). One fisher exclusively used trotlines on the Gold coast and 3 fishers each on the Sunshine Coast and in Moreton Bay. At the time of preparation of this report there was an increasing tendency to place pots in a trotline configuration in waters outside Moreton Bay. Because pots are generally placed in deeper waters offshore, pots configured in this way offer logistical advantage to individually set pots. There is also the advantage that trotlines reduce the interactions of gear with turtles, as there is less rope in the water column. Pots on trotlines also have the added advantage of reducing boat strikes on buoys or propellers cutting ropes. Fishers noted that accidental damage to ropes and floats by passing vessels was a major reason for the loss of pots (see later). Trotlines thus allow fishers to place pots in high traffic areas without the increased risk of gear loss due to boat strikes. When a buoy at either end of a trotline is lost fishers are often able to retrieve their gear with the aid of a grappling hook. While this is also possible with individually buoyed gear the chance of success in recovering lost individual pots is reduced particularly in the deeper offshore areas.

A disadvantage of trotlines is that trawlers that normally avoid an area when they sea buoys may be unaware that there are large numbers of submerged pots in an area and inadvertently trawl up trotlines of pots. Both commercial pot crabbers and trawler operators report that these instances have sometimes occurred.

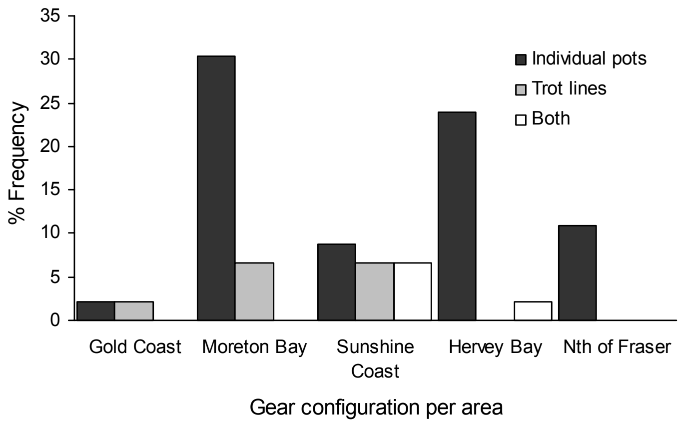


Figure 15.7 Percentage of fishers in the blue swimmer crab fishery using different gear configurations in all areas of the fishery.

Gear Change

Of the fishers interviewed about how the type of gear they used changed over time, 65% indicated that they had changed from using wire pots to trawl mesh pots (Fig. 15.8). Thirty two percent indicated that they made no change in fishing gear, but because trawl mesh has been used widely in the fishery for only the past five years and there were 11 (24%) new fishers entering the fishery in this time, the use of trawl mesh would not have been registered as a change in gear by the more recent operators. One fisher changed to using dillies as the preferred fishing method. There has thus been a clear shift in gear used in recent years.

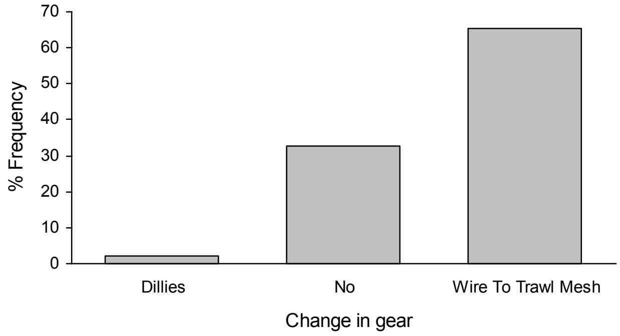


Figure 15.8 Proportion of fishers in the blue swimmer crab fishery experiencing a change in the use of fishing gear.

Gear Loss

Gear Lost In The Past 12 Months

Fishers in the blue swimmer crab fishery recorded a large range of gear loss, ranging from 0 to 400 pots (Fig. 15.9). The tightest grouping of pots lost from the majority of the areas was from the 0-9 to 30 pots lost categories. The highest numbers of pots lost, in excess of 100 pots, was largely recorded from Moreton Bay, with one fisher on the Sunshine Coast losing 100 pots and one fisher in Hervey Bay loosing 150 pots. One fisher in Moreton Bay recorded a loss of 400 pots although the accuracy of this must be questioned. Given these figures it is estimated that over 6000 pots are lost each year in the fishery. The actual proportion of these that remain in the environment is difficult to estimate as trawled pots and pots that are stolen obviously do not remain in the environment. Many fishers noted that they often had their trawled pots returned but there is also a proportion of trawled pots that are wilfully destroyed due to the inconvenience caused to trawl operators. Based on the reasons given for gear loss (see next section) it would appear that less than 50% of lost pots remain in the environment.

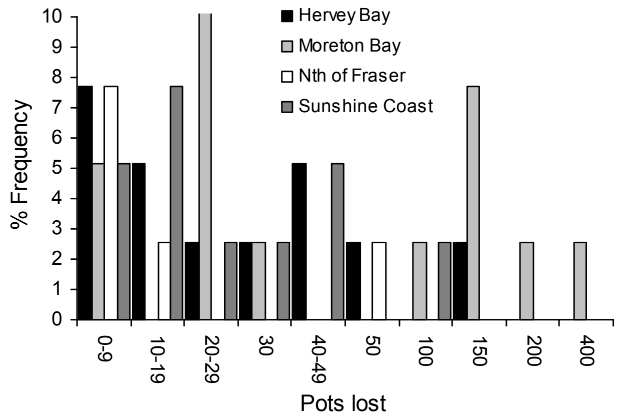


Figure 15.9 Percentage of pots lost by fishers in Hervey Bay, Moreton Bay, Sunshine Coast and Nth of Fraser areas in the past 12 months.

Gear Loss Cause

When asked the major cause of pot loss, theft was identified by 19 of the 44 fishers who responded as the sole cause and theft identified with other causes, by 13 fishers (Table 15.1). Trawlers were the second major sole cause of pot loss being identified by 7 fishers and combined with other causes, was also the second major cause identified by 9 fishers. Pot losses to passing boats was a significant cause, with tides and weather also contributing factors.

Table 15.1 Identified causes of pots lost by fishers in the blue swimmer crab fishery.

Loss cause	No. of responses
Ships	1
Theft	19
Theft, Commercial	2
Theft, Tidal Run	1
Theft, Recreational	1
Theft, Lost To Passing Boats	1
Theft, Tides, Speed Boats	1
Trawlers	7
Trawlers, Barges	2
Trawlers, Theft	6
Trawlers, Theft, Recreational	1
Turtles	1
Weather, Boats	1

Pot Loss Trends

Fishers on the Gold Coast and Nth of Fraser identified pot loss as remaining the same over the years and the majority of fishers in Moreton Bay (22%) recognised pot loss as remaining the same (Figure 15.10). Pot loss in Hervey Bay was recognised as remaining the same or being on the increase while 13% of fishers in Moreton Bay identified pot loss as increasing. The Sunshine Coast was the only fishing area to experience a significant decrease in pot loss.

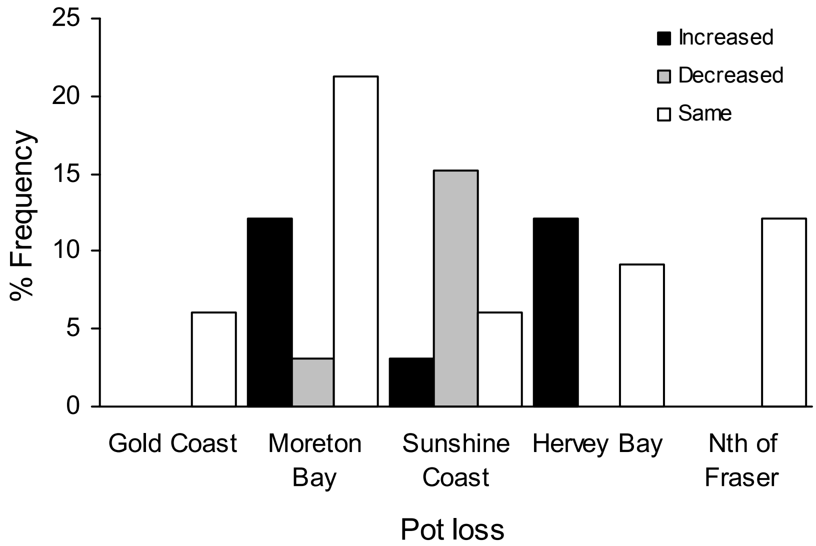


Figure 15.10 Percentage of responses by fishers in all areas of the blue swimmer crab fishery to the perception that pot loss has increased, decreased or remained the same.

