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Department of Primary Industries
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INTRODUCTION

Part of Moreton Bay was closed permanently to commercial trawling more than 15 years ago (Haysom 1975). The purpose of these permanent closures were not only to reduce fishing effort on juvenile prawns and their habitats, but also to reduce the trawler-generated noise near foreshore developments. As such, the permanent shallow water trawl closures in Moreton Bay have social, as well as biological and economic functions.

In 1988 the then Minister for Primary Industries, the Queensland Fish Management Authority (QFMA) and the Queensland Commercial Fisherman's Organisation (QCFO) introduced a seasonal prawn trawl closure in Moreton Bay to further reduce fishing effort on small prawns. These more recent closures to commercial trawling have been described in *The Queensland Fisherman* (Mitchell 1988) and restrict access to approximately 15 per cent of the trawlable grounds in Moreton Bay. Although initially introduced for approximately 13 weeks in July 1988, the timing and duration of the seasonal closures in 1989 and 1990 has varied slightly.

Seasonal closures are currently a popular form of fisheries management in Queensland. Closures have an instinctive appeal as a method of lowering fishing effort on sub-optimal sized individuals and on first impressions their introduction and management appear relatively simple. However, quantitatively assessing such a manipulation of fishing effort is complex, particularly for mixed species fisheries. Parameter estimates of growth, natural mortality, fishing mortality and prawn distribution patterns should be determined beforehand. Computer aided simulations which model the fishery and the proposed closure could then indicate whether such a measure would increase prawn production before being introduced.

A characteristic feature of most of Queensland's prawn trawl fisheries, which complicates management decisions relating to closures, is their multi-species nature. Individual species in mixed prawn trawl fisheries usually display different recruitment periods - probably as a result of differing spawning periods. Consequently, small prawns may be recruiting to the fishery for many months of the year. Growth, natural mortality and fishing mortality rates may also differ for each species in the fishery. Management strategies targeted at improving the yield of a particular species in a fishery may result in a lower yield for other species and/or lower total yield. Hence, the importance of evaluating closures and predicting any effects before their introduction.

Shortly after the introduction of the seasonal closure in Moreton Bay the QDPI Fisheries Branch was asked by the QFMA to provide information for the assessment of the closure. Consequently, a research programme was initiated in August, 1988 to review the seasonal closure in the Bay and quantify the likely effects, if any, such a manipulation of fishing effort had on the fishery. The function of this report is to present and disseminate the findings of the programme.

The prawn trawl fishery in Moreton Bay has some features which distinguish it from the State's other trawl fisheries. Because of its close proximity to a capital city, high density population, ports, markets and accessibility it has been subjected to greater long term fishing effort, more user groups, and more political, management and research attention than other fisheries in the State. Before detailing the current research aims, methods and results it is important to review the research literature on previous penaeid prawn studies in Moreton Bay and adjacent areas. A number of studies have generated information of direct relevance to the assessment and appropriateness of seasonal closures in Moreton Bay.

Current status of the Moreton Bay trawl fishery

Historically, it has been difficult to quantify total annual prawn landings from the Moreton Bay fishery. The fishery commenced in 1949 and developed rapidly during the 1950s (Haysom 1975) with total annual prawn production being less than 200 tonnes in the early part of that decade. Stephenson and Williams (1981) have discussed some of the shortcomings of the Queensland Fish Board (QFB) (no longer in existence) data. The most obvious problem with these data is that only landings processed at certain ports and processors are represented, and not necessarily what was trawled from a given area. Prawns may have been trawled from the Bay without catches being recorded at local processors, and conversely, product may have been trawled outside the Bay but processed inside.

It should be stressed therefore, that if QFB data is used as a quantitative summary of the Moreton Bay catches, then it is assumed that whatever was processed in a particular Bay port or processor represented the catch from the adjacent Moreton Bay fishing grounds. Secondly, fishing effort was not recorded with landings in the QFB data base, and so it cannot be used as an indicator of change in annual catch rates or catch per unit of effort (CPUE).

Hegerl and Stock (1982 p.178) have been more critical of the old Queensland Fish Board system...

'It has not been possible to accurately determine a cash value or catch size for the commercial fishing industry dependent on Southern Moreton Bay. An unknown per centage is sold through the QLD Government's Fish Board system, but a large proportion (conceded by Fish Board officers to be more than half) is sold outside the Board system and to interstate buyers. In other words, the Board statistics probably represent less than half of the region's commercial fishery catch.'

Nevertheless, the Queensland Fish Board data has been used to generate total prawn landings in Moreton Bay. The data collated by Stephenson and Williams (1981) for the period 1956-1978 (Figure 1) represent the catch of prawns received at the ports of Brisbane, Doboy Creek, Cleveland, Sandgate, Scarborough and Wynnum and vary from about 400 tonnes to 1200 tonnes over that period. In the immediate years after this period, and following Stephenson and Williams' (1981) paper, analysis of the QFB data from those same ports suggests landings ranged from about 500 tonnes to 700 tonnes from 1978 to 1981 (Figure 1).

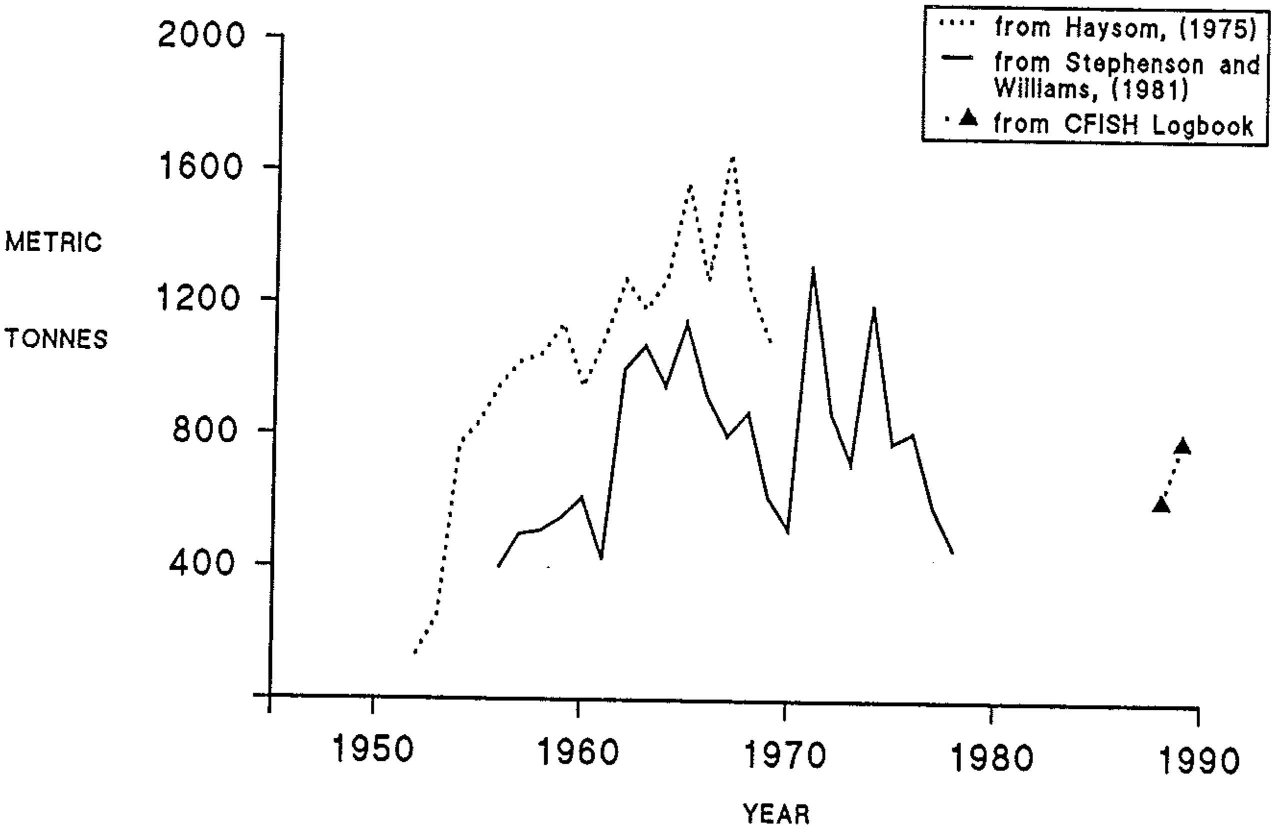

Figure 1. Total prawn landings from the Moreton Bay fishery.

Haysom (1975) also presented data on the annual prawn landings from Moreton Bay. Annual catches for the period 1955 to 1970 varied from about 1000 tonnes to 1600 tonnes, and as such are generally higher than those of Stephenson and Williams (1981) for the same period. Haysom's figures were clearly not related to the QFB data and unfortunately he did not refer to the source of his information.

As the senior research scientist during a joint CSIRO/QDPI project on prawn population dynamics in the early 1970s, Young (1975 p. 18) wrote...

'Moreton Bay supports an annual prawn fishery of approximately two million kilograms. Of this 33 per cent are juvenile eastern king prawns (*Penaeus plebejus* Hess). The rest are juvenile and adult tiger prawns (*P. esculentus* Haswell) and "bay" prawns.'

In a later publication Young and Carpenter (1977 p. 745) put forward...

'Moreton Bay supports an annual prawn fishery of 2000 tonnes.'

Young, however, made no reference in any of these papers as to how this estimate of total landings for the Bay was derived and therefore his estimate cannot be verified.

In 1988 the first compulsory Queensland logbook programme (CFISH) was instigated. In order to record geographic information on the distribution of catch and effort the logbook has partitioned the Queensland coastline into 30' x 30' longitudinal and latitudinal grids. The grid coded W37 (Figure 2) encompasses the entire Moreton Bay fishery, and a small part of the trawlable grounds outside the Bay adjacent to Moreton Island. Catch and effort data recorded for grid W37 provide information on landings for the Bay and may include a small amount of the landings from outside the Bay. Total prawn landings for the first two years of the database for grid W37 indicate that 610 tonnes and 788 tonnes of prawns were trawled in 1988 and 1989 respectively (Figure 1).

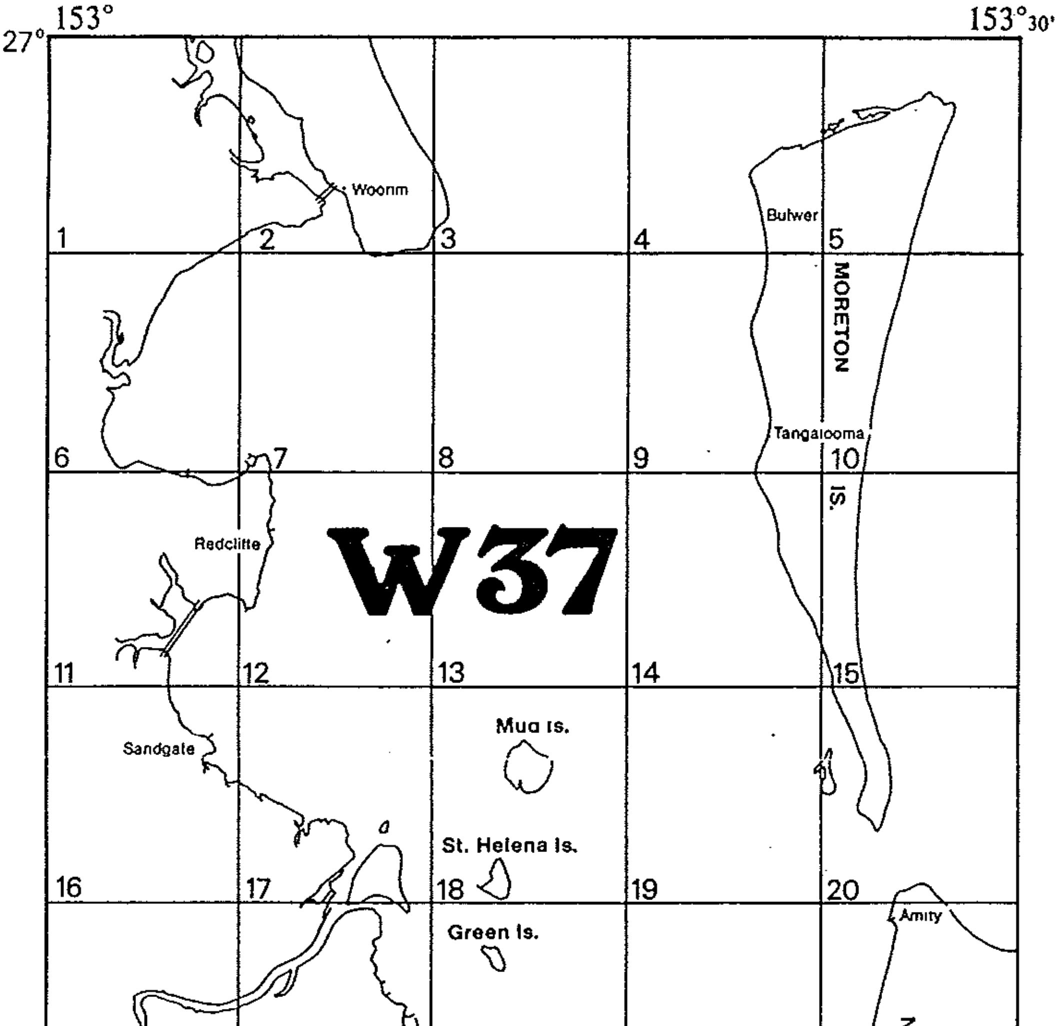

Figure 2. *CFISH logbook grid W37.*

There appears to be, therefore, considerable conjecture regarding any long term account of the total annual prawn landings for the Moreton Bay fishery. The larger estimates of 1600 and 2000 tonnes, put forward by Haysom (1975) and Young (1975) respectively, have not been substantiated and the figures put forward by Haysom tend to be about twice as large as the old QFB figures. That these rather high figures are unsubstantiated does not necessarily imply they are incorrect. The smaller estimates which have been generated from the QFB data in the past (Stephenson and Williams 1981) are generally considered to be well under the real total landings. If the estimates by Haysom (1975), Young (1975), Young and Carpenter (1977) and the CFISH database statistics are accurate, then it would indicate that there has been a general decline in total prawn landings for the Bay fishery over the past 20 years. This does not necessarily imply that catch rates or CPUE have declined, since the levels of annual fishing effort associated with these landings in previous years is largely unknown.

Temporal and spatial distribution of catch and effort in the Moreton Bay trawl fishery.

Mean monthly CPUE for the commercial logbook categories known as bays, kings and tigers, based upon CFISH data for the Bay fishery (grid W37) over the first two years of the logbook's introduction indicate a high degree of similarity in CPUE between years (Figure 3). The category known as bays does not represent any single prawn species and is therefore of limited value. It is, however, most likely to be heavily dominated by greentail prawn, *Metapenaeus bennettae*, and as such could be interpreted as being representative of the species. There is evidence that the bays have two peaks in CPUE each year; a major one in November-December and a minor peak in April-May. The category known as kings display a single peak in CPUE in October-November which declines through the Summer and Autumn until June. Tigers also display a single peak in CPUE, which occurs in February and declines markedly through to July.

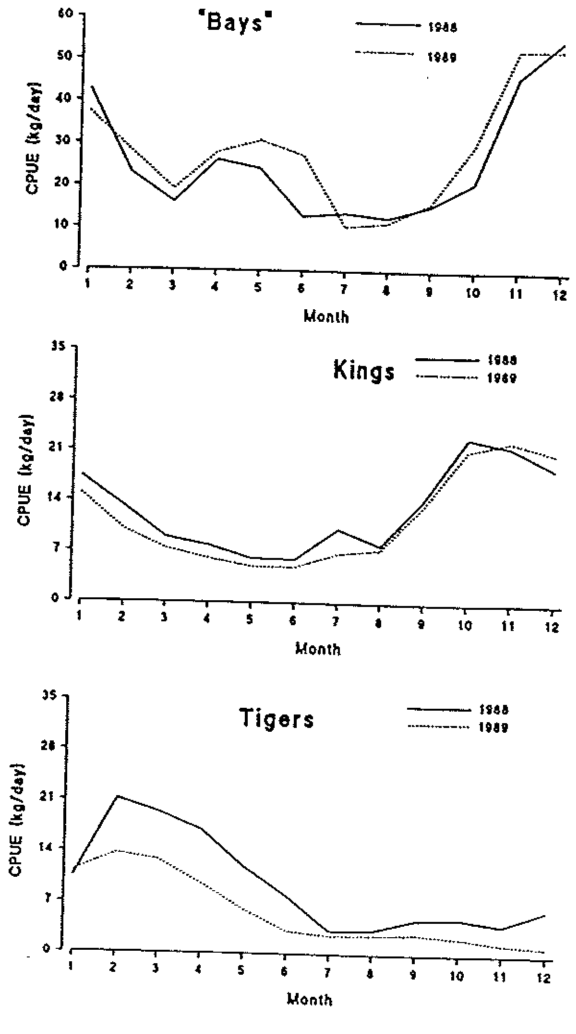

Figure 3. Monthly catch per unit of effort (kg/boat-day) for CFISH grid W37 in 1988-89 for 'bays', kings and tigers.

The grids used for CFISH are quite large (30' x 30'), but they are also subdivided into 6' x 6' sites. Each grid is made up of 25 sites and any reference to a specific site within a larger grid provides a much more detailed account of catch and effort. Further analysis of the 1988 CFISH logbook data for grid W37 indicated that a small proportion (15 per cent) of fishermens' logbook records also included a site reference number. Figure 4 is based on all CFISH logbook data records which included a site reference number for grid W37 in 1988. The percentage (Figure 4) for each site is that proportion of the total for the whole grid. The vast majority of catch and effort in the Bay for bays, kings and tigers is generated in sites 7, 8, 12, and 13, and particularly in sites 7 and 12. Fishing mortality was assumed to be proportional to the total area in the Bay which was swept over by trawl gear. Each percentage mortality in each site is a function of the amount of total area swept by trawling and the total trawlable ground within the site

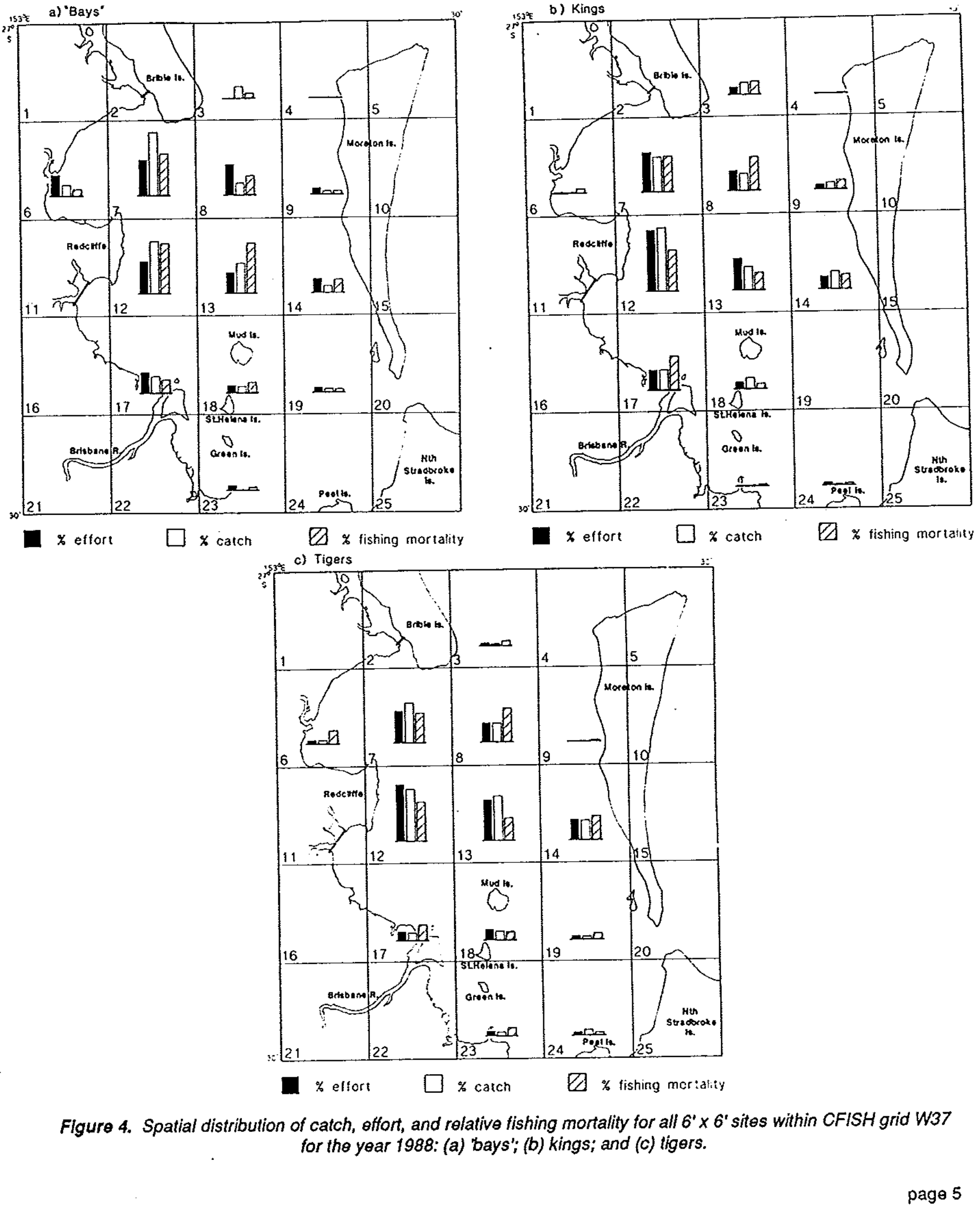

Figure 4. Spatial distribution of catch, effort, and relative fishing mortality for all 6' x 6' sites within CFISH grid W37 for the year 1988: (a) 'bays'; (b) kings; and (c) tigers.

Previous studies in southeast Queensland relevant to the introduction of seasonal closures.

In order to avoid confusion over the categories used to differentiate between species groups used in the logbook, common terminology and the generic names of commercially important prawn species trawled in the Moreton Bay, the following nomenclature will be used throughout this report;

1) 'greasy prawns or greasys' will refer to the species known as *Metapenaeus bennettae*, also known as the greentail prawn, inshore greasyback prawn or bay prawn;
2) 'king prawns or kings' will refer to the eastern king prawn, *Penaeus plebejus*; and
3) 'tiger prawns or tigers' will refer to the brown tiger prawn, *Penaeus esculentus.*

Dall (1958), and Aziz and Greenwood (1981, 1982) studied the distribution, abundance, behaviour and physiology of the greasy prawns in the Brisbane River. A significant conclusion drawn by Dall about the distribution of greasy prawns within the river was that males tended to be more influenced by salinity than females:

'... approximately equal numbers of each sex are spawned, but that males are less tolerant of low salinities than females. The upstream male/female ratio increases with the higher salinities of summer, but the sharp drop of salinity following seasonal late summer rains results in males moving well down stream.' (Dall 1958 p. 125-6). This is particularly relevant to the management and assessment of the seasonal closures, because (as will be discussed later) male greasys are the smaller gender of the greasy prawns and large catches of males during wet seasons may give trawlermen the impression they are landing the resource too soon.

Hyland (1987) found that the size of greasy prawns decreased in shallow areas in the Logan River and in Moreton Bay. Within the Logan River, the size of greasy prawns was actually related to their distance upstream; the smaller prawns being further upstream. Within Moreton Bay, seasonal changes in the abundance of greasy prawns and the changes in their modal size classes suggested that there are at least two periods each year when greasys recruit to the fishery. This would suggest that more than one seasonal closure, or a very extended closure would be required to reduce fishing mortality on small greasys. Abundance of king prawns in the Bay was well defined and peaked in October for both years of the study, however, Hyland (1987) provided no information on the size of the kings, only the abundance. Hyland (1987) concluded that since a) king prawns are 'immature and provide recruits to the offshore fishery' and, b) one of the recruitment periods for greasy prawns was also in October that this would be the most appropriate time for a seasonal closure in Moreton Bay, should one ever be required.

Results from extensive tagging studies on king prawns in the early 70s by Lucas (1974) and Potter (1975) generated information on the natural mortality, fishing mortality, emigration and migration patterns for this species in the Bay and southeast Queensland. Within the Bay the combined natural mortality rate (the rate at which prawns die off naturally) and the emigration rate (the rate at which prawns leave the Bay) for kings was high and about eight times greater than fishing mortality. Because of these high mortality and emigration rates the population of king prawns in the Bay is reduced by about half in two weeks. Lucas (1974) suggested that the reason catches remain high is due to a continual rapid migration of kings through the Bay over a period of several months (October to November), which is part of an overall northerly migration.

This is relevant to the current seasonal closure study within Moreton Bay. Eastern king prawns, unlike the majority of Australian penaeid prawns, are very mobile and have been known to travel distances of over 1000 km (Montgomery 1981). From Lucas' (1974) work it seems that any seasonal closure in Moreton Bay aimed at reducing fishing effort on small king prawns will have little or no benefit to the Moreton Bay fishery because these prawns die off quickly and/or rapidly emigrate to "outside" grounds. Any benefits to the "outside" king prawn fishery would be difficult to determine since it is unknown how significant the recruiting Moreton Bay king prawns are to the fished populations outside the Bay. A closure in Moreton Bay targeted at reducing effort on king prawns would have the greatest positive influence on outside catches if the outside fishery is totally dependent on Moreton Bay for its recruits. If however, the Moreton Bay kings contribute only a small proportion to the overall population of kings outside the Bay then a reduction of fishing mortality on small kings in the Bay will have little or no effect on the outside fishery. It should be noted that any effects of seasonal closures upon emigration rates (from inside the Bay to outside fisheries) of prawns is only relevant for the kings. Greasys and tigers most likely complete their life cycles within the Bay, and thus unlike kings, will still be in the Bay at the lifting of the closures.

Stephenson *et al.* (1982) trawl sampled the biota from three sites in Moreton Bay each lunar month for a period of two years. Although they did not refer to actual prawn sizes, they did confirm mathematically that annual cycles occur in the abundance of all three commercially important prawn species. Within the Bay, abundance of kings peaked in mid October, greasys in early December and tigers in mid February. This work is relevant to the seasonal closure, and most other management decisions regarding the fishery, because it confirms that the populations of prawns are generally behaving in a similar fashion from one year to the next. If seasonal closures proved to be an appropriate form of management then their implementation is made easier when they do not have to be adjusted from one year to the next.

Some researchers have focused their attention on the post-larval and juvenile stages of the commercially important prawns in southeast Queensland. Such studies can give an indication as to when large numbers of recruiting small prawns become prone to fishing effort. Young and Carpenter (1977) studied seasonal immigration of postlarval (2-3 mm Cl) king, greasy and tiger prawns onto a wide range of nursery grounds in Moreton Bay. The recruitment of post-larval tiger prawns is generally associated with seagrass areas and appears well defined with peaks each year from January to February. Recruitment patterns for post-larval greasy and king prawns are not so clearly defined. Post-larval greasy prawns were found over the whole study area but more were found on seagrass areas and abundance peaked in March-May. These results agree with those of Coles and Greenwood (1983), who found that post-larval greasy prawns recruit to the Noosa River system from March to June.

Unlike greasy prawns, fewer post-larval kings tend to settle on nursery areas with a freshwater influence. Recruitment periods of post-larval king prawns within the Bay are not clearly defined. Young and Carpenter (1977) found that king prawns display at least two peaks in the annual cycle with a maximum usually from July to September, while Coles and Greenwood (1983) found that post-larval kings recruited to the Noosa River system throughout the year. In the Noosa River the king prawn post-larvae tended to settle only very briefly and in the mouth of the river and not further upstream. This supports the conclusion by Young and Carpenter (1977) - that kings tend to settle in areas which are less influenced by freshwater. Coles and Greenwood (1983) suggested that an egress of sub-adult greasy prawns from the Noosa estuary occurs in December-January. This is of particular relevance to the current seasonal closures of Moreton Bay as it suggests significant numbers of small greasy prawns could be expected to migrate out onto commercial grounds around this period.

In summary, there are some important results from various biological studies in the region which are directly relevant to the implementation, assessment and appropriateness of seasonal closures in the fishery. In particular, the earlier work by Dall (1958) may partly explain why small greasy prawns, which are mostly males, become vulnerable to fishing at certain times of the year. Lucas' (1974) work is also particularly relevant since it identifies the high natural mortality and emigration rates for king prawns and the rapid turnover of individuals migrating through the Bay. Because of their highly migratory nature, king prawns are probably less suited for small geographic seasonal closures than some of the other less migratory species.

CURRENT RESEARCH AND FIELD PROGRAMME

The aims of the current research programme were to:

a) describe the temporal and spatial patterns in the distribution of recruiting (or 'small') prawns of all major commercial species in Moreton Bay in order to determine the months and regions that may be associated with prawn growth over-fishing; and

b) assess the effects of the seasonal closure in Moreton Bay by way of a simulation model.

Methods

Prawn sampling

In order to obtain current data on the distribution, size and abundance of prawns most likely influenced by the seasonal closures, prawns were sampled in various habitats and in various stages of their life cycles. Any variation in abundance of prawns due to lunar periodicity was reduced by sampling the prawns at a standardised lunar phase, the new moon, each lunar month. Sampling was initiated in August 1988 and continued, on a lunar-monthly frequency, over the following two years.

Nine sample sites were established on commercial trawl grounds in the Bay. Three of these sites were inside the new closure grounds, while the remaining six were outside. Particular emphasis was placed on determining when and where large numbers of 'small' prawns (new recruits) become vulnerable to commercial fishing effort. In order to determine if and when large-scale emigrations of small prawns from nursery areas occur, (coinciding with an influx of small prawns to the commercial grounds), a juvenile sampling programme was also established in two shallow intertidal nursery areas on the western side of the Bay.

The nine sites were each sampled with twin trawl gear for thirty minutes (bottom time) at about 2.6 nautical miles per hour (ground speed) each lunar month (on or as close as possible to the new moon) for a period of two years. Site positions were obtained each month with radar. Two four-fathom nets were used; the starboard side net was the standard 40 mm (1 5/8") commercial mesh size for the Bay while the port side was 31 mm (1 1/4") and particularly selective for 'small' prawns. The sites were trawl sampled on two consecutive (weather permitting) nights using research trawlers (QDPI 'Bar-ea-mul' , 'Deep Tempest' and Queensland University 'Sea Wanderer'). All of the prawns landed were frozen on board and later sorted to species, sex and measured (carapace length) to the nearest millimetre in the wet laboratory at the QDPI Southern Fisheries Research Centre (Deception Bay). The abundance of 'small' prawns each month was determined by summing the number of small (those weighing less than 5 grams or more than 200 count per kg) prawns from both nets at each of the nine sampling sites and provided a method for determining recruitment times of 'small' prawns to the fishery and closure areas.

A number of gear types and sampling strategies were experimented with to obtain a method for sampling juvenile and sub-adult prawns on the shallow intertidal nursery areas. Eventually a small 1 m x 0.5 m beam trawl towed from an aluminium dinghy, and fitted with a 23 mm stretched mesh cod end (27 ply multifilament) was found to be most suitable. Following this period of gear trials, sampling on the intertidal areas began in November 1988 and continued to July 1990. Again, sampling took place during the new moon phase, coinciding with the research trawler sampling in the deeper commercial grounds.

Two dense intertidal seagrass beds of *Zostera capricorni* (eel grass) were identified from a recent survey of the seagrasses in the Bay (Hyland *et al.* 1989); one in Deception Bay and one near Fisherman Islands. At each location, two permanent markers were set up 200 m apart delineating a transect on the seagrass beds. Reflective buoys were attached to the markers making the transects visible at night. All sampling of juveniles was restricted to night time when the prawns were active and within one hour either side of the high tide. Four replicate parallel trawls were undertaken over each transect on each sampling trip (eight trawls in all each month). The vast majority of the nursery habitat samples were obtained over two nights. Samples were placed in a plastic bag, chilled on board and later sorted to species and measured in the wet laboratory. Sexes of prawns obtained from the nursery areas were not determined as most prawns were juvenile and as such did not yet display sexual dimorphism.

Modelling the closure

A general life history simulation programme (Die *et al.* 1988) especially designed for the study of multicohort fish stocks was used to determine the change in yield per recruit of prawns by simulating the effects of the seasonal closures. The model uses a monthly time step and therefore allows for the computation of monthly and yearly yields in numbers and weight. Growth rates that were used in the model, and which differ between species and sexes, were based on the von Bertalanffy growth equation. Yield-per-recruit was calculated firstly by simulating the fishery without any seasonal closure and then with the seasonal closure. Change in yield was determined by subtracting the later yield from the former. Simulations were run separately for each species and sex. The overall yield-per-recruit for any particular species was then determined by summing the yields for both sexes according to the specific sex ratio at recruitment.

King prawns are migratory and become unavailable to the Bay fishery after they reach a certain size - migrating out to sea. Therefore, as far as modelling the effects of the seasonal closure on the yield of kings from the Bay fishery is concerned, emigration of kings is analogous to an extra mortality component which contributes to the natural mortality rate when the prawns reach a certain size - that size at which they migrate out of the Bay. The size at which migration of eastern kings occurs in the Bay is unknown and so simulations were carried out for a range of sizes at which migration starts.

The timing of recruitment of small prawns to the fishery influenced the effects of the closure on yield. The model was designed to consider the timing of recruitment for each species and sex into the fishery and to consider whether multiple recruitment or multicohorts occurred.

The absolute proportion of prawns of different sizes, sex and species within the seasonal closure area during the time of the closure was unknown. It was also unknown whether fishing effort was actually reduced during the closure months or only redistributed from the closed to the open areas. In order to define the possible effects of the closure on fishing mortality, analysis of the programme sampling data and the CFISH data for Moreton Bay was undertaken. The analysis of such data provided the basis for three general hypotheses about the effects of the closure on fishing mortality and the intensity of the reduced fishing mortality...