Turtle and by-catch information

Very few commercial fishers claimed to have seen dead turtles entangled in fishing apparatus however most described incidences where they had freed turtles that had become entangled in their buoyed ropes attached to their pots. Most fishers did not perceive that there was a problem with turtle interactions but many agreed with the point that turtles could be entangled with gear, dragging the gear away from the fishing grounds and subsequently drowning. These turtles may not be detected by fishers who would only note that one of their pots was missing and possibly blaming that loss on trawlers/theft etc. When asked of ways to minimise turtle interactions fishers noted that pots on trot lines and a lead weight a couple of metres below the float would minimise the number of rope entanglements. Most fishers already do the latter.

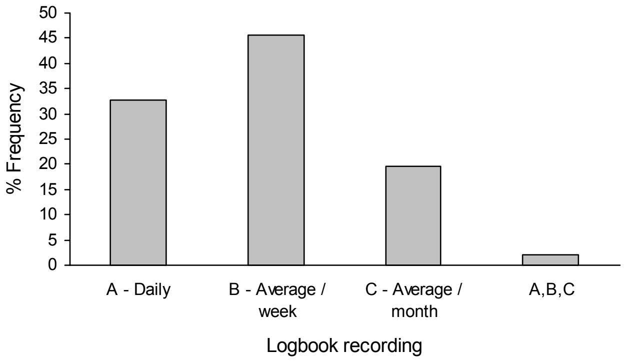
Only one of the fishers interviewed said that he had seen a turtle entangled in the pot itself. All fishers who had used wire pots in the past described numerous instances when turtles had damaged pots (particularly older weaker pots) by tearing out the wire to gain access to the bait. Many fishers also described how turtles would often push their head in through the funnels of wire pots to gain access to crabs and bait. Often these funnels were pulled inside out as the turtle removed its head. All fishers believed that turtles getting caught by this means was rare a rare event but most acknowledged that ropes were the main cause of entanglement with crab pots. The newer, trawl mesh pots were universally acknowledged as being less able to be entered and damaged by turtles.

When asked about the incidence of turtle interactions most fishers were unable to provide an answer as they generally reported few interactions, however only one fisher reported an overall increase in interactions. Fishers in Moreton Bay in particular noted that there were certain areas (such as the Amity banks in southern Moreton Bay) where turtles tended to be more abundant and more likely to interact with fishing apparatus.

Logbook Data Reliability

Logbook Recording

When asked whether they recorded logbook data either on a daily basis, averaged over the week or averaged over the month, the greatest proportion (46%) recorded logbook data as an average over the week (Fig. 15.11). Thirty three percent recorded their logbook data daily and 19% as an average per month. One fisher responded as recording logbook data by all three methods. While the practise of data averaging does not decrease the overall precision of some forms of analysis (particularly if monthly totals are still accurate) it does limit the information that can be gained from small scale temporal analyses of the data (such as that attempted in Chapter 7)



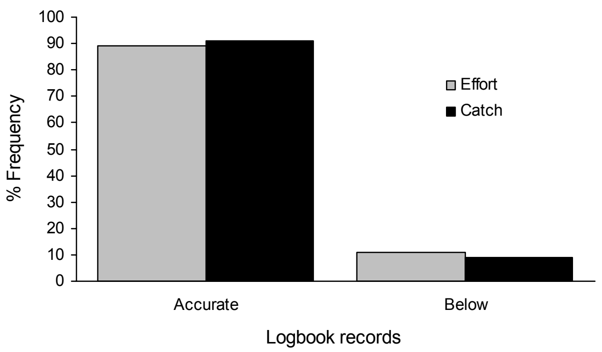


Figure 15.11 Proportion of fishers in fleet sample recording logbook data daily, averaged over the week, averaged over the month or as a function of all three.

In the next question fishers were asked if their logbook catch and effort records were above, below or accurate figures. As expected, roughly 90% responded as having accurate records to both catch and effort and the remainder as having below catch and effort figures (Figure 15.11). No fishers claimed that they inflated either their catch or effort records. Fishers generally were also willing to more accurately record the number of lifts they undertook rather than recording the number of pots used.

Other Information

When asked questions about how crabbing had changed in recent years there was a diversity of responses which appeared to be related to both crabbing experience and the area fished. The majority of respondents in the established Moreton Bay fishery, and less in Hervey Bay, said they weren't fishing further from port (Figure 15.12). This is possibly the result of geographical constraints of embayment fisheries. A small proportion of fishers who were now operating on the Gold coast, Sunshine coast and Nth of Fraser were fishing further from port.

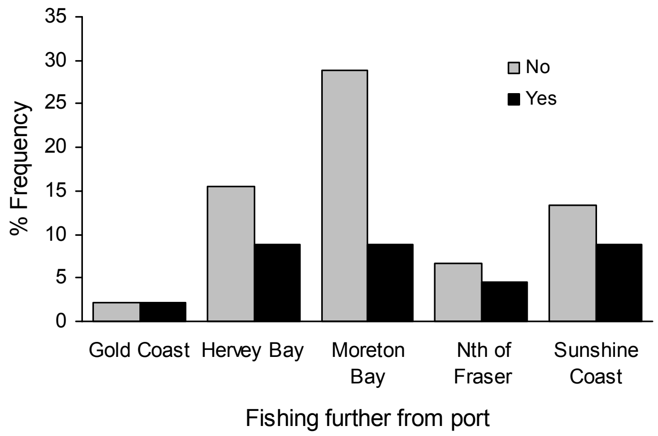


Figure 15.12 Perception of fishers about whether they are fishing further from port from when they first entered the blue swimmer crab fishery.

Generally fishers on the Sunshine Coast and Nth of Fraser said their catch rates have remained the same or increased (Figure 15.13). Fishers operating on the Gold Coast said catch rates have remained the same. Catch rates in Hervey Bay have been perceived as remaining the same or decreasing while the majority of fishers in Moreton Bay said catch rates remained the same, with a small proportion experiencing decreased catch rates and one fisher recording an increase.

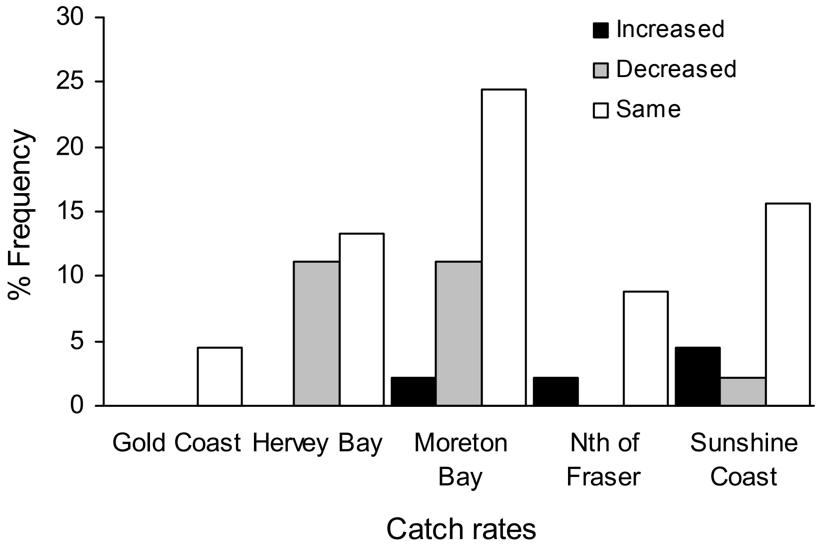


Figure 15.13 Perception of fishers about whether their catch rates have increased, decreased or remained the same from when they first entered the blue swimmer crab fishery.

Income Derived from Fishery

Forty six percent of fishers surveyed in the blue swimmer crab fishery derive up to 20% of their income from crabbing (Fig. 15.14). Twenty nine percent earn more than half their income from the fishery, while

16% derive just under 50% of their income. Only seven percent of fishers recorded crabbing as their sole source of income.

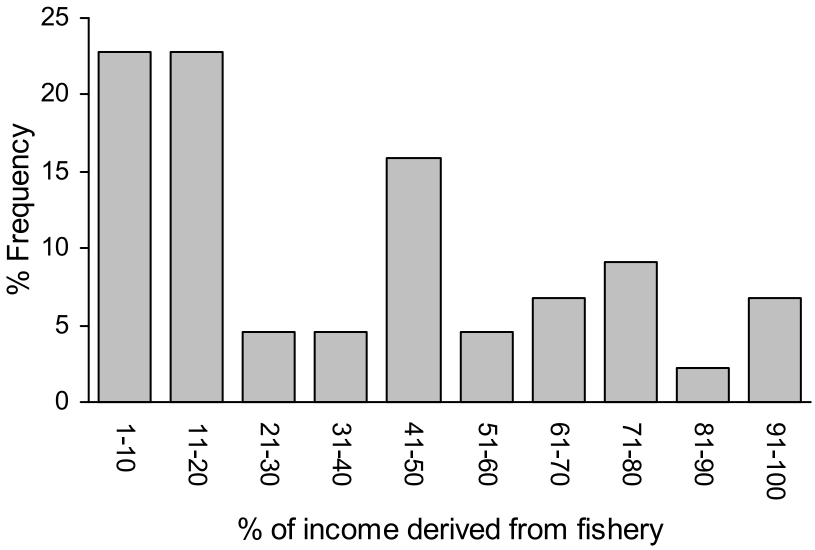


Figure 15.14 Percent of income derived by fishers of the fleet sample from the blue swimmer crab fishery.

One of the most important questions asked to fishers was whether they retained "tippers", and also whether they recorded these in their log returns. There was a very wide range of responses to these questions. Virtually all fishers who fished in Moreton Bay kept "tippers" and most also claimed to record all these crabs in the logbooks, however this practise was not universal. The majority of fishers who fished outside Moreton Bay claimed to not keep tippers. These responses were confirmed by the analysis of the observer recorded size information which showed a significantly higher proportion of smaller crabs landed from Moreton Bay when compared to elsewhere in the fishery.

Questionnaire Completed by Commercial Pot Crabbers

BLUE SWIMMER CRAB FISHERY QUESTIONNAIRE

COASTAL AND ESTUARINE FISHERIES RESEARCH GROUP

SOUTHERN FISHERIES CENTRE (AFFS)

JUNE 2000

Vessel characteristics

Length: ☐ metres

Cruising speed (approx) ☐ Knots

On-board catch holding facilities (eg. mist sprays, refrigeration)____________________________________

Is the vessel predominantly skippered by the owner Y N

How long has the main skipper been involved in BSC fishery? ☐

Gear characteristics

Collapsible Y N

Material of construction (A) metal wire on steel frame

(B) trawl mesh on metal frame

(C) other (Specify)________________________

Mesh Size <2in >2in Number of funnels ☐

Diameter (m) ☐ Height (m) ☐

What is the common configuration of the gear you use (Circle)?

Individual pots or Trot Line (Number of pots in line) ☐

Number of pots you have lost and never seen again in last 12 months ☐

Has pot loss increased decreased or remained the same over the years (circle)

Major cause of pot loss (circle) trawlers theft turtles other ☐

Which areas do you predominantly fish? ☐

How has the type of gear you use changed over the years?

Turtle and by-catch information

Are turtles common in your main fishing grounds?

Number of turtles caught and released unharmed in last 12 months.

Tangled in trap   Tangled in rope

Number of turtles caught but dead in last 12 months

Tangled in trap   Tangled in rope

Have turtle interactions been on the increase or decrease in last 10 years.

Are there any ways that interactions with turtles could be minimised?

Other information

Since you started crabbing how has crabbing changed?

Using more pots? (% more or less)

Fishing further from port?   Y   N

Catch rates? (Circle)   increased   decreased   same

What proportion of your income is generated from the BSC fishery?

Any other comments you would like to make?

Logbook data precision and accuracy

Does a large proportion of your catch have damaged spines? ☐

Are crabs with damaged spines included in your logbook records? ☐

When you record logbook data do you (tick)
- ☐ Record daily?
- ☐ Average over the week?
- ☐ Average over the month?

Are your log book catch and effort records above, below or accurate figures

Effort ☐ Catch ☐

Would you be prepared to more accurately record number of lifts? ☐

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16. FUTURE MONITORING

The blue swimmer crab fishery is a valuable commercial and recreational fishery to Queensland and is one that warrants ongoing monitoring in order to achieve a continued sustainable harvest. At present the only monitoring that is regularly conducted is as a part of the annual fishery independent scallop survey of the Hervey Bay region. During this survey blue swimmer crabs are also sampled (see Chapter 11) and relative abundance estimates are calculated. Due to the fact that the fishery is now predominantly a commercial pot fishery it is advisable to at least continue with some form of fishery dependent monitoring of the pot fishery. This is because most commercial pot fishers are willing to assist with research and monitoring by readily allowing observers onto their boats. The nature of pot fisheries also means that it is difficult for fishers to manipulate the areas in which they fish to give a biased view of their catches and by-catch. It is certainly possible for fishers not to check all their pots, however fishers are unlikely to be able to reposition their pots prior to a trip by an observer. Observers also enable the by-catch and turtle interactions to be monitored in a more robust manner than just relying on logbook records. Power analysis suggested that fishery dependent monitoring of size and catch rate was an effective way to monitor the pot fishery, particularly for monitoring change in size. Collection of samples from the pot fishery is not a reliable method of collecting some biological information due to the selection against recently moulted as well as pre-moult crabs. Yet information about parasitism and spawning, amongst other things, correlates well with independent samples taken using research trawls (see Sumpton *et al*. 1989).

Due to its importance to both the commercial pot and trawl fishery as well as the recreational pot fishery and its proximity to the states biggest centre of population it is important that the Moreton Bay fishery is monitored. This is also the area with the longest exploitation history and also has the highest exploitation rate. The use of an independent survey to monitor blue swimmer crabs in Moreton Bay may be a useful way to achieve this although power analysis indicates that over 100 sites would need to be incorporated into the survey. Such a survey has additional advantages of being able to monitor other species in addition to blue swimmer crabs.

As mentioned earlier the independent monitoring of blue swimmer crab stocks by way of megalopae relative densities in plankton is not advisable but the use of megalopae collectors still warrants further investigation due to their success in other portunid fisheries overseas. At this stage too little is known however to incorporate megalopae collection into a monitoring program.

17. GENERAL DISCUSSION

CFISH data discrepancies

There are a number of features of the CFISH data that require immediate attention in order to increase the accuracy and precision of some of the parameters derived from models that use these data. The lack of fit of some of the models can be partially attributed to problems with the reporting of both catch and effort in the CFISH system.

Due to differences in the size of crabs caught in the offshore areas compared with Moreton Bay it is also advisable to have different "weight to number" conversion factors for the different regions of the fishery since crabs are on average about 25% larger in the offshore areas of the fishery. We attempted to get information from fishers with which to standardise both catch and effort since the beginning of the logbook program but found that the process was too unreliable due partly to different operators and the small-scale nature of many of the fishers. Errors in effort recording are perhaps the most critical to fix in order for the fishery to be monitored effectively using logbook data. It is vital that the number of lifts recorded is accurate. The current restriction of 50 pots per fisher is almost impossible to enforce and is widely abused in the fishery. Indeed in some areas of the fishery at times of low seasonal catches it is virtually impossible to be economically viable using 50 pots. However this form of effort control is probably one of the simplest (and potentially effective) controls that can be placed on the fishery.