Hypothesis 1. The seasonal closure reduces fishing mortality for small prawns (defined as those weighing less than 5.0 grams).

Hypothesis 2. The seasonal closure reduces fishing mortality for prawns of all sizes.

Hypothesis 3. The seasonal closure reduces fishing mortality of small prawns and increases fishing mortality of large prawns (because fishing effort is redistributed).

The intensity of these reductions or increases was assumed to represent changes of 10, 25 or 50 per cent of the monthly fishing mortality during the closure months.

Estimation of model parameters

The yield-per-recruit simulation model used in the analyses required estimates of growth, mortality and recruitment parameters for each species considered. These estimates were obtained from analysis of the sample programme data and from previous studies. A summary of all parameters is presented in Appendix 2.

Growth

King prawn growth rates were obtained from previous studies (Glaister *et al.* 1987), while growth rates for the greasy prawns were obtained by modal progression analysis of the sampling programme data (Appendix 1). The length-weight relationships required for transforming growth in length to growth in weight were estimated from the sampling programme data for greasy prawns. The length-weight relationship published by Glaister *et al.* (1990) was used for king prawns.

Natural mortality and emigration

Previous studies had published estimates of natural mortality rates for king prawns (Lucas 1974), but at present there are no quantitative estimates for greasy prawns. Simulations were, therefore, carried out for a very wide range of monthly instantaneous natural mortality coefficients, ranging from 0.1 to 0.5, for greasy prawns. The size at which kings start emigrating outside the Bay is unknown. Therefore, simulations were carried out for a range of sizes (13 mm, 19 mm and 25 mm Cl) at which emigration commenced. The ratio of natural mortality to emigration was assumed to be 1:3 as reported by Lucas (1974). Simulations were run for a range of monthly instantaneous coefficients of natural mortality between 0.08 and 0.42 and emigration rates between 0.25 and 1.25. This range of rates included Lucas' (1974) estimates for natural mortality and emigration, as well as Glaister's *et al.* (1990) estimate of natural mortality.

Fishing mortality

The instantaneous coefficient of fishing mortality was assumed to be directly correlated with fishing effort. Data obtained on fishing effort from the CFISH database was used to define a constant seasonal pattern of fishing mortality for all simulations. CFISH data for the 1988 and 1989 seasons were also used to estimate the present fishing mortality coefficient for the Bay fishery with the swept-area method of Baranov (1918). This method requires an estimate of the proportion of prawns in the path of the gear *p*, that enter the codend. Given that this parameter was unknown a range of values of *p*, (0.1 to 1.0) were used in the estimation of fishing mortality. For these values of *p* the estimated maximum monthly instantaneous coefficient of fishing mortality ranged from 0.22 to 2.21. Joll and Penn (1990) estimated values of *p* ranging from 0.31 to 0.53 for the western or blue-legged king prawn, *Penaeus latisulcatus*. If an average value of 0.4 is used for the Moreton Bay fishery the maximum monthly instantaneous coefficient of fishing mortality estimate would be 0.88.

These estimates of fishing mortality reflect the present fishing effort in the Bay, estimated to be around 10 000 trawl hours per month at the peak of the fishing season. Lucas (1974) reported fishing intensity in the Bay for the peak of the 1969-70 fishing season to be 50 trawl hours per square mile. Given that the area of trawlable grounds in the Bay is about 257 square miles, the estimated fishing effort for the 1969-70 fishing season was about 12 850 trawl hours. Since the 1988-89 seasons were the first two years of data collection for the CFISH database, its possible that the level of recorded fishing effort was lower than the actual fishing effort in the Bay. This suggests that the level of fishing effort in the Bay 20 years ago was about the same, or slightly greater than it was for the 1988-89 seasons.

Lucas (1974) estimated, through tagging experiments, the monthly instantaneous coefficient of fishing mortality for the peak of the 1969-70 season to be 0.23. Given that the fishing effort during the 1969-70 and 1988-89 seasons were comparable, it is difficult to explain the disparity between our estimate of fishing mortality and Lucas'. The differences are possibly due to the fact that Lucas used tagging to estimate the monthly instantaneous coefficient of fishing mortality, while we used the area swept method by Baranov (1918). In the analysis, a value midway between Lucas' estimate of monthly instantaneous coefficient of fishing mortality and our estimate was considered to represent the present state of fishing mortality in the fishery. Even so, simulations were run for a very wide range of maximum monthly instantaneous coefficients of fishing mortality, from 0.14 to 2.24.

Gear selectivity, estimated by the Kimura (1978) method, from the sampling programme data was also included in the formulation of fishing mortality used in the simulations (Figure 5). Monthly instantaneous coefficients of fishing mortality were therefore determined to be a product of the fishing mortality for a particular month and the gear selectivity for the age/size of prawns present in that month.

Recruitment

Those months when recruitment occurred were determined from the sampling programme for each species and sex. To estimate recruitment, the length-frequency distributions from the sample programme were corrected by gear selectivity. The smallest modes in the corrected length-frequencies should approximate the size at which the prawns recruit to the trawl grounds. The estimated recruitment size for greasys and kings was between 13 mm and 15 mm Cl. Tiger prawns recruited at the much larger size of 25 mm to 30 mm Cl. Based upon these recruitment sizes, the relative number of recruits entering the fishery each month was estimated from the monthly sampling size-class frequencies.

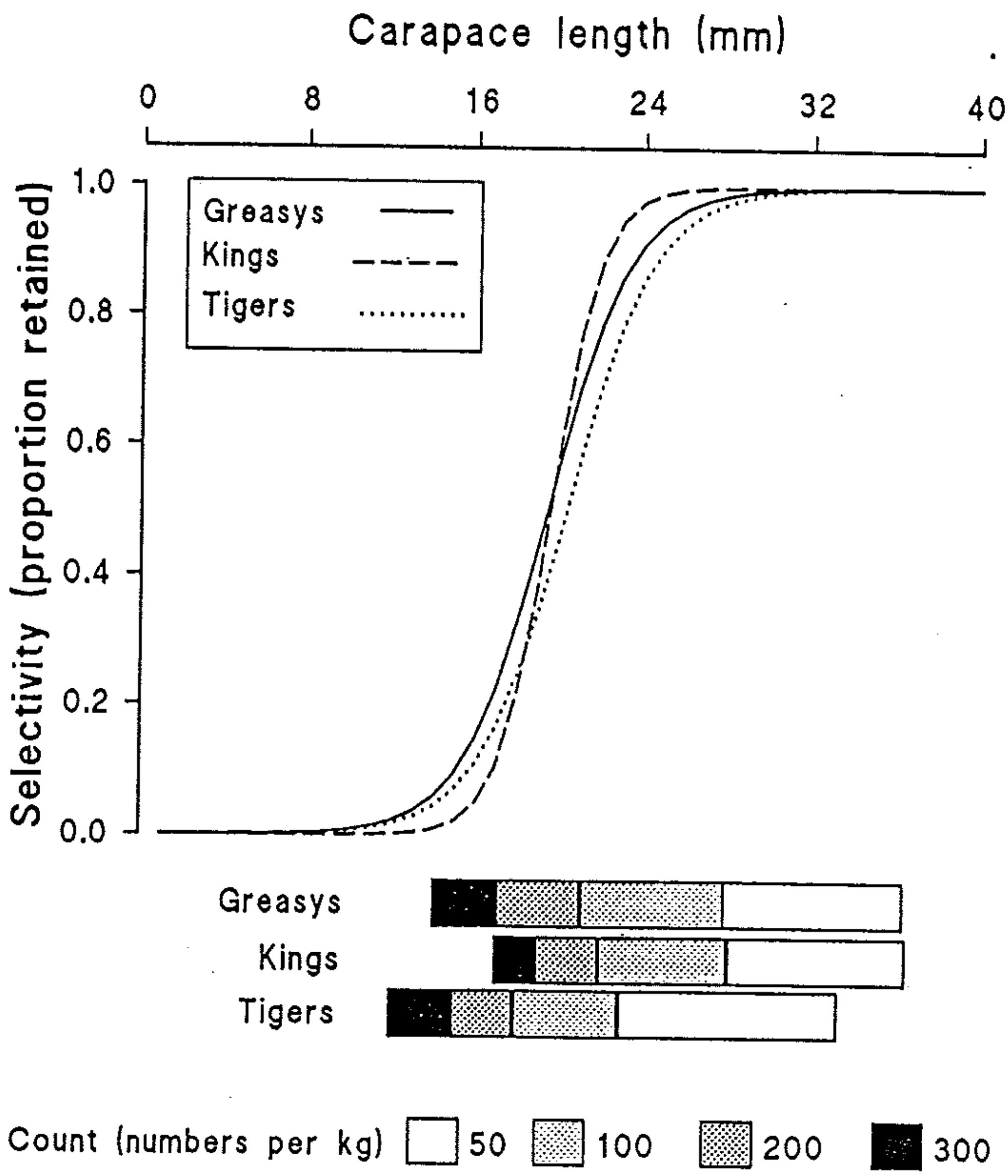

Figure 5. Selectivity curves for greasy, king and tiger prawns estimated for a 1 5/8" mesh otter trawl in Moreton Bay.

Results

Prawn distribution patterns

Over the two-year period (August 1988 to July 1990) 25 field trips were undertaken to sample the nine sites (Figure 7) on commercial trawl grounds. Mechanical failure prevented the eleventh trip (new moon in early June 1989) from being carried out, but all other trips were successfully completed. Juvenile and sub-adult prawns on the two intertidal seagrass nursery areas (Figure 7) were sampled with the beam trawl on 22 consecutive trips from November 1988 to July 1990.

On both commercial trawl grounds and nursery areas greasy prawns were by far the most numerous of the commercially important species. Kings were the second most abundant, with tigers being least abundant of the three species. Greasys were particularly abundant on the western side of the Bay (where the bulk of the area under the seasonal closure lies) because this area is subjected to estuarine conditions and greasys are essentially a shallow-water, estuarine-dependent species. Monthly size-class frequency histograms for each species and sex have been provided in Appendix 1.

On the nine commercial trawl sample sites, greasys were about three times more abundant than kings, and about nine times more abundant than tigers (Figure 6). An approximate ratio for the abundance of greasy, king and tiger prawns, based upon the nine sample sites on commercial trawl grounds is therefore 9:3:1, respectively. Greasys are however, a relatively small species and their total weight constituted a lower proportion (approximately half) of the total trawled weight of commercially important species from in and around the closure area (Figure 6).

Although there were relatively few tiger prawns sampled, their contribution to the weight of commercially important prawn landings was more significant than their abundance (Figure 6). This is noteworthy, particularly in the context of seasonal closures and the prevention of growth-overfishing and suggests that tiger prawns are already quite 'large' (relative to the other species) by the time they become vulnerable to fishing (recruitment time) in Moreton Bay.

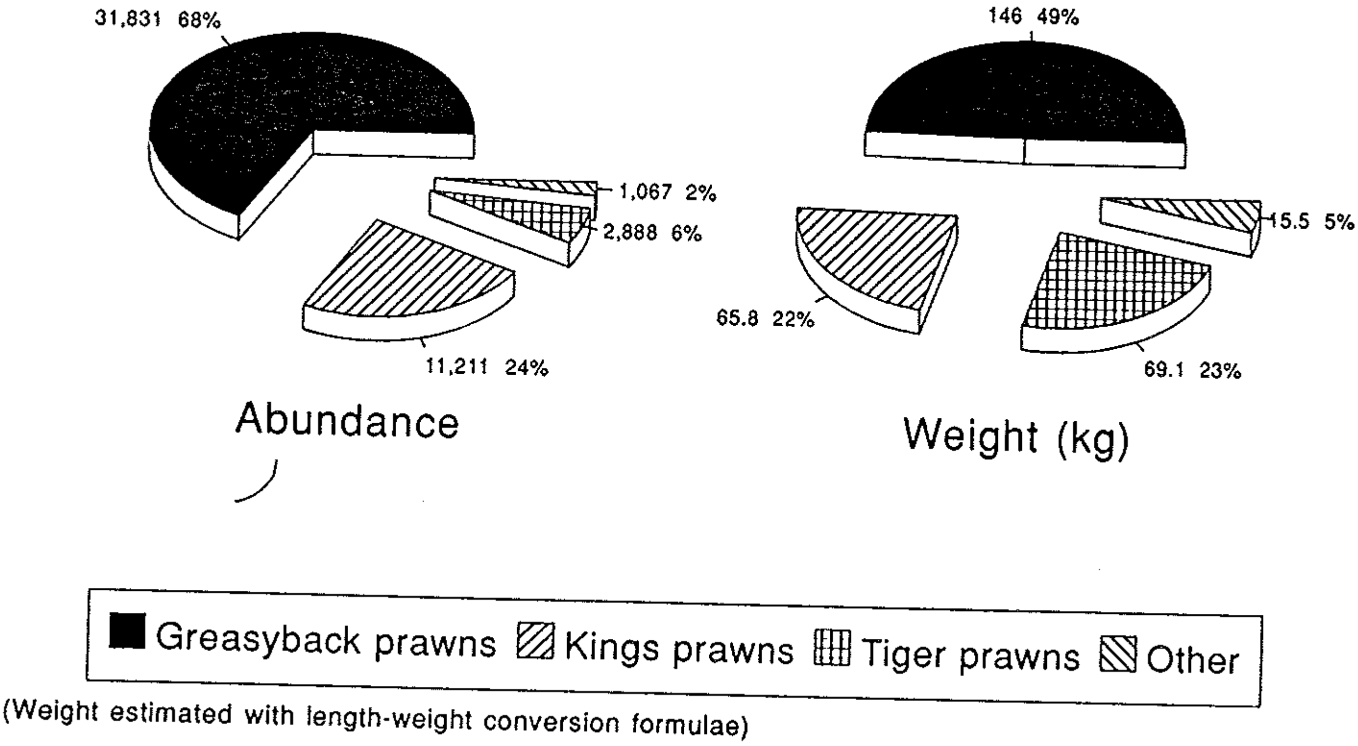

Figure 6. *Breakdown of the commercially important prawn species trawled from the nine sample sites in Moreton Bay (all trips pooled).*

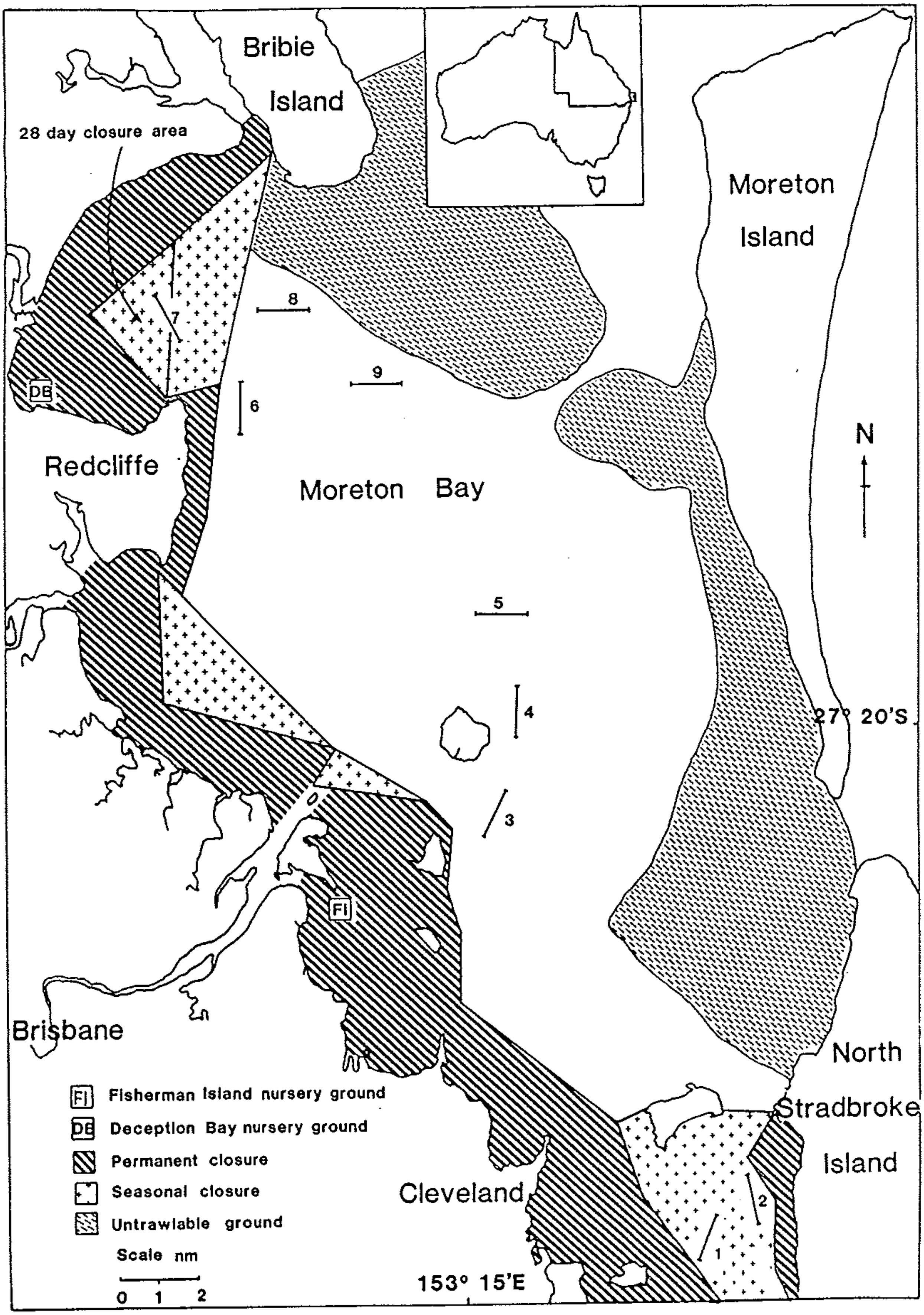

Figure 7. Permanent and seasonal closures, sample sites and untrawlable grounds in Moreton Bay.