There is also a wide range of practises that fishers use for recording "tippers"(crabs that have damaged spines). These are the crabs that are effectively less than the minimum legal size of 150 mm but because they have damaged spines they can be measured by the alternative "underbody measurement". Some fishers record these in their logs as part of their catch while others do not. Whatever change in management is envisaged it is vital that there is no incentive to inaccurately record both the number of pots used and the actual catch. It is important that everything that is landed is recorded in the logbook system. From observer trips carried out in the 1980s and the current research it is clear that individual effort has effectively increased, yet this is not obvious from an analysis of the logbook data. Some long-term participants in the fishery are now using more than 30% more pots than they were 15 years ago.

Trawl effort in this fishery is also problematic. Much of the trawl effort in areas outside of Moreton Bay is probably in areas where catch rates of blue swimmer crabs are very low (or even zero) yet this effort is often included in the analysis because of the problem of spatially segregating the data. Most trawl shots in Moreton Bay have the potential to catch crabs so this problem is not as great in this area. Certainly the independent beam trawl survey using much smaller and less efficient gear than that used by the commercial fleet caught blue swimmer crabs at most sites in Moreton Bay. In contrast to this many of the trawl shots outside the Bay failed to catch any blue swimmer crabs.

Impact of trawling on blue swimmer crab fishery

Despite the greater risks associated with the capture of blue swimmer crabs by the trawl method available evidence suggests that trawling is not having a dramatic detrimental effect on the blue swimmer crab stocks. It would be interesting to determine the catchability of blue swimmer crabs to trawling as experiments carried out using trawls and pots in an area have generally shown much higher catch rates in pots compared with trawls given the likely area that each method effectively covers. This observation was not objectively quantified in this study but a number of fishers regularly trap on trawl ground during weekends when trawlers are prohibited from operating in Moreton Bay. At times their catch rates exceed 4 per pot. During the same time of the year trawlers working in the same area were landing fewer than 80 crabs after 8 hours trawling. Although the effective area of attraction of baited traps is not known, swept area calculations for trawlers (usually towing twin 4 fathom nets at a speed of 2 knots) suggest that pot catchability is much higher than trawls.

Recent changes to the trawl management plan which have allowed by-catch limits for blue swimmer crabs of 100 inside Moreton Bay and 500 elsewhere are broadly supported by the analysis of regional catch and effort data. Information suggests a 6 times differential between the two areas but there are additional discard concerns with the Moreton Bay fishery due to the large numbers of small crabs that are inadvertently caught compared with the offshore fisheries that catch few immature crabs.

Discard mortality in trawl and pot fisheries

Discard mortality of blue swimmer crabs should not be a major problem in either the trawl or pot fisheries. Of the two methods of capture, trawling poses the greatest risk since it catches a high proportion of smaller individuals, it inherently causes more damage to the crabs and exposure times before crabs are returned to the water can be longer. However, some sorting practises of pot crabbers are more damaging than those of some trawl operators. Pot fishers may check 20 or more pots before sorting their catch resulting in crabs being exposed to the air for 30 minutes or more before they are returned to the water. On the other hand, best practise handling procedures of some pot fishers can result in undersized and female crabs being back in the water less than 30 seconds after removal from the water. There is evidence from both tagging studies (Potter *et al.* 1994) and mortality trials from this research and Western Australia (Melville-Smith *et al*. 2001) which indicates that mortality of trawled and pot discarded blue swimmer crabs is comparatively low. In both fisheries steps should be taken to minimise the amount of time that crabs are exposed to air before they are returned to the water. Over the years there have been informal arrangements to ensure the survival of discarded blue swimmer crabs. These have involved the use of mist sprays on sorting trays as well as practises to ensure that crabs are sorted within a "reasonable" time after being removed from the pot. As is the case with most fisheries the practises employed by various fishers varies dramatically from sorting each pot immediately it is lifted to sorting the entire catch at the end of the day. Certainly the latter practise results in unnecessary mortalities of discarded crabs since few would survive being kept out of water for up to 5 hours. There are also difficulties in being too prescriptive with sorting practise regulations and there is a need to ensure that whatever regulation is in place is also enforceable by compliance officers. If crabs are sorted immediately after each pot unnecessary damage may also be caused to both the marketable and discarded portions of the catch. This is because crabs remain quite active for several minutes after being placed in a sorting tray, tending to grab at everything with their claws. During this time they may lose claws and legs if they are moved around and sorted as they will continue to hold on to one another inflicting damage as they are prised apart. Normally after a few minutes the crabs have settled down enough to make sorting easy and less likely to damage crabs.

The practise of placing crabs in an ice slurry prior to sorting (as is commonly used in Western Australia) reduces the damage to crabs but there is the additional problems of mortalities related to cooling discarded crabs as well as the additional cost pressures that such a process places on fishers. The mortality rates caused by this sorting practise are described in Melville Smith *et al*. (2001) but it is doubtful whether it would be warranted in most areas in Queensland.

Damage and product quality

Trawling causes greater damage to both retained and discarded blue swimmer crabs as previously mentioned. Overall the product quality of trawl caught crabs is lower but this does not need to be the case as best practise cooking and handling practise could greatly improve the quality of trawl caught product. Some trawl operators do produce a high quality trawl caught product but the practise of cooking frozen green crabs which is still common in the fishery continues to produce an inferior product that often has a negative effect on the market. Factors affecting product quality have been addressed by recent research in Western Australia and by previous research in Queensland. It would be beneficial to once again brief industry on the best handling and cooking practises and we intend to address this by conducting industry meetings to educate fishers about handling practises at the same time as briefing them on the results of this research.

Environmental influences on catch.

We have established that short-term fluctuations in catch rates are not determined by temperature but insufficient environmental data is presently available to determine the broad scale environmental effects on seasonal catch rates. Yet we believe that other abiotic variables may play a significant role in determining the success of particular years recruitment to the fishery. Such a relationship will only be possible to determine when a longer environmental data series is available with which to correlate catches.

Megalopae collectors and megalopae in the plankton

Megalopae collectors were trialled as part of a related project conducted by Dr Greg Skilleter from the University of Queensland. Unfortunately these did not prove highly effective at catching large numbers of blue swimmer crab megalopae, although megalopae from a range of other species were collected (similar to those found in the plankton as part of this project). Despite this we believe that some type of megalopae collection device may be useful in helping to predict the strength of subsequent recruitment. Plankton collection of megalopae however is not recommended due to the large spatial and temporal variance in density and the lack of clear understanding of factors affecting their density. It was clear that despite some spawning throughout the year it was the spring spawning that was providing the bulk of the megalopae and recruits to the fishery.

Similar biology to previous work

In general there appears to be little difference in the key biological characteristics of the blue swimmer crab between the embayment areas that have a long exploitation history and the more recently exploited offshore areas. Levels of parasitism are comparable, as are the key characteristics of fertilisation rates and spawning season. Parasitism by *Sacculina granifera* is not as great in the offshore areas and levels of parasitism in Moreton bay have not changed dramatically since research conducted during the mid 1980s. Microsporidain prevalence has also changed little in the population.

In addition, the symbiotic association of the barnacle *Octolasmis spp* with the blue swimmer crab suggests population differences outside and inside Moreton Bay despite the fact that the populations are genetically homogeneous (Chaplin *et al*. 2001). Results of a number of independent surveys support the observation that blue swimmer crabs are primarily estuarine dependent in the early phase of their life. One of the best pieces of evidence for this comes from the scallop survey where a progressive decline in abundance with increasing distance out of the estuarine environment of Hervey Bay.

One of the important areas for future research relates to accurately determining the longevity and moulting frequency of crabs once maturity is reached. There are good data available now from a number of sources that provide growth estimates of crabs up to about 120-cm carapace width. Despite this, growth of crabs greater than this size is poorly understood due to blurring of size frequency modes and insufficient tagging growth data. Based on the size of crabs in the offshore fishery (which can reach over 220mm CW) it is likely that growth parameters derived from modal length frequency information are biased.

The fisheries with the longest history of exploitation are also the ones that have the more abbreviated size structures and higher total mortalities but they may also be the main nursery areas contributing crabs to the less heavily exploited offshore areas. It is not possible to say with certainty that the offshore areas are solely fed recruits from the inshore fishery but there are several lines of evidence that support this view including - (1) The lack of juveniles in trawl catches in offshore waters, (2) Size frequency data which show an abundance of pre-recruits from inshore waters with a general increase in average size of blue swimmer crabs related to increased depth.

Female mortality differed dramatically among the different regions despite females not being fished. In Hervey Bay the total mortality of females actually exceeded that of males. This is most likely a spurious result brought about by inaccuracy in growth estimates, particularly the estimates post maturity. But females that are not exploited have a similar population structure both in inshore and offshore waters. It will be interesting to monitor the change in size structure of the offshore component of the fishery as it develops further in future years. Given the rapid growth rate and short life cycle it is expected that the level of exploitation in the offshore areas could have resulted in a reduction in the proportion of larger individuals in the catch by now (particularly in Hervey Bay). Yet this was not really evident in the data.

By-catch and ghost fishing of pots

Lost blue swimmer crab pots are considered an environmental hazard by conservation groups since they remain in the environment and are slow to degenerate because of the use of synthetic material (particularly trawl mesh) that persists in the environment for many years if a pot is lost. In some areas, particularly in high current areas offshore, the movement of bottom sediment quickly buries lost pots but in other areas they persist on the surface of the seabed for long periods. Lost pots also continue to attract crabs even though the bait is exhausted. While fish may enter the pot, die and then serve as a source of bait, crabs also appear to enter empty unbaited traps. The older style traps that were made exclusively of wire and steel did not pose as much of an environmental threat because they rapidly rusted away. Nowadays the frames of pots are made of thicker steel resulting in a longer life and therefore a much greater ghost fishing potential than the full wire pots. Trawl mesh and other plastics used in pot construction add to the environmental risk of pots. In comparison to other forms of fishing, however, pots have the advantage of being highly target species specific and generally posing few by-catch problems.

The by-catch of seabirds is a problem overseas but this appears to be a minor problem in the blue swimmer crab fishery being restricted to pots placed in shallow waters. In over 200 observer trips on board commercial vessels only three dead trapped seabird was encountered in traps but fishers do note that at times sea birds are caught in traps. This appears only to be a problem when pots are placed in shallow water and are visible to the birds.

The capture of threatened sea turtles by crabbing apparatus (predominantly float ropes) is a significant threat to the industry. Once again in over 200 observer trips only 1 sea turtle was seen entangled in blue swimmer crab trapping apparatus and this turtle was released unharmed. Interviews with fishers also indicated that encounters with turtles were rare. However entangled dead turtles continue to be found in crabbing apparatus. As mentioned earlier once a turtle is entangled in a rope it may drag the apparatus out of position and thus not be found by fishers. The pots used by commercial fishers do not entangle turtles but some collapsible designs sold mainly to recreational anglers do snare turtles. These traps usually have a rigid entrance capable of snaring a turtle by the neck when they try and access the bait through the funnel entrance. The softer entrances of trawl mesh pots pose no such threat to turtles.

There are measures that can be taken to minimise the entanglement of turtles in the buoyed ropes lines attached to pots. These include placing traps on trot lines, minimising the amount of rope used and placing a weight a couple of metres from the buoy to limit the amount of rope on the surface during times of slack water. The lack of observed interactions with marine mammals suggests that the pot fishery poses no real threat to these animals.

The bait used in traps also attracts a wide range of fish species to pots. Many of these readily enter the pot via the funnels and consequently become entrapped. Many fish and other species have been recorded in crab pots (see Chapter 12) but overall the impact of discarded by-catch species can be regarded as low due to the high ratio of target species numbers to by-catch numbers. In addition, the fishery generally takes place in shallow areas (<50m) that minimises the effects of barotrauma on discarded fish species. Best practice handling procedures also enable fish to be returned to the water shortly after capture. Despite this by-catch could be further reduced by either the introduction of escape gaps or a larger mesh size of pots.

It was interesting that the smaller mesh size used in the trawl mesh pots was not responsible for significantly increasing the catch of smaller undersized blue swimmer crabs. This is despite the fact that the mesh size would normally retain crabs as small as 70 mm carapace width. It is purely the non-target species by-catch components that are increased by the smaller mesh size of the trawl mesh pots. It appears that small immature crabs will not enter pots as easily as adults of the species. These small crabs are known to be attracted to the bait used in the pots so this may be a behavioural response where hierarchical interactions prevent smaller crabs from entering pots. Alternatively it may be related to smaller crabs being less able to walk up and across the mesh used in the construction of the funnels.

Whatever the reason this behaviour is beneficial to the fishery as it reduces sorting times and minimises discard rates of undersized individuals.

Modelling and current management arrangements

The current management practises for the blue swimmer crab fishery have remained virtually unchanged for many years despite considerable changes in the fishery. Since the pot fishery became established in the 1950s effort has been transferred from the western part of Moreton Bay to the entire Bay and in the last few decades to offshore waters. Results of research in Western Australia and South Australia suggest that the biology of the species does not differ dramatically throughout its range. Despite the similarity in biology of the blue swimmer crabs among the various states where the fishery operates and the common practise of using input controls such as a minimum legal size to manage the fisheries the size limits differ dramatically between the States. In Western Australia there is a minimum size of 128 mm but fishers in some areas have implemented a minimum size of 135 mm for marketing reasons. In South Australia the size limit is equivalent to 130mm but there the size is measured across the base of the spines rather than tip-to-tip. This is the preferable method since it is a much better indicator of the weight of the crab than the spine measure since crabs can have very long spines. This has previously been pointed out (Potter and Sumpton 1986) and it is not our intention to further discuss the issue here.

The taking of females has also been a contentious issue since Queensland is the only state that offers complete protection to female crabs. The question of taking female crabs is a complex issue and one which is difficult to model given our lack of understanding of the stock recruitment relationship for blue swimmer crabs. Certainly theory suggests that at high spawning stock levels recruitment may be lowered due to density dependent effects. From a biological point of view there is no reason why females should not be exploited but there are a number of marketing and economic concerns that suggest caution. The development of an export market may provide a greater incentive to re-examine the question of marketing females. Prices on the local market are to some extent driven by supply so an increased total catch due to the ability to market females would probably cause a reduction in the wholesale price for crabs and therefore have only a marginal impact on increasing profits of fishers. It also has the risk of stock collapse due to possible overexploitation of females, which given the high fishing mortality of male crabs, is a legitimate concern. Both tagging studies and mortality estimates derived from catch curves indicate that fishing mortality on males is high. The tendency of crabs to segregate by sex, with females being more abundant on shallow sandbank areas means that changed targeting practises towards females may result in unpredictable impacts. In Western Australia where the take of females is allowed, fishers sometimes voluntarily avoid catching females for marketing reasons (Melville Smith *et al*. 2001).

The argument for taking females has often included statements about large females being reproductively inactive having achieved their full reproductive potential, producing all their egg batches. However the size structures of both mature and ovigerous females do not differ significantly and thus it is impossible to tell (based on size) whether a female has produced all their eggs.

Anomalies in the fisheries regulations in Queensland with respect to the two ways of measuring crabs have essentially allowed a defacto size limit of about 138 mm to be implemented in parts of the fishery. The majority of recreational fishers do not use the underbody measure and a proportion of fishers operating outside Moreton Bay also do not keep the crabs less than 150 mm that have broken spines. In Moreton Bay, however, during some times of the year the proportion of the marketed catch that is less than 150 mm can exceed 50%.