Temporal patterns in the distribution of small prawns.

Greasy prawns

Juvenile greasys (5 mm Cl to 15 mm Cl) were present, and abundant, on the intertidal seagrass areas for most months of the year (Figure 8c) which suggests that this species has extended or multiple spawning periods throughout the year. Generally, abundance of juveniles was low over the summer months, November - December, for both years of the study.

Changes in the abundance of greasys on commercial grounds over the two years (August 1988 to July 1990), as determined from the nine sample sites, suggested that greasys were abundant within the fishery for most months of the year but showed a marked decline during the winter months, from May to August (Figure 8a). This was apparent for both years of the study.

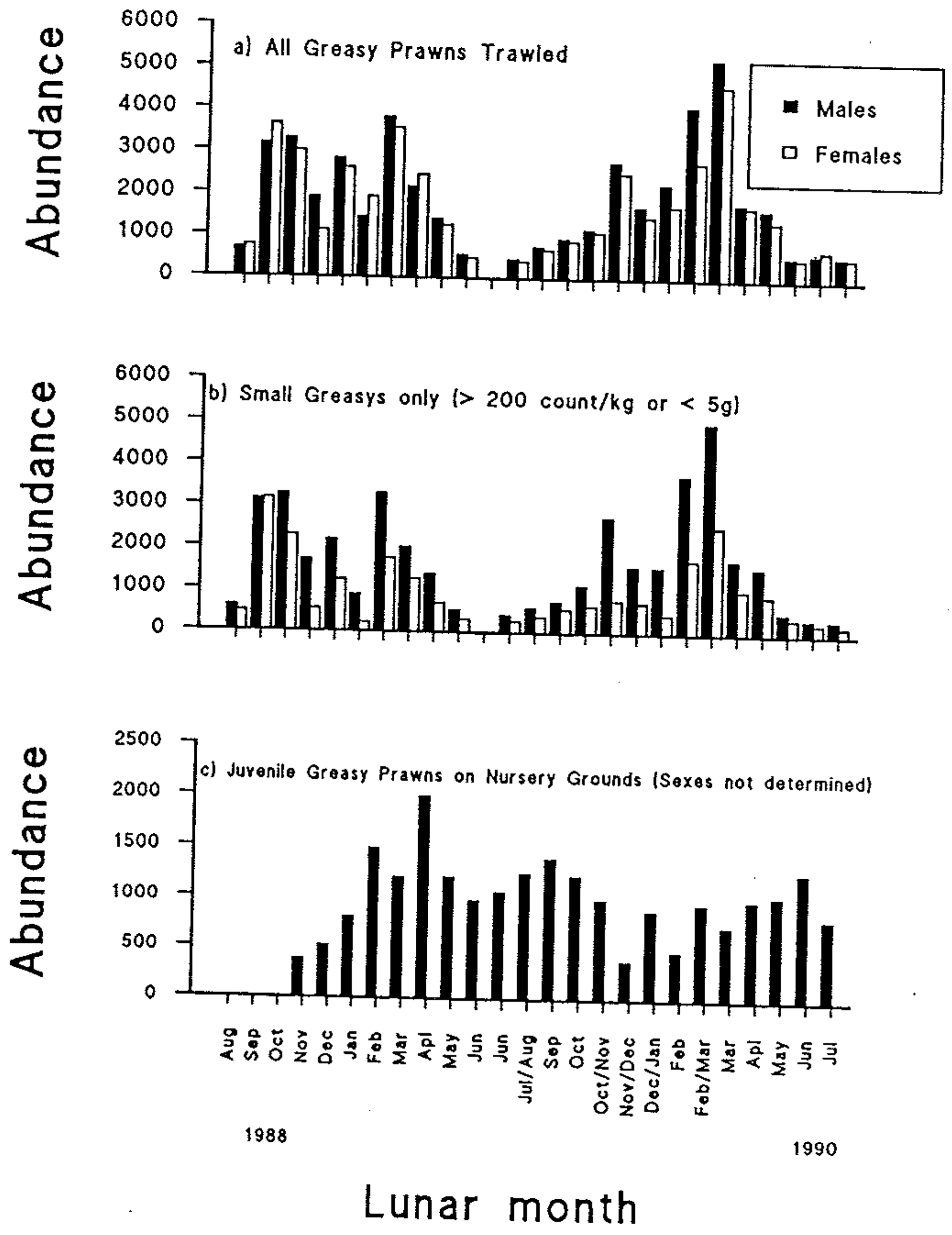

Figure 8. Time series of abundance for greasy prawns: (a) all prawns trawled from the nine sample sites; (b) small prawns only from the nine sample sites; and (c) juveniles from the two intertidal seagrass sample areas.

Table 1. Sex ratios and total number of prawns trawled in each net for all commercially important prawn species.

Species	Sex	Frequency Net 1	Frequency Net 2
Penaeus esculentus	males	1440	1443
	females	1458	1382
	Ratio	0.99	1.04
Penaeus plebejus	males	5443	8967
	females	5768	9300
	Ratio	0.94	0.96
Metapenaeus bennettae	males	15891	30550
	females	15940	26098
	Ratio	1.00	1.17
Metapenaeus endeavouri	males	156	167
	females	173	162
	Ratio	0.90	1.03
Metapenaeus ensis	males	263	262
	females	264	210
	Ratio	1.00	1.25

The sex ratio for male to female greasy prawns trawled from the nine sample sites over the whole two year period was close to 1:1 for the commercial mesh net (Table 1, net 1), suggesting that commercial fishing catches approximately equal numbers of males and females. However, the sex ratio for the smaller mesh net (Table 1, net 2), which was more selective for small prawns, was 1.17:1, suggesting a male dominance. This domination of males in the population was apparent in the monthly samples (Figure 8a) which were based on the total abundance of greasys in both nets from all nine sites each month. In 19 out of the 24 successfully completed field trips, male greasys outnumbered females.

There were at least two recruitment periods per year for 'small' (< 5 grams or > 200 count per kg) greasy prawns entering the fishery and closure areas - one in October and the other in February-March (Figure 8b). The recruitment timing was similar for both years of the study, but occurred slightly later, (by about two to three weeks) in the second year of the study, 1989-90. It was also apparent that male greasys dominated this small prawn category (Figure 8b) each month. There was little or no recruitment of greasys to the fishery over the winter months, May to August (Figure 8b).

King prawns

Temporal variation in the abundance of king prawns was clearly defined and more so than for greasy prawns. Abundance of juveniles (5 mm Cl to 15 mm Cl) on the intertidal nursery areas (Figure 9c) was seasonally marked and low during Summer/Autumn (January to April). There was a general increase in abundance of juvenile kings on the nursery grounds from May to July in both 1989 and 1990, while peaks were observed in November 1988 and October 1989.

Abundance of king prawns trawled over the commercial grounds was also highly seasonal, with little interannual variation (Figure 9a). Abundance was high for only three months each year and peaked in

October 1988 and October/November 1989. Relatively very few kings were sampled from February through to August for both years of the study. Abundance of males and females was similar each month and overall was approximately 1:1 (Table 1) for both nets.

Abundance of small (> 200 count per kg) kings (Figure 9b) in the samples was clearly defined for both years and showed a very similar pattern to that for all size categories of kings (Figure 9a) sampled each month, with peaks occurring in October, 1988 and October-November, 1989. Again, small kings are only present in high numbers for three months of the year.

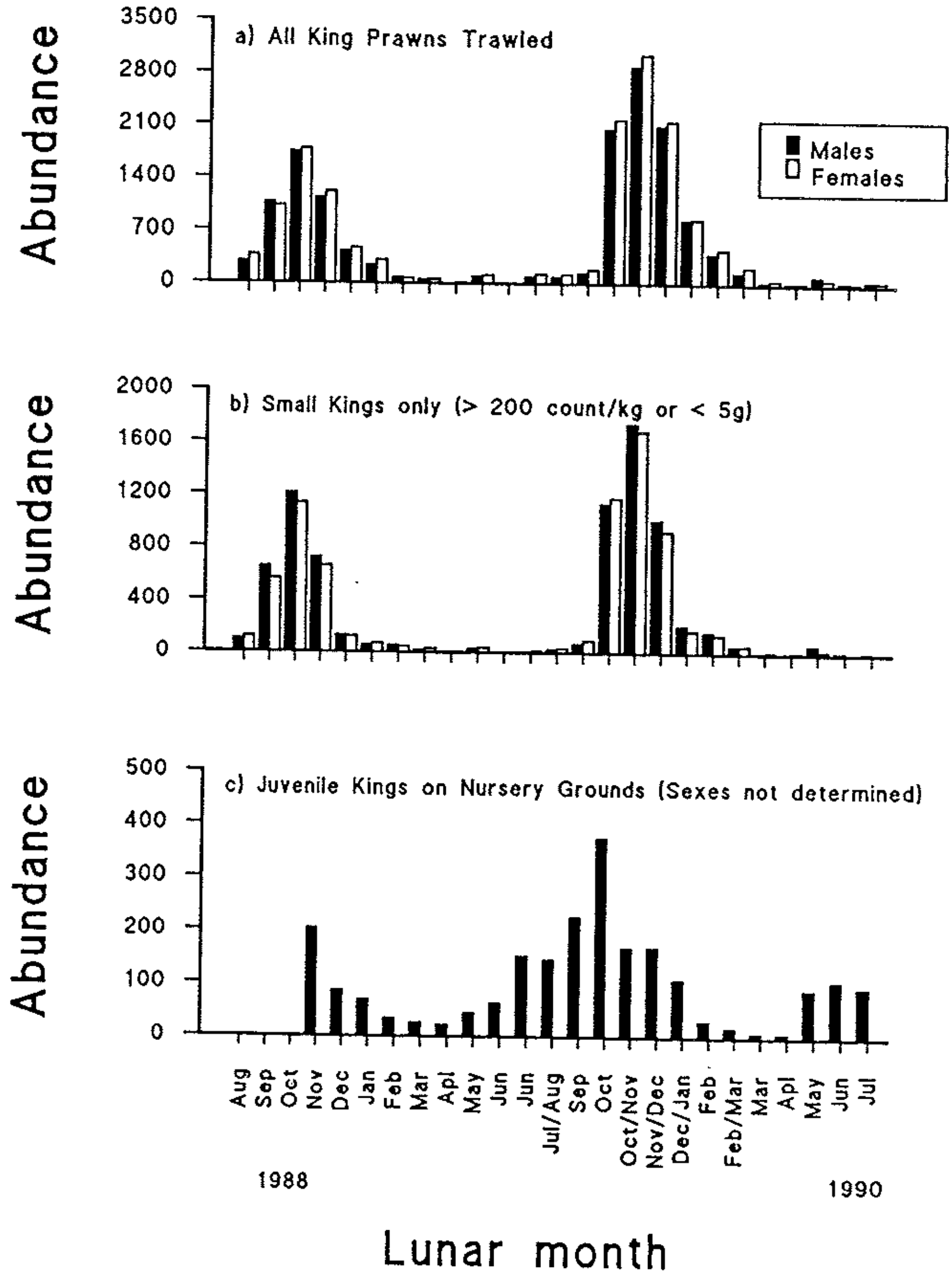

Figure 9. Time series of abundance for king prawns: (a) all prawns trawled from nine sample sites, (b) small prawns only from the nine sample sites; and (c) juveniles from the two intertidal seagrass sample areas.

Tiger prawns

Temporal patterns in tiger prawn recruitment and abundance were very different from both greasy and king prawns. Juvenile abundances in the nursery areas were high in the summer and peaked in February/March 1988 (Figure 10c). This peak was followed by a steady decline through to October 1989. During the second year of the study abundance remained relatively high from December to June.

On the commercial ground sample sites, abundances peaked in February for both years of the study and declined over winter (Figure 10a). Tigers were the least abundant of the three commercial species and sex ratios were close to 1:1 for all field trips.

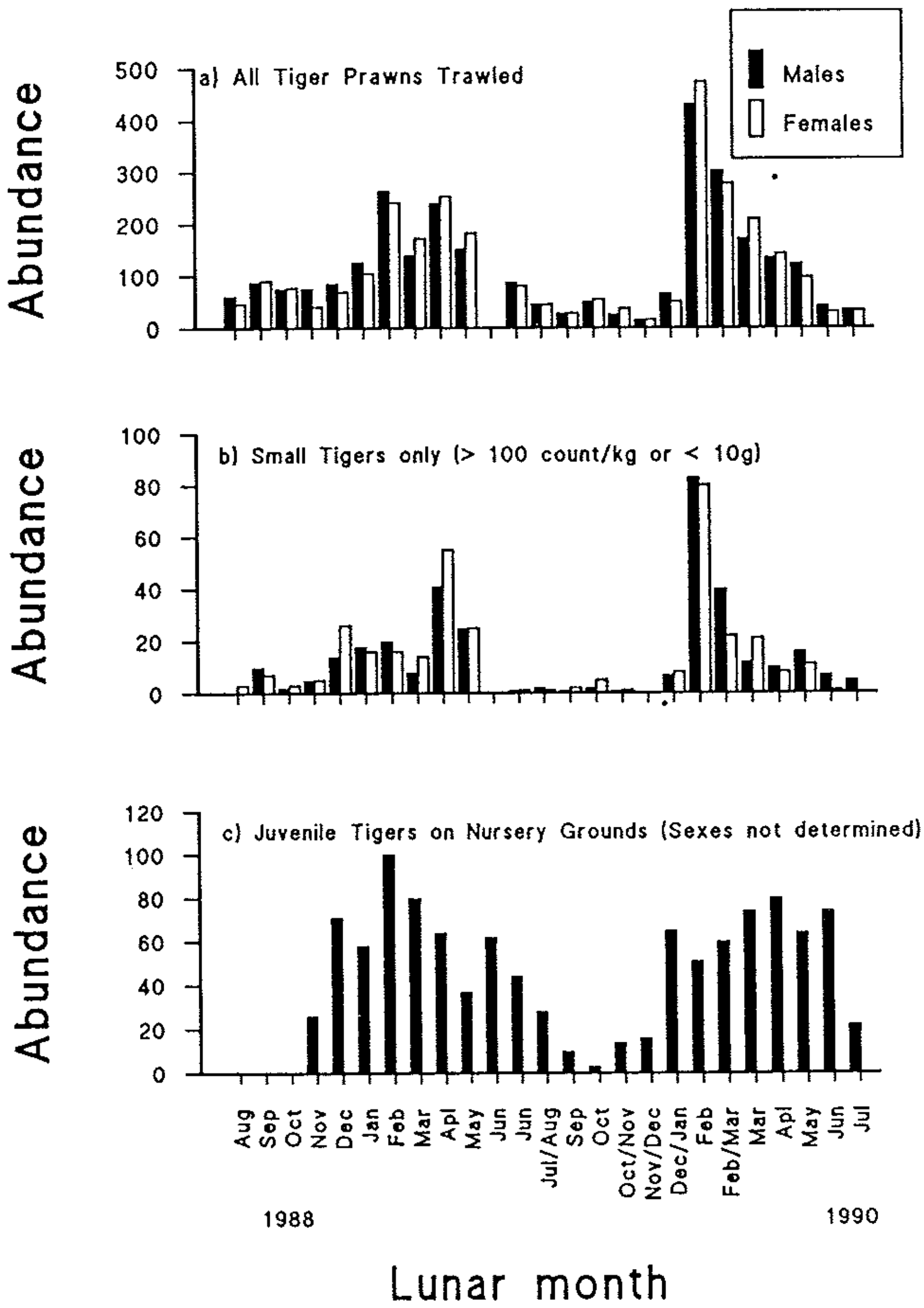

Figure 10. Time series of abundance for tiger prawns: (a) all prawns trawled from the nine sample sites; (b) small prawns only from the nine sample sites; and (c) juveniles from the two intertidal seagrass sample areas.

There were extremely low numbers of small (< 5 g or > 200 count per kg) tiger prawns on the commercial trawl sample sites during the course of study. This suggests that small tiger prawns aren't as vulnerable to growth overfishing in Moreton Bay as the greasy and king prawns. Analysis of the size-class frequency distributions for juveniles on the seagrass nursery areas suggested tiger prawns may reach a considerably larger size than the greasy and king prawns before they undertake migration off the nursery areas to the commercial grounds (Table 2).