The use of trotlines in this fishery should be encouraged since they would reduce the interactions of turtles with crabbing gear. However they are probably not as useful in Moreton Bay due to the patchy distribution of crabs and the generally shallower conditions inside Moreton Bay. Much of the crabbing areas in Moreton Bay are located in less than 20m of water and it is not efficient to set pots on a trot line in such shallow areas as the appropriate distance between pots is greater than the length of rope used on individual pots. Crab fisheries in deeper waters however benefit from the ability to place pots on a trotline should fishers so wish.

The short-term impact of any proposed change in management would impact differently in each region. Increases in minimum legal size (or the effective enforcement of the current MLS of 150mm) would cause almost a 50% reduction in catch in the Moreton Bay while having virtually no impact on the income of fishers in Hervey Bay. While it can be argued that this effective increase would quickly be compensated by an increase in the weight of crabs caught as crabs grew. This conclusion is not supported by the available modelling information and other observations about the fishery. There has effectively been a 138mm size limit in some areas of this fishery for the last few decades, firstly as a result of a regulation anomaly which allowed fishers to remove the carapaces of slightly undersized crabs and more recently by changes which prevented this practise but allowed fishers to use an alternative measure if spines became damaged.

Method of measurement

The current method of measurement used for blue swimmer crabs in Queensland (carapace width spine to spine) is certainly not the preferred method. Arguments for this have already been made in length in Potter and Sumpton (1986) and Sumpton *et al.* 1999 and it is not our intention here to repeat the pros and cons of the other ways of measuring crabs. It is clear however that all states would at least benefit from a common way of measuring blue swimmer crabs (and indeed other fisheries resources), particularly given the importance of national competition policy. At present there are 3 main methods of measurement and all states have a slightly different effective minimum legal size. NSW uses carapace length, West Australia, Queensland and the Northern Territory use carapace width, while South Australia utilises a base of spine measure. From a biological point of view the base of the spine measurement is clearly the preferred method.

18. BENEFITS

The project has provided a number of benefits and added to our understanding of the fishery and population dynamics of the blue swimmer crabs.

- An observer-based program demonstrated that bycatch issues were not a major cause of concern. The incidental entanglement of threatened turtles was identified as a problem that can be partially addressed by the minimisation of the number of ropes in the water. A code of conduct currently being prepared by the QSIA should help to address some of the turtle related issues in the pot fishery.
- Ghost fishing of lost apparatus was recognised as an environmental threat that can be minimised by the introduction of corrodible panels in traps that cause them to collapse after a period of time.
- The project confirmed that under current management practises there are no sustainability concerns about the blue swimmer crab fishery. The project also identified considerable scope for increased production under modified management arrangements related to the reduction of the minimum legal size.
- Confirmation that the data currently collected as part of QFS long term monitoring was providing data that was useful for monitoring parts of the fishery.
- A number of problems were identified with the recording of both catch and effort in the CFISH logbook system and recommendations were made to address these problems. The implementation of these suggestions will increase both the accuracy and precision of estimates derived from blue swimmer crab data held on the CFISH system.
- Estimates of biological parameters suggest that there have been no major population changes in Moreton Bay in that last 15 years.
- The establishment of a long term temperature monitoring program throughout Moreton Bay as part of this research has already benefited other authorities by providing data which can be `linked to other biotic events such as outbreaks of the toxic algae *Lyngbia.*

19. FURTHER DEVELOPMENT

A number of areas of further development exist:-

Despite considerable efforts over a long period of time a cost effective and logistically practical method of tagging blue swimmer crabs (and other crab species) remains a challenge. No externally visible tag that is reliably retained through several moults has been developed despite considerable research.

The importance of areas such as Moreton Bay and Hervey Bay as nursery areas for blue swimmer crabs is still not fully established. Efforts to tag large numbers of blue swimmer crabs in the 1980's failed to demonstrate the migration of large numbers of crabs out of Moreton Bay. This was probably due to a lack of fishing effort in offshore waters during that time. A tagging program carried out nowadays when offshore effort is considerable would help to determine the importance of Moreton Bay to the success of the offshore fisheries. As mentioned earlier, however, this objective is complicated by the lack of a suitable externally visible tag that can be used to mark crabs. It was originally intended to explore the option of tagging crabs if an effective tagging protocol was developed as a result of tagging work in other states. Unfortunately, as mentioned above a suitable tag is yet to be developed.

Megalopae collectors did not prove to be a highly efficient method of catching large numbers of blue swimmer crab megalopae yet the success with which these collectors have been used to monitor stocks of blue crabs *Callinectes sapidus* in the USA suggests that these should be further researched.

Sperm limitation has been demonstrated in other crustacean fisheries around the world. In this study it was investigated via an analysis of the fertility rates of eggs and the number of eggs in egg-masses. However, this proved an imprecise method as the size of egg-masses is known to vary depending on which batch of eggs is extruded. It would be informative to develop techniques that would enable the determination of whether crabs were carrying their first, second or third batch of eggs in the particular moult that they were sampled. It is often easy to determine if crabs have spawned before due to the condition of the pleopods, and the "stained" nature of area surrounding the underneath of the carapace but the particular batch is still indeterminate.

The recommendations from this research (see Chapter 21) have also been discussed with the Resource Manager in Queensland and are in the process of being put for public discussion prior to the introduction of any management change. Without pre-empting the results of the consultation there appears to be widespread support for a change in the method of measurement and support within industry for changes in the gear to further reduce bycatch in the fishery.

20. CONCLUSIONS

Achievement of Objectives

1. *To determine key biological parameters (growth, mortality etc) of blue swimmer crabs in Queensland.*

Previous work conducted during the 1980's provided a good indication of the biological features of the blue swimmer crab fishery in Queensland, although this work was predominantly limited to the waters of Moreton Bay and did little to address other areas of the fishery. In this report a comprehensive analysis of the key biological parameters dealing with growth, reproduction, parasitism, mortality can be found in Chapters 8 to 11. The key points to note are the relatively rapid growth of blue swimmer crabs. The size structure of mature crabs in the offshore areas that have a more recent exploitation history tend to have a higher proportion of larger males. Indeed it appears that male crabs in these areas achieve an additional moult. The size of females in all areas does not differ significantly. Levels of parasitism are at similar levels to the 1980s although the more economically important parasites are not as prevalent in oceanic areas.

1. To determine the impact (if any) of environmental variables on blue swimmer crab catch.

Environmental effects on the blue swimmer crab fishery were described in Chapter 7. Additional information on factors impacting on blue swimmer crab megalopae was also described in Chapter 8. Too few data were available to determine conclusively the effect of the environment on blue swimmer crab catches although temperature alone was not having a dramatic small-scale effect. Environmental factors including temperature continue to be monitored.

2. To produce models which describe the impacts of alternative management strategies.

The modelling conducted, as part of this work was limited to the extent that information collected as part of the nationwide research has not been incorporated in the analysis. Modelling continues to progress in both South Australia and Western Australia and links will be maintained with modellers in both of these states. However, alternative management strategies in terms of altering the minimum legal size were assessed using simple yield per recruit analysis (see chapter 14). This analysis has clearly demonstrated that substantial gains can be made by a reduction in the minimum legal size. These findings are further supported by independent modelling carried out in Western Australia that showed that yield was also maximised at sizes considerably less than the current minimum size in Queensland at present (Melville-Smith *et al*. 2001). The application of simple biomass dynamic modelling using commercial catch and effort data was limited in this report by uncertainties in the accuracy of both the catch and effort records in the commercial logbooks and the violation of equilibrium conditions in some areas in which the fishery operates.

Additional Objectives

In addition to the objectives stated in the original application a number of other objectives were addressed as a result of emergent issues since the project was formulated in 1997. Subsequent consultation with industry and management highlighted a number of other issues that were addressed by this research. These predominantly related to fulfilling the Environment Australia guidelines for Schedule 4 listing of the blue swimmer crab under the Wildlife Protection (Regulation of Exports and Imports) Act 1982. In order to address these guidelines bycatch information as well as the environmental impacts of fishing apparatus were assessed in Chapters 12 and 13. Issues related to the trawl bycatch and by-product of blue swimmer crabs were also considered a key industry concern and were also assessed in Chapters 5 and 6.

21. RECOMMENDATIONS

1. That the minimum legal size be lowered to 11.5 cm (base to base measurement) similar to that used in South Australia at present. This would also bring management practises (in terms of minimum legal size) closer to in line with other states of Australia.

2. That no more than 1% of the catch be allowed to be crabs that have a damaged base of spine.

3. That a code of conduct be developed to minimise the threat of the pot fishery to threatened sea turtles. Such a code to include steps to minimise the amount of rope in the water and to ensure that lines are weighted at least 1 m below the float.

4. That a process be developed with industry to minimise the ecological damage caused by lost pots. This would include the installation of corrodible panels in all trawl mesh collapsible pots and a minimum mesh size of pots set at 2.5 inches. Alternatively escape gaps should be installed in pots.

5. That steps be taken to make catch and effort recording practises consistent among fishers. This will involve stressing the need to accurately record the number of lifts and to address the “tipping issue”. This will only be achieved by eliminating the current discrepancy in the two size measurements in the Fisheries Regulations.

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24. APPENDICES

Appendix 1 Intellectual Property

No patents are anticipated from this project. Results of this research will be published in scientific and popular literature and will be provided to the FRDC as they become available.

Appendix 2 Staff

Name (% time contribution)	Position	Organisation
Wayne Sumpton (50%)	Principal Investigator	QDPI, AFFS Fisheries
Shane Gaddes (70%)	Fisheries Technician	QDPI, AFFS Fisheries
Mark McLennan (35%)	Fisheries Technician	QDPI, AFFS Fisheries
Greg Skilleter (5%)	Senior Lecturer	University of Queensland
Matthew Campbell (10%)	Fisheries Technician	QDPI, AFFS Fisheries
Mark Tonks (10%)	Fisheries Technician	QDPI, AFFS Fisheries
Brett Davidson (5%)	Vessel Skipper	QDPI, AFFS Fisheries
Norm Good (2%)	Statistician	QDPI, AFFS Fisheries
Wayne Hagedoorn (2%)	Fisheries Technician	QDPI, AFFS Fisheries

Appendix 3 Results of regression models assessing the effect of environmental parameters on blue swimmer crab catch.

Appendix 3.1 Regression models with Log catch weight as the response variable

Table 24.1 Model selection of daily catch data for fishers who fish more than 100 days in Moreton Bay. Response variable is log catch weight.

Adjusted r^2	Partial r^2	Log Pot Lifts	Month	Site	Morning Temp.	VSN (Fisher)	High tide	Moon Illumination
Best subsets with 1 term								
55.57	55.57	-	-	-	-	0.00	-	-
30.35	30.35	-	-	0.00	-	-	-	-
21.27	21.27	0.00	-	-	-	-	-	-
4.13	4.13	-	0.00	-	-	-	-	-
0.35	0.35	-	-	-	-	-	0.008	-
0.2	0.2	-	-	-	-	-	-	0.034
0.1	0.1	-	-	-	0.097	-	-	-
Best subsets with 2 terms								
62.92	7.35	-	0.00	-	-	0.00	-	-
Best subsets with 3 terms								
64.11	**1.19**	**0.00**	**0.00**	**-**	**-**	**0.00**	**-**	**-**
63.85	**0.92**	**0.000**	**0.000**	**0.000**	**-**	**-**	**-**	**-**
Best subsets with 4 terms								
65.06	0.95	0.00	0.00	-	0.00	0.00	-	-
Best subsets with 5 terms								
66.02	0.96	0.00	0.00	0.00	0.00	0.00	-	-
Best subsets with 6 terms								
66.23	0.21	0.00	0.00	0.00	0.00	0.00	0.001	-
Full model								
66.33	0.1	0.00	0.00	0.00	0.00	0.00	0.001	0.016

Table 24.2 Regression ANOVA for Log pot-lift, Month and VSN for the model with log catch weight as the response variable.

Source	D.F	SS	MS	VR	F prob.
Log Pot Lifts	1	344.88	344.884	1033.2	<.001
VSN	6	579.83	96.639	289.54	<.001
Month	11	118.65	10.786	32.32	<.001
Error	1722	574.75	0.334		
Total	1740	1618.1	0.93		

Table 24.3 Parameter estimates for Log pot-lift, Month and VSN model.

Parameter	Estimat	SE	t (1722)	t prob
Constant	-0.617	0.330	-1.870	0.062
Log pot-lift	0.688	0.090	7.630	<.001
vsn A	1.125	0.060	18.910	<.001
vsn B	0.250	0.064	3.920	<.001
vsn C	0.776	0.062	12.480	<.001
vsn D	-1.628	0.073	-22.340	<.001
vsn E	0.680	0.064	10.550	<.001
vsn F	-0.359	0.077	-4.670	<.001
month 2	0.309	0.062	5.000	<.001
month 3	0.616	0.060	10.280	<.001
month 4	0.789	0.073	10.770	<.001
month 5	0.719	0.066	10.890	<.001
month 6	0.536	0.083	6.450	<.001
month 7	-0.099	0.107	-0.930	0.352
month 8	-0.276	0.089	-3.090	0.002
month 9	0.197	0.075	2.640	0.008
month 10	0.582	0.062	9.430	<.001
month 11	0.296	0.063	4.730	<.001
month 12	0.225	0.064	3.500	<.001

Table.24.4 Regression ANOVA for Log pot-lift, Month and Site for the model with log catch weight as the response variable

Source	D.F	SS	MS	VR	F prob
Log Pot Lift	1	344.8847	344.8847	654.36	<.001
Site	3	262.2811	87.427	165.88	<.001
Month	11	101.7954	9.2541	17.56	<.001
Error	1725	909.173	0.5271		
Total	1740	1618.134	0.93		

Table 24.5 Parameter estimates for Log pot-lift, Month and Site model.

Parameter	Estimate	S.E.	t (1725)	t prob
Constant	-2.988	0.362	-8.25	<.001
Log pot-lift	1.4682	0.0947	15.5	<.001
Gilligans Is.	0.1249	0.0634	1.97	0.049
Hanlon Lt.	-0.1976	0.0625	-3.16	0.002
Measured Mile.	-1.1563	0.0717	-16.13	<.001
month 2	0.3084	0.0777	3.97	<.001
month 3	0.544	0.075	7.25	<.001
month 4	0.7774	0.0921	8.44	<.001
month 5	0.6844	0.0812	8.43	<.001
month 6	0.87	0.103	8.41	<.001
month 7	0.095	0.133	0.71	0.476
month 8	0.081	0.111	0.73	0.463
month 9	0.4528	0.0932	4.86	<.001
month 10	0.7359	0.0771	9.54	<.001
month 11	0.4268	0.0783	5.45	<.001
month 12	0.3391	0.0807	4.2	<.001

Appendix 3.2 Replacing month with period in catch regression models

Table 24.6 Model selection of daily catch data for fishers who fish more than 100 days in Moreton Bay only. Response variable is Log Catch weight. Month is replaced by Period.