Table 2. *Breakdown of the proportion of juveniles in different size classes beam trawled from the nursery habitats. Both intertidal seagrass sites (Deception Bay and Fisherman Islands) and all juvenile sampling trips were pooled.*

Weight	Greasy	King	Tiger
Larger than 2 grams	2%	8%	24%
Larger than 4 grams	0	1%	7%
Larger than 6 grams	0	0	3%

Only two per cent of juvenile greasy prawns on the seagrasses were larger than 2 g, but 24 per cent of the juvenile tigers were larger than 2 g (Table 2).

Because there were very few tiger prawns that were less than 5 g in the commercial ground sample sites, a slightly larger size class of tigers was used as an indicator of the recruitment - all tiger prawns in the samples less than 10 g (> 100 count per kg). The recruitment periods for these small tiger prawns to the fishery occurred from December to May in 1989 and from February to May in 1990 (Figure 10b); well outside the introduced seasonal closure periods. There were extremely low numbers of small tigers on the commercial grounds from August to December during both years of the study.

Spatial patterns in the distribution of small prawns.

Small prawns were not evenly distributed across all of the sample sites, suggesting that some areas of the seasonal closure may have had a greater effect at reducing fishing effort on small prawns than others. Of all the small greasy prawns trawled over the commercial ground sample sites, the majority were from the northern sites (6, 7 and 8) (Figure 11). Site 7, which was within the seasonal closure and Deception Bay, was particularly abundant in small greasy prawns. Relatively few small greasys were sampled from the five most southern sites (sites 1-5), including sites 1 and 2, which were within the seasonal closure.

Small kings (< 5 g or > 200 count per kg) were more evenly distributed across the sample sites and closure areas than greasys and were relatively abundant in both southern and northern parts of the Bay (Figure 11). The lowest proportions of small kings were associated with the sites of greatest depth (sites 5 and 9). Of the relatively few tiger prawns sampled over the two-year period, high proportions of small tigers (< 10 g or > 100 count per kg), were found in sites 1, 2 and 7; all of which were within the seasonal closures and in shallow areas close to seagrasses.

When species were pooled and undifferentiated, the highest proportions of small prawns were in the northern sites 6, 8, and particularly site 7. This pooling of species could be used if a 'blanketing' approach to the seasonal closure was required, without necessarily differentiating between species. The results of pooling the species produce proportions which are heavily biased by the high greasy prawn abundances.

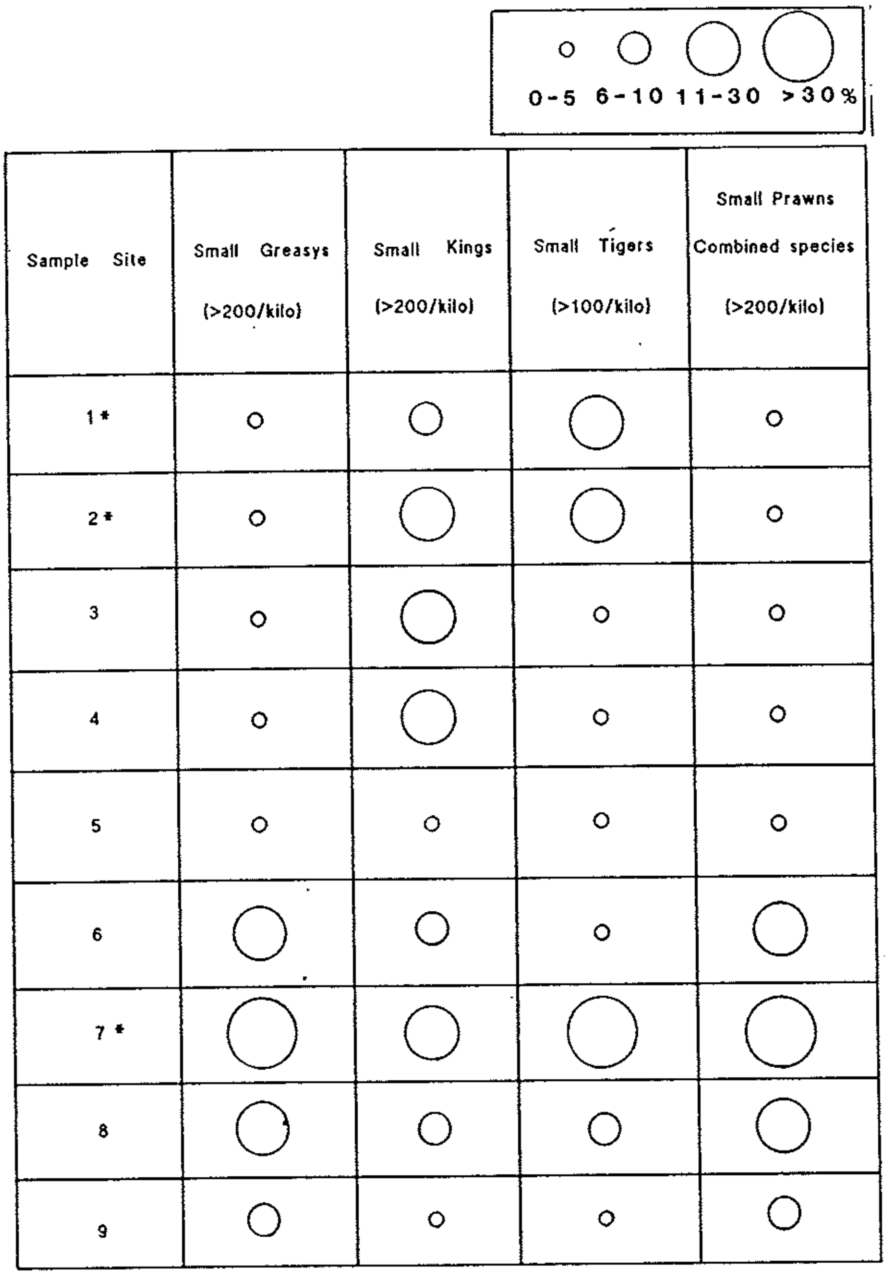

***Figure 11.** Relative abundance of small prawns (trips pooled) at each of the nine sample sites (* sites within seasonal closure).*

A preliminary comparison (non-parametric Kolmogorov-Smirnov test) of the size classes of prawns in different depths determined that the dissimilarity between the sizes of prawns was much greater for greasys, than for the kings or tigers. Further analysis of the distribution of small prawns found that very high proportions (70 - 95 per cent) of the greasy prawns trawled in the shallow (5 m - 8 m) sites weighed less than 5 g each (> 200 count per kg). This high proportion decreased markedly as depth increased, so that in depths of about 20 m the proportion of small greasys was only around 10 per cent (Figure 12). Although there were high proportions (40 - 65 per cent) of small kings in these same shallow sites, the proportions were not as high as those for the greasys. Again, as with the greasy prawns, there was a decline in the proportion of small kings as depth increased, but this decline was not as marked as that for the greasys. The proportion of small (< 5 g or > 200 count per kg) tigers did not exceed 23 per cent for any of the depths sampled and was characteristically low.

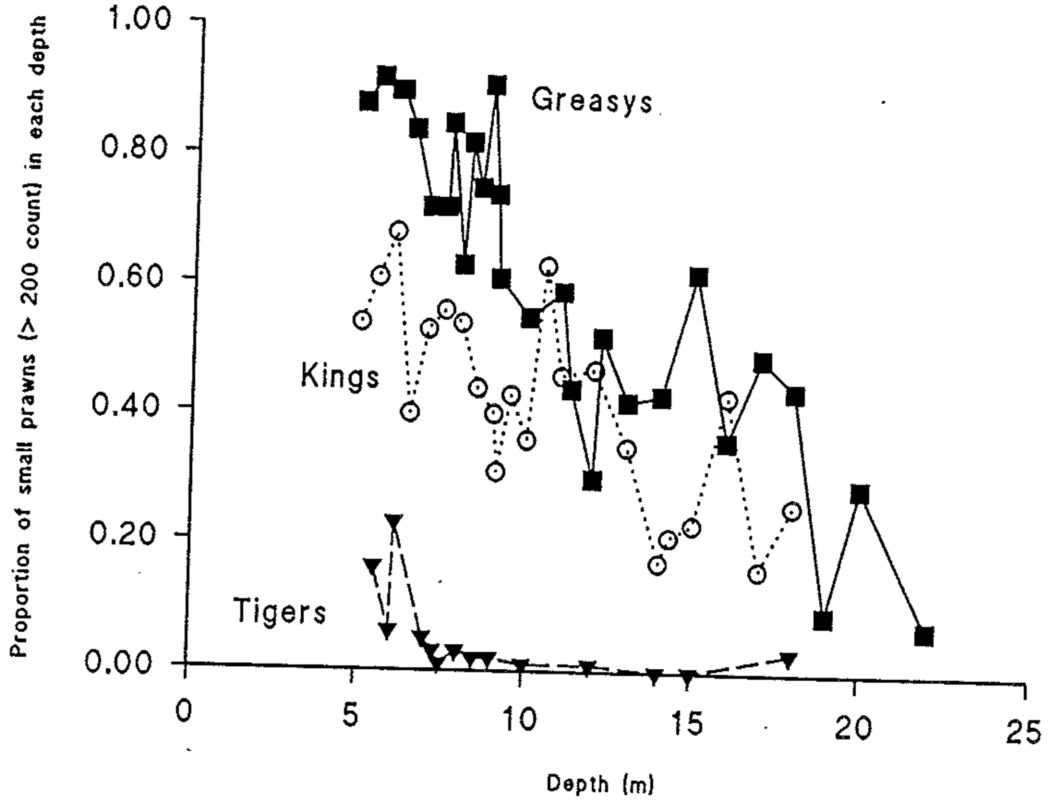

Figure 12. Proportion of small prawns (>200 count per kg) by depth in the nine sample sites.

The high proportions of small greasys in the shallow depths is a result of a sex-related distribution pattern for this species. Males dominate numerically in the shallow sample sites while females are more abundant in the deeper sites (Figure 13). This was not the case for kings and tigers; their sex ratios remained at around 1 for most depths. Male greasys are much smaller than females. The average, or modal size of the male greasy prawns using commercial sampling gear is only 3.5 grams, (or 285 count per kg or 16-17 mm Cl, Figure 14). Only a very small proportion of the male greasy prawn population will grow larger than 5.0 grams (200 count per kg or 19 mm Cl). Female greasys grow considerably larger than males, and have an average, or modal size of 6.5 grams (or 154 count per kg or 20 mm Cl). A considerable proportion of the female greasys trawled with commercial gear are in the 6.5 grams to 10.0 grams size class range (154 to 100 count per kg or 20 mm Cl to 25 mm Cl, Figure 14), but males don't reach these larger size class ranges.

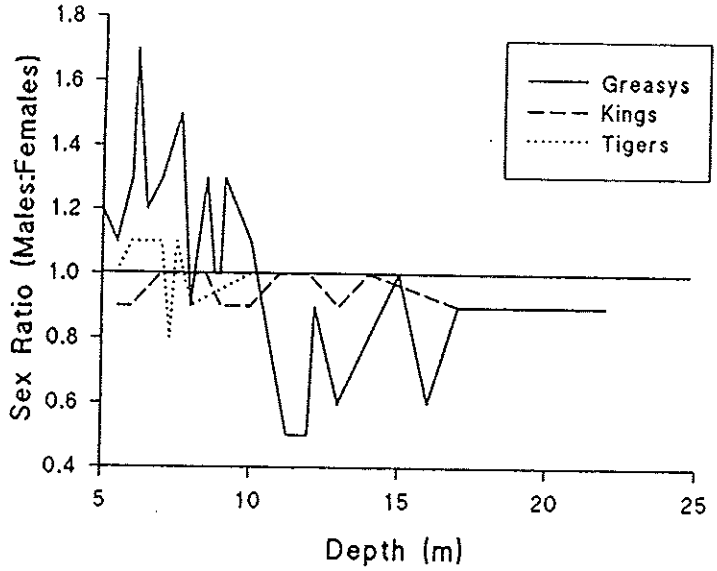

Figure 13. Sex ratio by depth for prawns trawled in the nine sample sites.

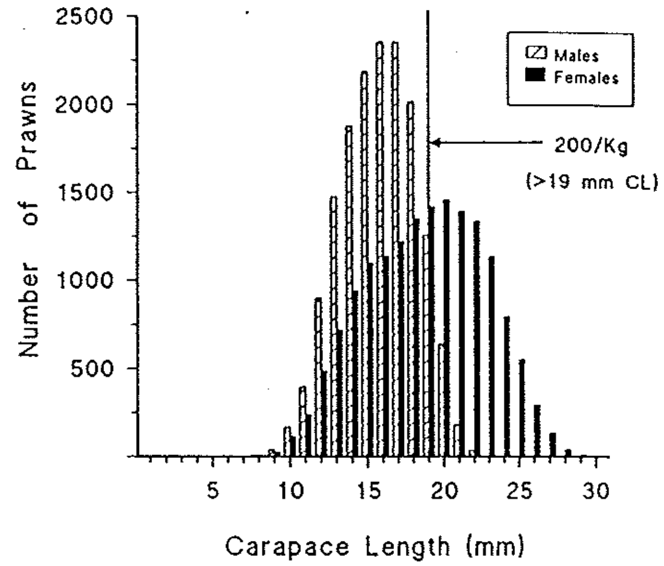

Figure 14. Size-class frequency histogram for male and female greasy prawns for the nine sample sites (trips pooled) trawled with the commercial mesh net (1 5/8").

Modelling the closure

Simulations were carried out to quantify the change in yield to the greasy and king prawn stocks only. The effects of the closure upon tiger prawns were not considered because the sampling programme had revealed that:

1) small tigers recruited to the fishery from around December to May, which was well outside the seasonal closure period;

2) tigers were the least abundant of the three major commercially important prawn groups; and

3) very low proportions of small tiger prawns were sampled on commercial trawl sample sites, which suggested that tigers are less vulnerable to growth overfishing in the Bay, possibly because they recruit to the fishery at a larger size than other prawns.

Effects on greasy prawns

Yield-per-recruit for female greasy prawns in the absence of a seasonal closure estimated from the simulations ranged from 0.152 to 3.09 grams depending on the combination of mortality values (Appendix 3a, page 62). An estimate of 1.028 grams was obtained with the best estimates of the present mortality parameters (M=0.3, F_{max}= 0.56). Yield-per-recruit in grams for males was estimated to range from 0.078 to 2.536 grams with a best estimate of 0.590 - about half of the female yield-per-recruit (Appendix 3a, page 61). Depending on the mortality combination used and the hypothesis about the effects of the closure, changes in overall yield-per-recruit (sexes combined) with the seasonal closure ranged from a 4.6 per cent decrease to a 1.6 per cent increase for a sex ratio at recruitment equal to 1.0 (Appendix 3a, page 64,65). For a female to male sex ratio of 0.7 (due to a dominance of male greasys) the changes in yield-per-recruit ranged from a 4.9 per cent decrease to a 1.3 per cent increase (Appendix 3a, page 66,67). Under the hypothesis that 25 per cent of effort was redistributed from small to large prawns (hypothesis 3), and for the best estimate of the present situation of the fishery (M=0.3, F_{max}=0.56, Sex ratio=0.7) the closure would have had very little effect on yield-per-recruit. It would only reduce it by 0.75 of a per cent (Figure 15).

The seasonal pattern of yield would have changed very slightly as a result of the seasonal closure. Most of the loss in yield-per-recruit would be the result of reduced catches during the months of the closure (Figure 16). Yield losses for the seasonal closure months may have been up to 24 per cent if there was a 25 per cent decrease in fishing mortality for all sizes of prawns (hypothesis 2), but should not be more than 14 per cent if effort was redistributed (hypothesis 3).