Adjusted r^2	Partial r^2	Log Pot	Period	Site	Temp Morn	VSN	High Tide	Moon Illum
Best subsets with 1 term								
55.57	55.57	-	-	-	-	0.000	-	-
30.35	30.35	-	-	0.000	-	-	-	-
21.27	21.27	0.000	-	-	-	-	-	-
10.19	10.19	-	0.000	-	-	-	-	-
0.35	0.35	-	-	-	-	-	0.008	-
0.2	0.2	-	-	-	-	-	-	0.034
0.1	0.1	-	-	-	0.097	-	-	-
Best subsets with 2 terms								
68.23	12.66	-	0.000	-	-	0.000	-	-
Best subsets with 3 terms								
69.37	**1.14**	**-**	**0.000**	**0.000**	**-**	**0.000**	**-**	**-**
69.02	**0.79**	**0.000**	**0.000**	**-**	**-**	**0.000**	**-**	**-**
Best subsets with 4 terms								
70.18	0.81	0.000	0.000	0.000	-	0.000	-	-

Table 24.7 Regression ANOVA for Ln potlift, Period and VSN model

Source	D.F.	SS	MS	VR	F prob
LN pot	1	344.88	344.8847	1197.23	<.001
VSN	6	579.84	96.6396	335.47	<.001
Period	22	200.53	9.1149	31.64	<.001
Error	1711	492.88	0.2881		
Total	1740	1618.1	0.93		

Table 24.8 Parameter estimates for Log pot-lift, Period and VSN model.

Parameter	Estimate	SE	t(1711)	t prob
Constant	0.312	0.321	0.970	0.331
Log pot-lift	0.577	0.086	6.710	<.001
vsn A	1.082	0.059	18.450	<.001
vsn B	0.224	0.062	3.600	<.001
vsn C	0.703	0.060	11.690	<.001
vsn D	-1.759	0.073	-24.160	<.001
vsn E	0.691	0.063	11.040	<.001
vsn F	-0.528	0.074	-7.110	<.001
period 2	0.192	0.095	2.010	0.044
period 3	0.411	0.092	4.450	<.001
period 4	-0.126	0.112	-1.120	0.261
period 5	0.123	0.099	1.240	0.216
period 6	0.058	0.113	0.510	0.608
period 7	-0.549	0.119	-4.630	<.001
period 8	-0.700	0.120	-5.810	<.001
period 9	-0.148	0.107	-1.390	0.165
period 10	0.224	0.095	2.370	0.018
period 11	-0.330	0.096	-3.440	<.001
period 12	-0.431	0.098	-4.390	<.001
period 13	-0.669	0.095	-7.070	<.001
period 14	-0.427	0.094	-4.560	<.001
period 15	-0.048	0.091	-0.520	0.600
period 16	0.698	0.106	6.570	<.001
period 17	0.428	0.098	4.390	<.001
period 18	0.081	0.128	0.630	0.526
period 20	-0.789	0.133	-5.910	<.001
period 21	-0.465	0.113	-4.110	<.001
period 22	0.003	0.094	0.030	0.979
period 24	-0.025	0.095	-0.260	0.793
period 24	-0.056	0.096	-0.580	0.564

Table 24.9 Regression ANOVA for VSN, Period and Site model

Source	D.F.	SS	MS	VR	F prob
VSN	6	901.5993	150.2666	527.47	<.001
Period	22	210.6625	9.5756	33.61	<.001
Site	1	18.44	18.44	64.73	<.001
Error	1711	487.4325	0.2849		
Total	1740	1618.1342	0.93		

Table 24.10 Parameter estimates for VSN, Period and Site model.

Parameter	Estimate	SE	t(1711)	t prob
Constant	2.298	0.091	25.140	<.001
vsn A	1.784	0.085	20.890	<.001
vsn B	0.430	0.057	7.490	<.001
vsn C	0.896	0.055	16.230	<.001
vsn D	-1.713	0.073	-23.620	<.001
vsn E	1.048	0.066	15.860	<.001
vsn F	-0.363	0.080	-4.540	<.001
period 2	0.287	0.095	3.020	0.003
period 3	0.491	0.092	5.330	<.001
period 4	-0.070	0.111	-0.630	0.527
period 5	0.194	0.099	1.960	0.050
period 6	0.114	0.113	1.010	0.314
period 7	-0.531	0.118	-4.500	<.001
period 8	-0.579	0.120	-4.840	<.001
period 9	0.045	0.107	0.420	0.675
period 10	0.365	0.095	3.840	<.001
period 11	-0.261	0.096	-2.720	0.007
period 12	-0.436	0.098	-4.470	<.001
period 13	-0.579	0.094	-6.150	<.001
period 14	-0.385	0.093	-4.140	<.001
period 15	0.034	0.091	0.370	0.711
period 16	0.821	0.105	7.810	<.001
period 17	0.536	0.097	5.540	<.001
period 18	0.157	0.127	1.230	0.217
period 20	-0.713	0.133	-5.370	<.001
period 21	-0.392	0.113	-3.480	<.001
period 22	0.094	0.094	1.000	0.318
period 23	0.029	0.094	0.310	0.756
period 24	0.009	0.096	0.100	0.922
Gilligans Is.	-0.506	0.063	-8.050	<.001
Hanlon Lt.	0.000	*	*	*
Measured M	0.000	*	*	*

Appendix 3.3 Best subsets regression models using CPUE as the response variable

Table 24.11 Model selection of daily catch per unit effort data for fishers who fish more than 100 days in Moreton Bay only. Response variable is Log CPUE. Month is replaced by Period

Adjusted r^2	Partial r^2	VSN	Period	Site	Temp Morn	Moon Illum	High
Best subset with 1 term							
50.83	50.830	0.000	-	-	-	-	-
26.23	26.230	-	-	0.000	-	-	-
10.04	10.040	-	0.000	-	-	-	-
0.39	0.390	-	-	-	-	-	0.005
0.23	0.230	-	-	-	0.025	-	-
0.23	0.230	-	-	-	-	0.026	-
Best subsets with 2 terms							
64.11	13.280	0.000	0.000	-	-	-	-
Best subsets with 3 terms							
65.49	**1.38**	**0.000**	**0.000**	**0.000**	**-**	**-**	**-**
Best subsets with 4 terms							
65.61	0.12	0.000	0.000	0.000	0.009	-	-
Best subsets with 5 terms							
65.77	0.16	0.000	0.000	0.000	0.002	-	0.003
Full model							
65.81	0.04	0.000	0.000	0.000	0.001	0.082	0.002

Table 24.12 Regression ANOVA for VSN, Period and Site model.

Source	D.F	SS	MS	VR	F prob
VSN	6.000	51.667	8.611	428.590	<.001
Period	22.000	13.866	0.630	31.370	<.001
Site	1.000	1.397	1.397	69.520	<.001
Error	1711.000	34.377	0.020		
Total	1740.000	101.306	0.058		

Table 24.13 Parameter estimates for VSN, period and Site model.

Parameter	Estimate	SE	t(1711)	t prob.
Constant	0.638	0.024	26.280	<.001
vsn A	0.415	0.023	18.320	<.001
vsn B	0.062	0.015	4.080	<.001
vsn C	0.175	0.015	11.940	<.001
vsn D	-0.472	0.019	-24.510	<.001
vsn E	0.231	0.018	13.160	<.001
vsn F	-0.074	0.021	-3.480	<.001
period 2	0.067	0.025	2.660	0.008
period 3	0.121	0.025	4.930	<.001
period 4	-0.023	0.030	-0.780	0.434
period 5	0.062	0.026	2.370	0.018
period 6	0.067	0.030	2.220	0.027
period 7	-0.134	0.031	-4.260	<.001
period 8	-0.161	0.032	-5.090	<.001
period 9	0.003	0.028	0.090	0.930
period 10	0.100	0.025	3.960	<.001
period 11	-0.058	0.025	-2.270	0.023
period 12	-0.106	0.026	-4.080	<.001
period 13	-0.153	0.025	-6.120	<.001
period 14	-0.102	0.025	-4.150	<.001
period 15	0.007	0.024	0.290	0.775
period 16	0.208	0.028	7.450	<.001
period 17	0.140	0.026	5.440	<.001
period 18	0.040	0.034	1.190	0.235
period 20	-0.1821	0.0353	-5.16	<.001
period 21	-0.101	0.0299	-3.38	<.001
period 22	0.022	0.0249	0.88	0.377
period 23	-0.0023	0.0248	-0.09	0.927
period 24	0.0011	0.0254	0.04	0.967
Gilligans Is.	-0.1394	0.0167	-8.34	<.001
Hanlon Lt.	0	*	*	*
Measured M.	0	*	*	*