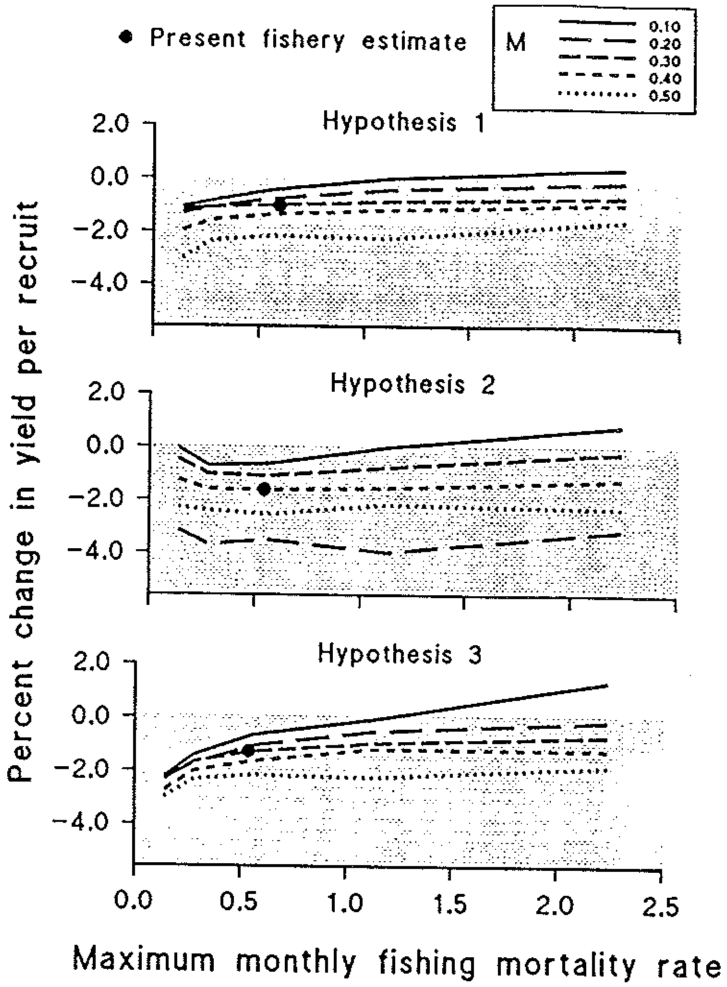

Figure 15. *Effects of the seasonal closure on yield-per-recruit of greasys assuming a 0.7 sex ratio at recruitment and a 25 per cent reduction or redistribution of fishing mortality.*

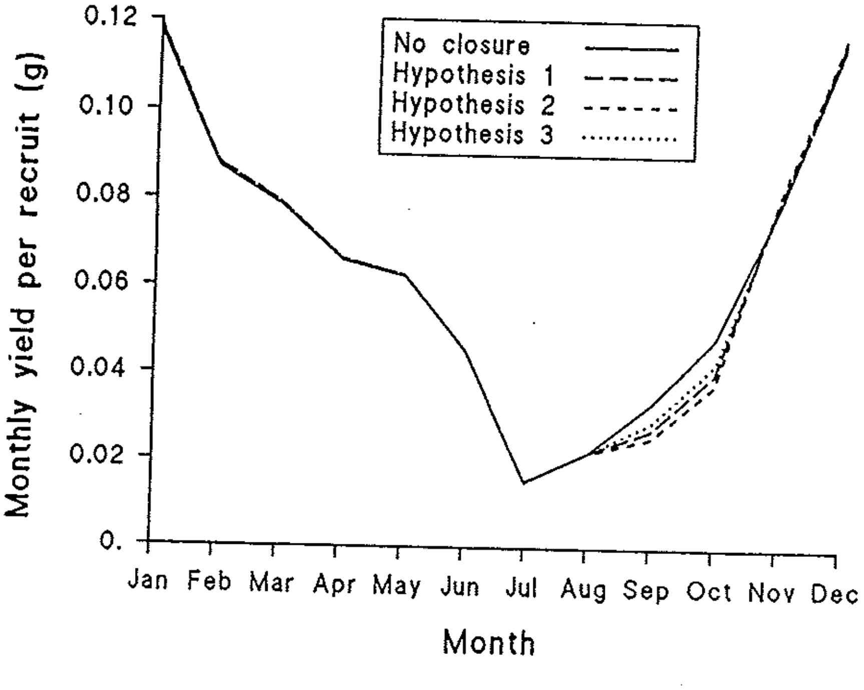

Figure 16. *Monthly yield-per-recruit for greasys for a 0.7 sex ratio at recruitment, for M=0.3, F_{max}=0.56 and a 25 per cent reduction or redistribution in fishing mortality.*

The average weight of greasys caught, was also changed as a result of the closure, with small increases in average weight during the closure months (Figure 17). Such increases would represent a 13 per cent increase in the average prawn weight during the second month of the closure if effort was redistributed from small to large prawns (hypothesis 3). However, if effort was reduced during the closure (hypothesis 1 and 2) smaller increases would have occurred.

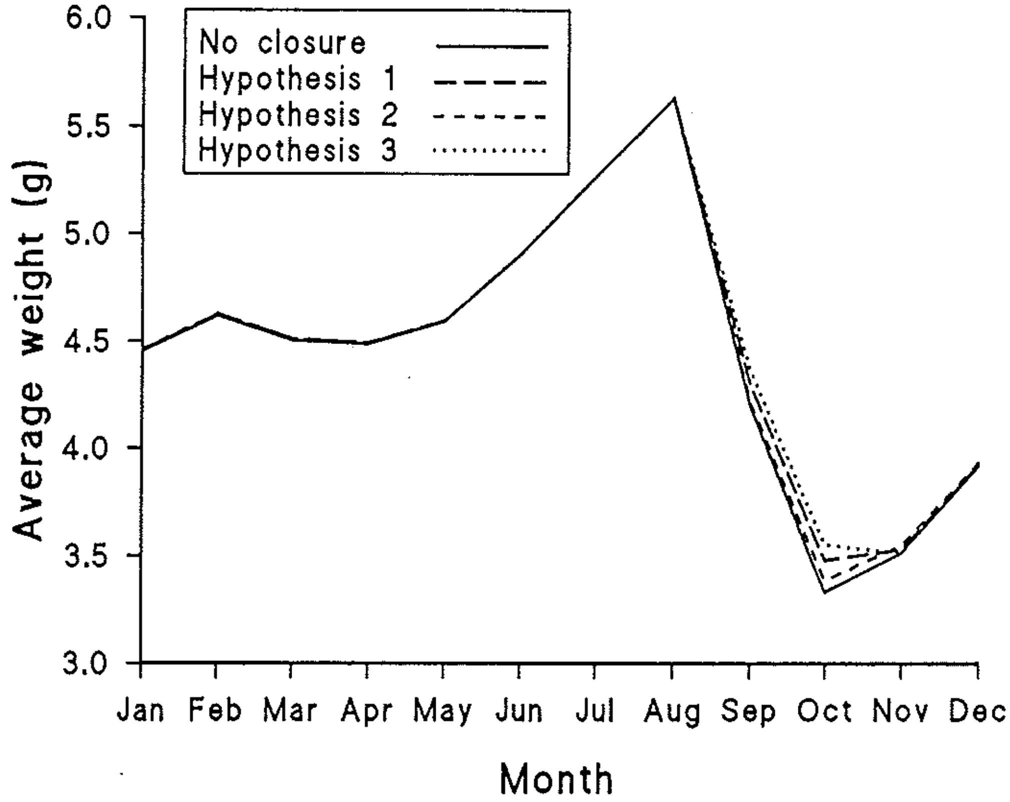

Figure 17. *Average monthly weight of greasys simulated for a 0.7 sex ratio at recruitment, M=0.3, F_{max}=0.56 and a 25 per cent reduction or redistribution in fishing mortality*

Effects on king prawns

Male and female king prawns do not have significantly different growth rates within the Bay. Their growth rates only start diverging when they approach maturity, which apparently only occurs when they leave the Bay. Therefore, yield-per-recruit for king prawns in Moreton Bay was calculated for both sexes combined. Kings are also much less stratified by size and depth than greasys. Therefore it is unlikely that the seasonal closure shifted mortality from small to large kings. It is much more likely that the net effect of the closure was either an overall decrease in mortality for all sizes of kings present in the Bay at the time of the closure (comparable to greasy's hypothesis 2), or a redistribution of effort from one part of the population (the closed area) to another (the open area). In the later case overall fishing mortality would not have changed, and the closure would have had no net effect on kings.

Yield-per-recruit in grams for king prawns within the Bay was estimated for three values of the size at which prawns start emigrating out of the Bay, and for a range of mortalities. Estimated yield-per-recruit ranged from 0.05 g to 4.66 g (Appendix 3b, page 71-73), with a best estimate (M+E=1.0, F_{max}=0.56, Size at migration > 19 mm Cl) of 1.13 g (Figure 18).

If the seasonal closure reduced fishing mortality on kings, the expected change in yield-per-recruit would have ranged from a 1.65 per cent reduction to a 1.55 per cent increase (Appendix 3b, page 74-76). The best estimate of this change being a 0.03 per cent increase (for M+E=1.0, F_{max}=0.56, Size at migration > 19 mm Cl., and a 25 per cent decrease in fishing mortality). Given that it is more likely that the true net effect of the closure is only a redistribution of effort, it is clear that the effect on kings yield-per-recruit would have been negligible.

In order to estimate the possible effects to the outside fishery for kings, estimates of the number of emigrating kings-per-recruit were obtained from the simulation. This number ranged from 0.001 to 0.4 migrating prawns-per-recruit in the absence of the closure depending on the combination of mortalities and minimum size at migration used (Appendix 3c, page 79-81). The best estimate of the number of emigrating prawns-per-recruit (M+E=1.0, F_{max}=0.56, Size at migration > 19 mm Cl) was 0.09.

In the presence of a closure, and if the closure reduced fishing mortality, the simulations estimated an increase in the number of emigrating prawns-per-recruit. However this increase was never higher than 2.5 per cent for any parameter combination (Appendix 3c, page 82-84) and the best estimate (M+E=1.0, F_{max}=0.56, a 25 per cent in fishing mortality and Size at migration > 19 mm) was an increase of 0.27 per cent. Again if the net effect of the closure was only a redistribution of effort, no net effect in migration of kings out of the Bay would have been observed.

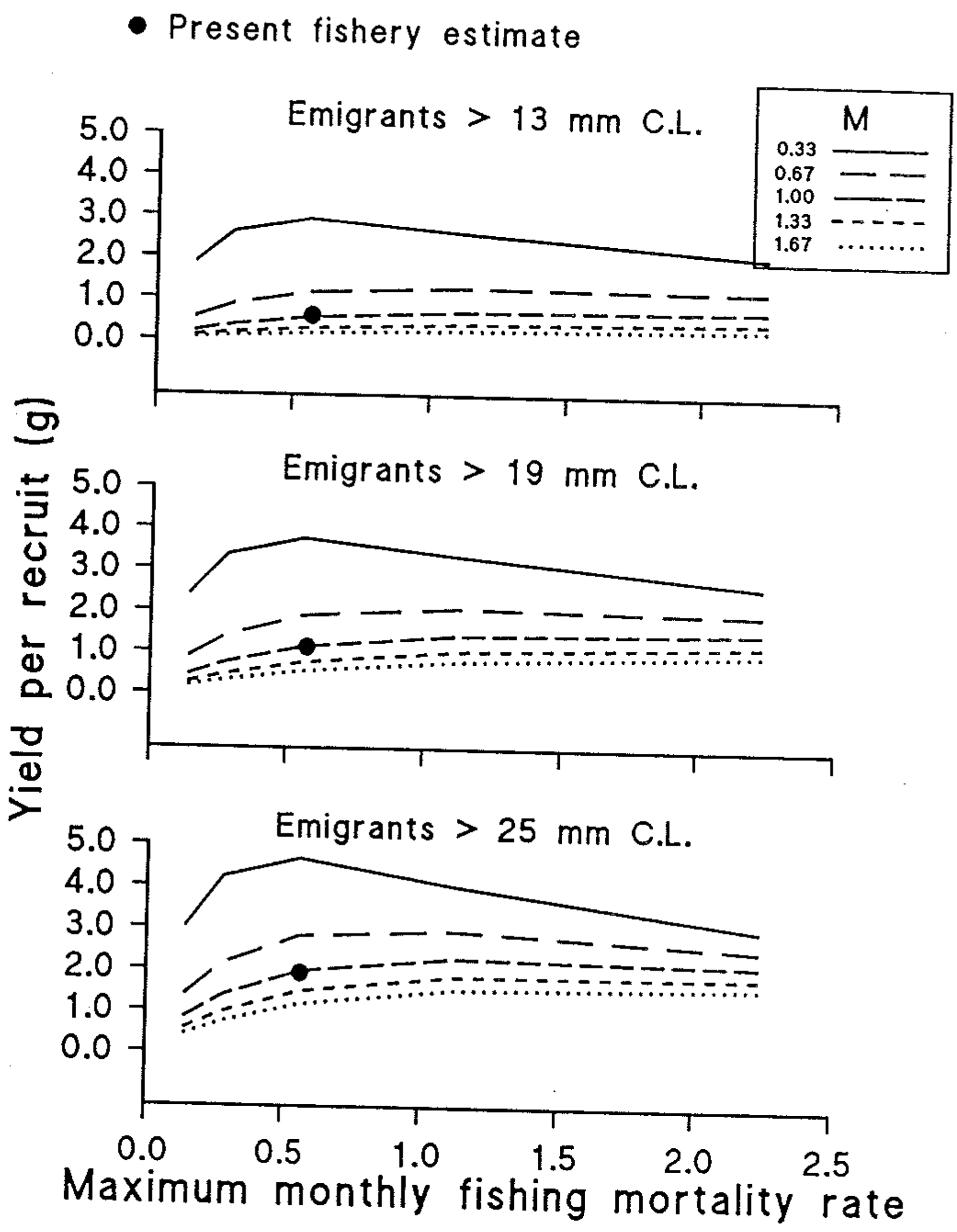

Figure 18. Yield-per-recruit for Moreton Bay king prawns in the absence of a seasonal closure and for several values of the minimum size at emigration.

DISCUSSION

It became obvious very early in the study that the seasonal closures would not have reduced fishing mortality on small tiger prawns in the Bay. The seasonal abundance and distribution of tigers in the Bay, from both the seagrass nursery areas and the nine trawl sample sites suggested that tigers recruit to the fishery at a much larger size than greasy and king prawns - thus lowering the likelihood of growth overfishing. Furthermore, the recruitment timing of the tigers (December to May) is such that it occurs well outside the period during which the seasonal closure was held (September to November). Consequently, the effects of the seasonal closures on tiger prawn growth-overfishing was likely to be minimal and has not been addressed in this study.

The greasy prawns were the most numerically abundant prawn species in Moreton Bay and are among the most numerous macro-invertebrates of the littoral zone in southeast Queensland. They are estuarine dependent and restricted to shallow coastal waters. Although a small species, their high abundance results in greasys constituting around 50 per cent of the landed prawn biomass (800 tonnes total, CFISH) from the Bay otterboard trawl fishery. Consequently, any management decision which influences the level or distribution of fishing effort in the Bay, even if it is targeted at reducing effort on king prawns, needs to assess its impact on the greasy prawn resource. Variation in the abundance of greasys on the commercial trawl sites suggested that they recruited to the fishery on two occasions each year (October and February-March). These recruitment times were consistent with those found by Hyland (1987) and are likely to be the periods during which greasys may be prone to growth overfishing.

Males numerically dominated the greasy prawn population in shallow areas (< 10 m). This dominance by one particular sex was quite marked and is uncommon in penaeids, where sex ratios are usually around 1:1. Such a distribution pattern may be either size or sex-dependent, and may also be partly explained by the lower salinity tolerance of males purported by Dall (1958) which results in them leaving the rivers more readily than females during heavy wet seasons. Whatever the reason for the difference in the distribution patterns between male and female greasys, the consequences for the fishery are profound. The shallow areas of the western side of the Bay will always be dominated by small male greasys; which have a population modal size class that only ever reaches around 3.5 g (286 count per kg or 16-17 mm Cl). The modal size class of females is almost twice that of males (6.5 g, 154 count per kg or 20 mm Cl) and although a significant proportion of the female greasy prawn population can reach 7 - 10 g, the proportion of males that will grow beyond 5 g is negligible. Any closure, therefore, with the function of lowering fishing mortality on small prawns and increasing yield-per-recruit will have limited effect on greasy prawns because at least 50 per cent of the population will remain small (285 - 200 count per kg), regardless of the timing, duration or position of a seasonal closure.

The difference in the sex ratios between the two nets (Table 1) used to sample the prawns from the nine sites suggested that the size selectivity of commercial mesh nets used by the fleet within the Bay (1 5/8" mesh) may already be reducing fishing mortality on small greasy prawns. Although the commercial mesh net sampled approximately equal numbers of both male and female greasys, the small mesh net (1 1/4") was significantly biased by males. This could be due a dominance of males, which only becomes apparent when small gear is used to sample the population. Large proportions of small greasys most likely pass through the commercial mesh. Because kings recruit to the fishery at about the same size as greasys, it is likely that large proportions of small kings are also not retained by the commercial mesh net. In contrast, tigers recruit to the fishery at a size larger than the selection range of the commercial mesh net. The present commercial mesh size, therefore, has no effect on the size of the tigers retained by the net.

Timing and position of the seasonal closure

The seasonal closure removed fishing mortality for about two months of the year over 15 per cent of the trawlable grounds in the Bay. Although aimed at reducing fishing mortality on small king prawns, the closure had a greater impact on small greasys. The reasons for this are due mainly to the position and size of the closure areas. Greasys are estuarine dependent and were more abundant on the western side of the Bay - where the bulk of the seasonal closures were. Small greasys were strongly associated with shallow water areas, which again, is where the closures were. Small kings, on the other hand, were not so strongly associated with the shallow, estuarine conditions of the western side of the Bay, but were more evenly distributed across sites and depths than greasys; which is what might be expected from a highly migratory, mobile species. These results are supported by the post-larval studies of Young and Carpenter (1977), who concluded that kings tend to settle in areas which have a lower freshwater influence. Consequently, while the distribution of small greasys was relatively well defined, small kings were not so restricted in their distribution. The distribution of the closures therefore, was such that they were more attune to reducing effort on small greasys than kings. In order to significantly reduce fishing mortality on small kings in the Bay, very large proportions of the trawlable grounds in the Bay (much more than 15 per cent) would need to be closed to fishing.

Although small kings were less spatially stratified than greasys, their recruitment timing to the Bay fishery appeared succinct and limited to only two or three months each year. This feature of king prawn recruitment lends itself well to defining seasonal closure periods for this species and is in contrast to the extended, multiple recruitment patterns displayed by greasys. Recruitment patterns and prawn abundances for the greasys and kings (Figures 8,9) suggested that the introduction of the seasonal closures in July 1988 was far too early in the season to lower fishing mortality on small prawns. At that time of the year there were very few small prawns of any commercial species in the Bay. The starting times in the subsequent 1989 and 1990 seasons were much more attune to the recruitment times of both greasys and kings.

Assessment of the seasonal closure

Overall, the effect of the present seasonal closures on yield-per-recruit of the three major species or on emigration of kings outside the Bay seems insignificant. There are several reasons for this.

The overall effect of the closure on effort did not seem to be very significant (as would be expected for a 25 per cent reduction over two months of the year). For a fishery which is based on a fast growing animal with a high mortality rate, such small changes in fishing mortality were unlikely to significantly effect yield-per-recruit. The expected effect of reducing fishing mortality on small prawns only affected greasys, which do not grow much larger than the size at which they recruit to the fishery. Therefore, even if there was a shift in fishing mortality from the small to the large prawns this shift may actually have reduced yield-per-recruit because it shifts mortality to a less productive portion of the population (in the case of the greasys it essentially represents missing the chance of catching small prawns before they die).

The effect on emigration of kings outside the Bay also appeared minimal. This again was a result of the fact that the reduction in fishing mortality, as a result of the seasonal closure was small and did not significantly change the number of kings caught by the Bay fishery.

It is difficult to estimate the detailed economic implications of such changes in yield-per-recruit, average weight, monthly yield or emigration. However, because of the small predicted changes relating to the above variables it is unlikely that the seasonal closures had any significant effect on the overall yearly economic return. The only possible effects worth discussing are those relating to changes in the monthly yield and average weight of greasys. The reduction in monthly yield of greasys predicted for the closure months should effectively put back the start of the peak fishing season for greasys by about a month, from October to November. The increase in average weight of greasys due to the closure will represent an increase in the average count for the month of October from about 300 to 285. Whether these changes have any effects on the revenue to the fishery remains to be determined. Because of its importance to local markets, changes in the prawn production from Moreton Bay may significantly affect prawn prices. Until research is conducted on the relationship between price and supply for the different species of prawns and the various commercial categories it will be impossible to evaluate the effects of changes in yield on revenue to the fishery. From the production point of view, it is clear that the effects of the seasonal closure are not very significant.

CONCLUSIONS

1) Greasy prawns showed a strong size stratification with depth; smaller animals were more abundant in shallow areas. Consequently, the spatial distribution of small greasys was well defined. Recruitment periods, however, were extensive, with at least two major recruitment peaks each year.

2) King prawns were less spatially stratified than greasys, but displayed a short and well defined recruitment period.

3) The spatial distribution of a seasonal closure for small greasy prawns, therefore, would be relatively simple to define, but the duration of such a closure would need to be prolonged due to the extended recruitment of this species. In contrast to the greasys, kings would require a closure of relatively short duration, but of broad geographic distribution.

4) Tiger prawn abundances were relatively low, with individuals recruiting to the fishery at a much larger size than greasy or king prawns. Recruitment occurred much earlier in the year; well outside the seasonal closure period.

5) The distribution of catch and effort, as determined from the 1988 CFISH data, suggests that the most intensive fishing takes place in the north-west areas of the Bay. Although the seasonal closures represented only 15 per cent of the total trawlable grounds, 25 per cent of all fishing mortality was directed to these seasonally closed areas.

6) Although the simulation results suggested that the seasonal closure had little or no positive effect on yield for greasy or king prawns in its present form, it should not be concluded that all forms of a seasonal closure have a similar effect.

7) Greasys are such a small prawn, with such a high mortality that their most productive size ranges are well below the sizes sought by the market or selected by the gears presently used. Therefore any decrease in fishing mortality for greasys will most likely lead to a decrease in yield-per-recruit.

8) The seasonal closure did not significantly affect king prawn yield because, at most, fishing effort was only reduced by 25 per cent for one-sixth of the year.

9) The simulations indicated that there were only very small increases in the number of emigrating king prawns-per-recruit from the seasonal closure.

10) If seasonal closures within Moreton Bay are to significantly enhance emigration of small kings out of the Bay, then it is likely that much larger areas within the Bay (larger than 15 per cent of the trawlablegrounds) would have to be closed to fishing.

11) In order to have any effect on tiger prawn yield-per-recruit, the closures would have to be imposed earlier in the year, around February. It is unknown whether yield-per-recruit for this species can be improved as a result of changes in the fishing effort within the Bay.

RECOMMENDATIONS

1) Given that the present seasonal closure does not have any significant effect on yield or emigration of any of the three major commercial prawn species, its continuation is unwarranted.

2) There may be a more appropriate alternative seasonal closure in the Bay trawl fishery, which reduces fishing mortality on emigrating kings without significantly lowering the yield for Bay fishermen. If such an alternative is to be considered in the future, then the following research needs to be undertaken:

a) further simulation work to establish optimal timing, duration and geographical distribution of closed areas;

b) re-evaluation of emigration sizes and rates for king prawns;

c) determine the significance of the emigrating Moreton Bay king prawns to the 'outside' fishery;

d) estimation of growth and survival parameters for greasy prawns;

e) estimation of capture efficiency for the trawl gears presently used in the fishery; and

f) monitor the size and species composition of commercial landings in the Bay fishery.

3) Given the level of conjecture about the history of catch and effort data for the Moreton Bay fishery, it is imperative that;

a) the level of logbook record accuracy and participation are validated; and that

b) fishermen are encouraged to provide a site number, or some other specific reference (for example, latitude and longitude) as well as a grid reference for a detailed allocation of catch and effort within the fishery.

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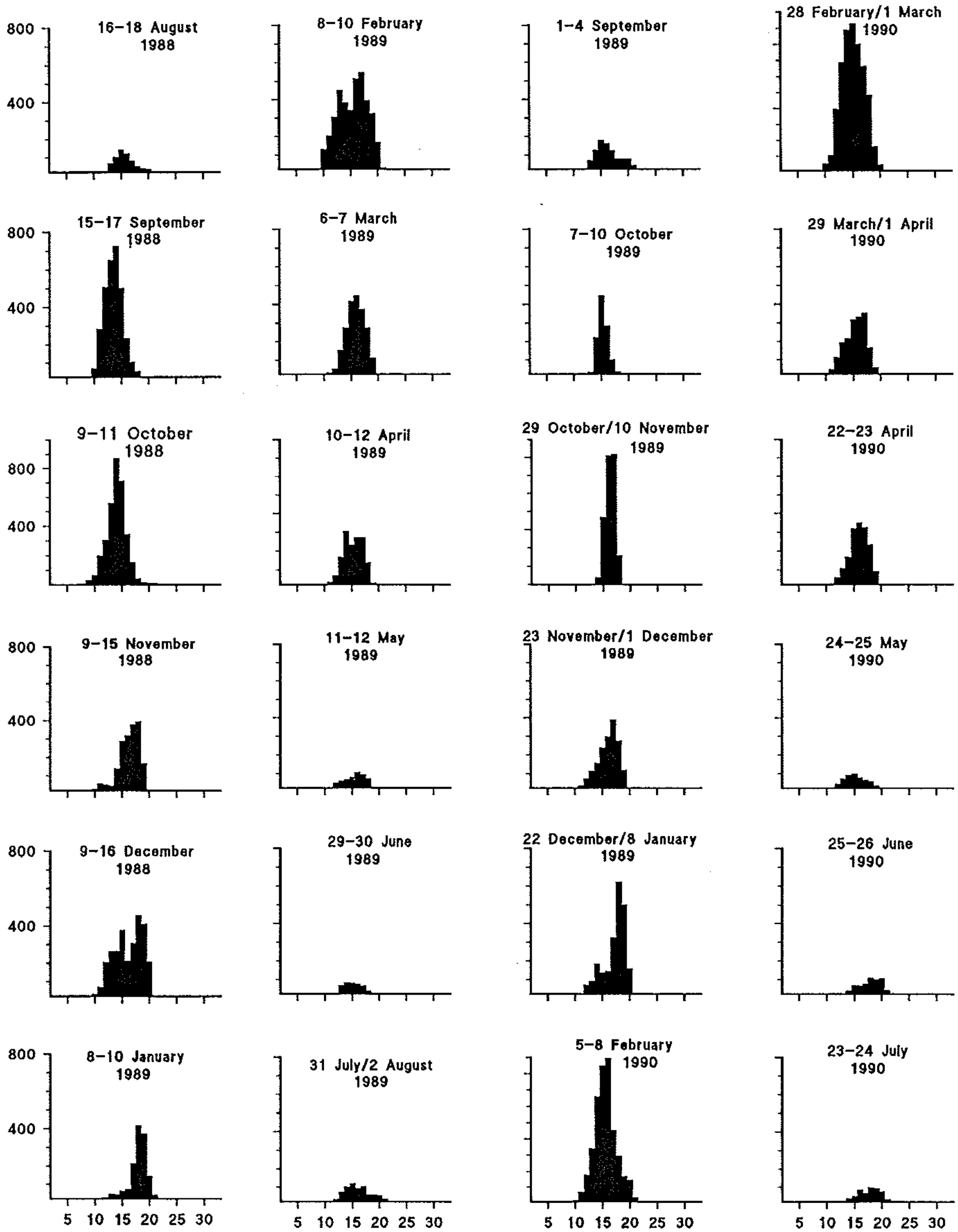
Appendix 1a

Length-frequency distributions of male greasy prawns in Moreton Bay for the nine sample sites.



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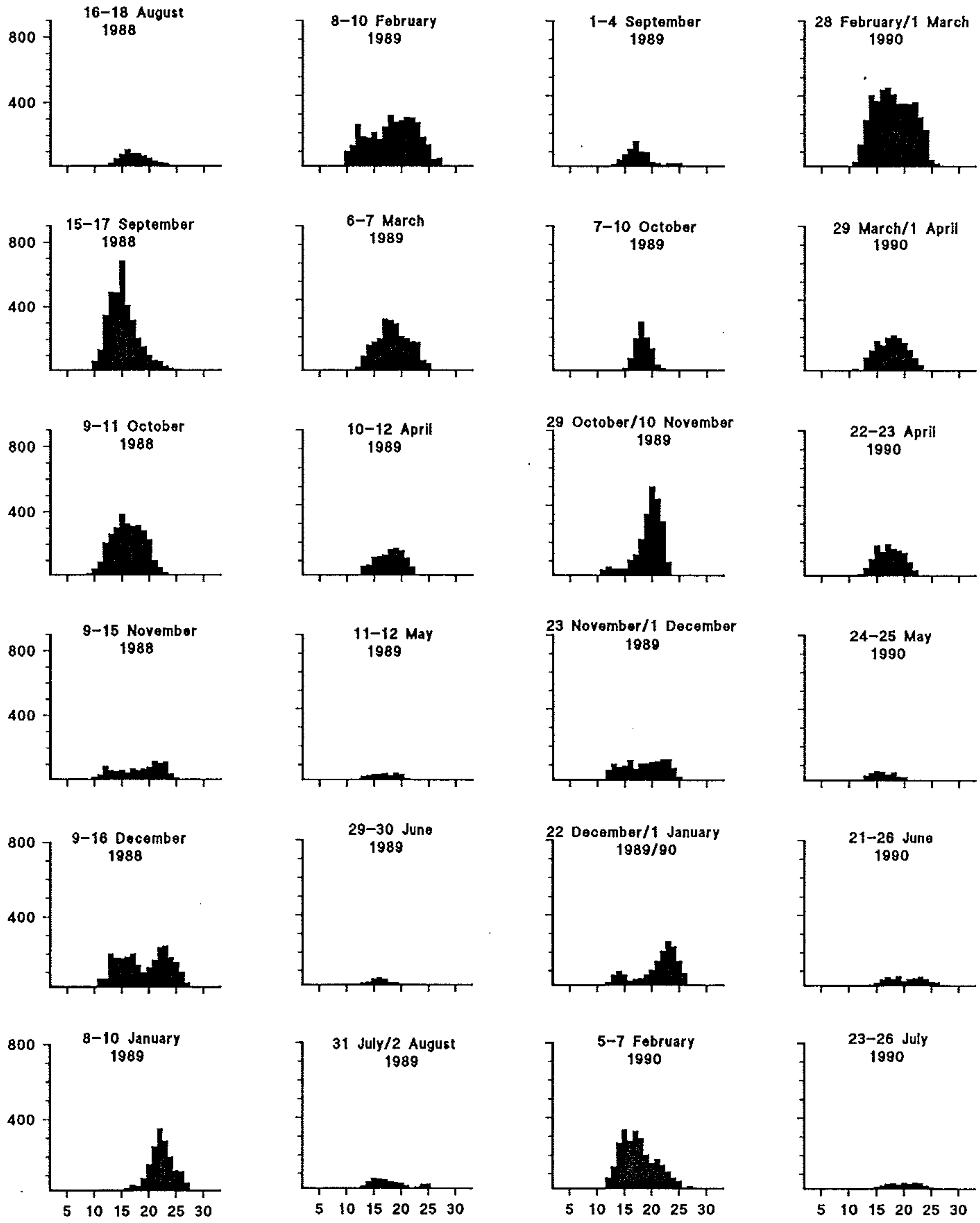
1-4 September 1989
28 February/1 March 1990
15-17 September 1988
6-7 March 1989
7-10 October 1989
29 March/1 April 1990
9-11 October 1988
10-12 April 1989
29 October/10 November 1989
22-23 April 1990
9-15 November 1988
11-12 May 1989
23 November/1 December 1989
24-25 May 1990
9-16 December 1988
29-30 June 1989
22 December/8 January 1989
25-26 June 1990
8-10 January 1989
31 July/2 August 1989
5-8 February 1990
23-24 July 1990
800
400
5 10 15 20 25 30

Appendix 1b

Length-frequency distributions of female greasy prawns in Moreton Bay for the nine sample sites.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29 March/1 April 1990
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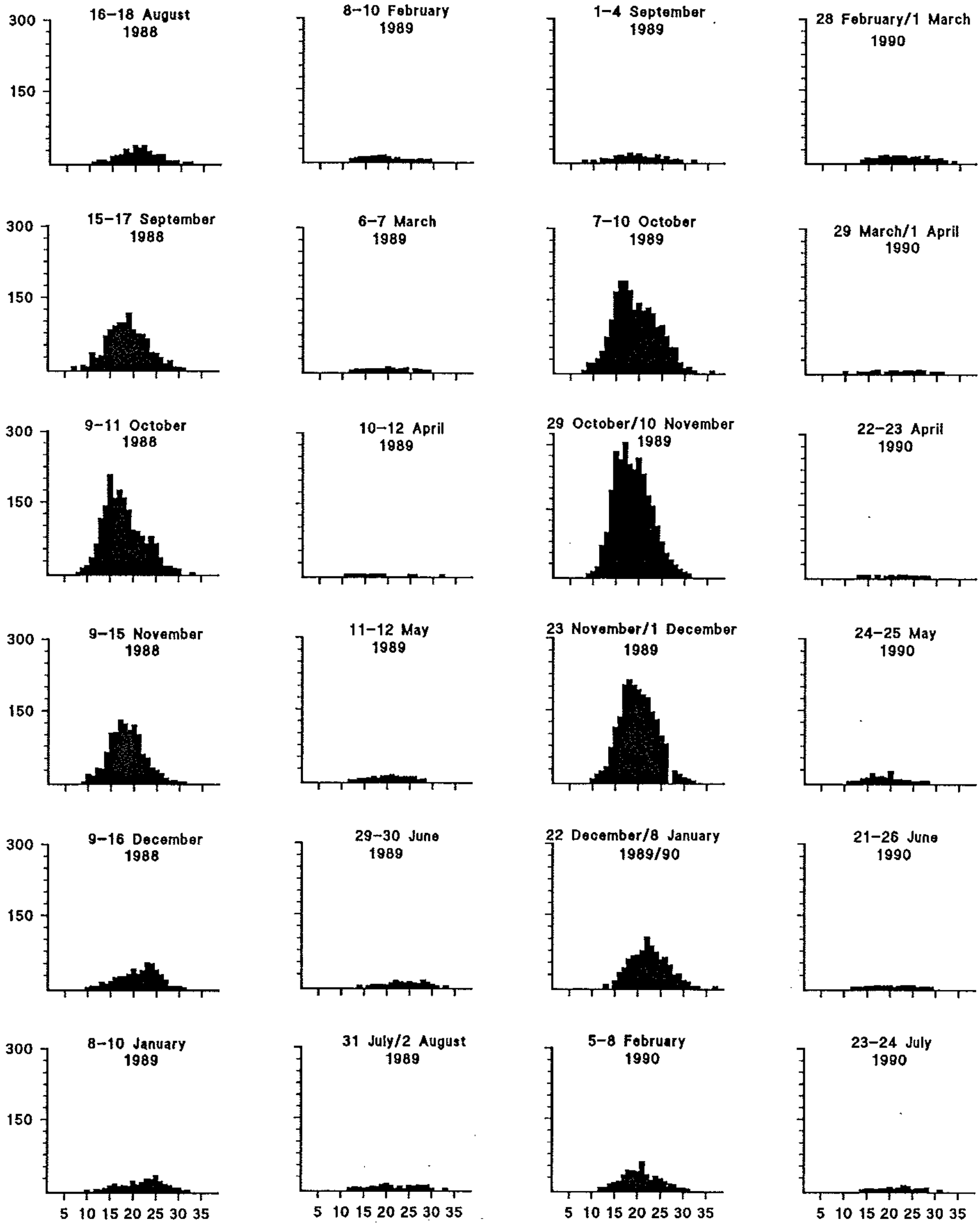
10–12 April 1989
29 October/10 November 1989
22–23 April 1990
9–15 November 1988
11–12 May 1989
23 November/1 December 1989
24–25 May 1990
9–16 December 1988
29–30 June 1989
22 December/1 January 1989/90
21–26 June 1990
8–10 January 1989
31 July/2 August 1989
5–7 February 1990
23–26 July 1990
800
400
5 10 15 20 25 30

Appendix 1c

Length-frequency distributions of male king prawns in Moreton Bay for the nine sample sites.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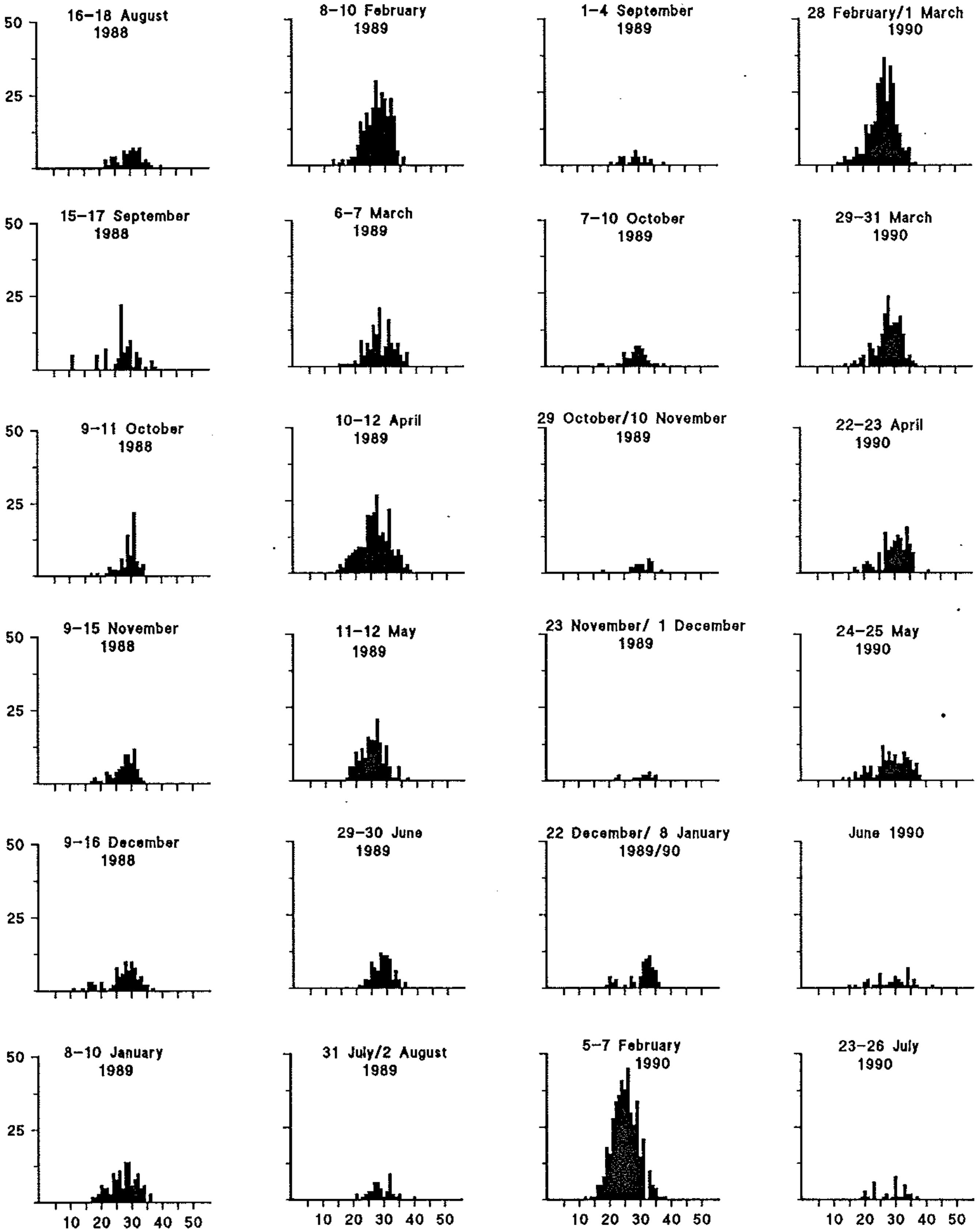
10–12 April 1989
29 October/10 November 1989
22–23 April 1990
9–15 November 1988
11–12 May 1989
23 November/1 December 1989
24–25 May 1990
9–16 December 1988
29–30 June 1989
22 December/8 January 1989/90
21–26 June 1990
8–10 January 1989
31 July/2 August 1989
5–8 February 1990
23–24 July 1990
5 10 15 20 25 30 35

Appendix 1d

Length-frequency distributions of female king prawns in Moreton Bay for the nine sample sites.

Appendix 1e

Length-frequency distributions of male tiger prawns in Moreton Bay for the nine sample sites.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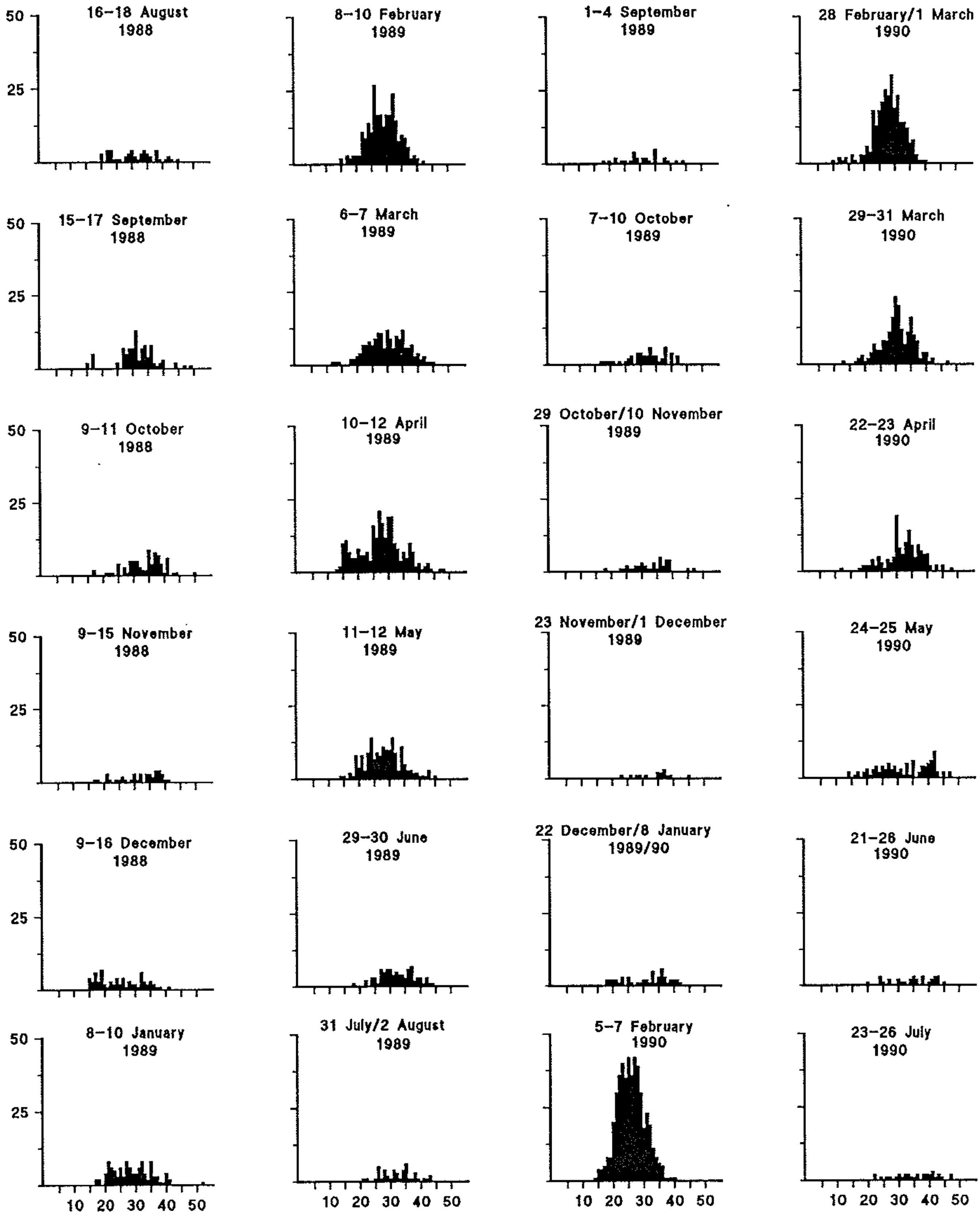
10-12 April 1989
29 October/10 November 1989
22-23 April 1990
9-15 November 1988
11-12 May 1989
23 November/ 1 December 1989
24-25 May 1990
9-16 December 1988
29-30 June 1989
22 December/ 8 January 1989/90
June 1990
8-10 January 1989
31 July/2 August 1989
5-7 February 1990
23-26 July 1990
50
25
10 20 30 40 50

Appendix 1f

Length-frequency distributions of female tiger prawns in Moreton Bay for the nine sample sites.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7-10 October 1989
29-31 March 1990
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10-12 April 1989
29 October/10 November 1989
22-23 April 1990
9-15 November 1988
11-12 May 1989
23 November/1 December 1989
24-25 May 1990
9-16 December 1988
29-30 June 1989
22 December/8 January 1989/90
21-26 June 1990
8-10 January 1989
31 July/2 August 1989
5-7 February 1990
23-26 July 1990
50
25
10 20 30 40 50

Appendix 2

Biological parameters used in the yield-per-recruit simulations

	♂ Greasys	♀ Greasys	Kings (sexes combined)
Growth			
W_{∞}(g)	5.85	10.20	62.5
K (monthly)	0.29	0.20	0.20
t_0 (months)	-0.66	-0.73	0.0
Recruitment			
Size (Cl) of recruits	13-15		
Relative monthly recruitment rates	Sep. 0.35 Oct. 0.35 Feb. 0.15 Mar. 0.15		Sep. 0.2 Oct. 0.5 Nov. 0.2 Dec. 0.1
Sex ratio at recruitment	1.0, 0.7		All immature
Emigration			
Monthly instantaneous emigration coefficient	No emigration out of the Bay		0.25, 0.5, 0.75, 1.0, 1.25
Smallest size of Emigrants (mm Cl)			13, 19, 25
Mortality			
Monthly instantaneous Natural mortality coefficient	0.1, 0.2, 0.3, 0.4, 0.5		0.08, 0.17, 0.25 0.33, 0.42
Relative monthly fishing rates	Jan. 0.120 Apr. 0.086 Jul. 0.026 Oct. 0.095 Feb. 0.095 May. 0.095 Aug. 0.043 Nov. 0.100 Mar. 0.095 Jun. 0.069 Sep. 0.069 Dec. 0.120		
Size at 50% selection (Cl)	19.43		20.33
Variance of size at 50% selection	1.97		2.07
Maximum monthly instantaneous coefficient of fishing mortality	0.14, 0.28, 0.56, 1.12, 2.24		

Appendix 3a

Simulation results for the yield-per-recruit model

Effects of the seasonal closure on yeild-per-recruit for greasy prawns, (*Metapenaeus bennettae*).

Yield-per-recruit for male greasy prawns, *Metapenaeus bennettae*

No closure Yield Per Recruit (grams)

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	0.931	1.473	2.015	2.384	2.536
0.200	0.390	0.667	1.024	1.396	1.695
0.300	0.199	0.357	0.590	0.885	1.183
0.400	0.116	0.212	0.372	0.594	0.853
0.500	0.078	0.139	0.251	0.421	0.636

With closure Hypothesis 1,2,3 and F decreased by 0.5

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	0.883	1.415	1.969	2.365	2.544
0.200	0.370	0.638	0.993	1.370	1.680
0.300	0.189	0.339	0.571	0.861	1.158
0.400	0.110	0.203	0.355	0.574	0.827
0.500	0.072	0.130	0.238	0.399	0.610

With closure Hypothesis 1,2,3 and F decreased by 0.25

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	0.907	1.444	1.994	2.376	2.540
0.200	0.381	0.652	1.009	1.385	1.687
0.300	0.194	0.349	0.580	0.873	1.171
0.400	0.113	0.209	0.365	0.584	0.840
0.500	0.072	0.134	0.242	0.408	0.623

With closure Hypothesis 1,2,3 and F decreased by 0.1

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	0.922	1.462	2.007	2.381	2.539
0.200	0.386	0.661	1.019	1.392	1.693
0.300	0.197	0.354	0.588	0.881	1.178
0.400	0.116	0.212	0.369	0.591	0.850
0.500	0.072	0.139	0.246	0.417	0.632

Yield-per-recruit for female greasy prawns, *Metapenaeus bennettae*

No closure Yield Per Recruit (grams)

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	2.061	2.739	3.080	3.090	2.912
0.200	0.878	1.312	1.711	1.973	2.081
0.300	0.440	0.711	1.028	1.316	1.522
0.400	0.249	0.425	0.657	0.910	1.139
0.500	0.152	0.269	0.439	0.650	0.865

With closure Hypothesis 1 and F decreased by 0.5

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	2.056	2.738	3.088	3.111	2.949
0.200	0.871	1.303	1.704	1.973	2.090
0.300	0.433	0.703	1.018	1.306	1.515
0.400	0.242	0.415	0.644	0.896	1.122
0.500	0.148	0.251	0.430	0.632	0.843

With closure Hypothesis 1 and F decreased by 0.25

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	2.060	2.739	3.084	3.101	2.931
0.200	0.875	1.308	1.707	1.972	2.085
0.300	0.438	0.708	1.023	1.311	1.518
0.400	0.246	0.418	0.651	0.903	1.135
0.500	0.152	0.264	0.435	0.641	0.856

With closure Hypothesis 1 and F decreased by 0.1

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	2.061	2.739	3.082	3.094	2.918
0.200	0.876	1.310	1.709	1.973	2.083
0.300	0.438	0.711	1.026	1.313	1.520
0.400	0.246	0.422	0.654	0.906	1.135
0.500	0.152	0.269	0.439	0.645	0.860

With closure Hypothesis 2 and F decreased by 0.5

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	1.978	2.678	3.063	3.103	2.948
0.200	0.840	1.274	1.684	1.964	2.088
0.300	0.421	0.689	1.006	1.299	1.513
0.400	0.239	0.408	0.641	0.893	1.119
0.500	0.148	0.260	0.426	0.632	0.843

Yield-per-recruit for female greasy prawns, *Metapenaeus bennettae* *continued...*

With closure Hypothesis 2 and F decreased by 0.25

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	2.021	2.711	3.072	3.097	2.993
0.200	0.858	1.294	1.698	1.968	2.085
0.300	0.430	0.701	1.018	1.309	1.518
0.400	0.242	0.415	0.647	0.903	1.129
0.500	0.148	0.264	0.435	0.641	0.852

With closure Hypothesis 2 and F decreased by 0.1

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	2.046	2.728	3.078	3.093	2.918
0.200	0.871	1.305	1.706	1.972	2.081
0.300	0.435	0.708	1.023	1.313	1.520
0.400	0.246	0.422	0.654	0.906	1.135
0.500	0.152	0.269	0.439	0.645	0.860

With closure Hypothesis 3 and F decreased by 0.5

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	2.129	2.787	3.107	3.115	2.951
0.200	0.900	1.330	1.720	1.979	2.092
0.300	0.445	0.716	1.026	1.311	1.518
0.400	0.249	0.422	0.651	0.900	1.122
0.500	0.152	0.264	0.430	0.632	0.847

With closure Hypothesis 3 and F decreased by 0.25

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	2.095	2.765	3.094	3.093	2.929
0.200	0.889	1.321	1.716	1.975	2.086
0.300	0.443	0.713	1.028	1.313	1.520
0.400	0.249	0.422	0.654	0.903	1.129
0.500	0.152	0.269	0.435	0.641	0.852

With closure Hypothesis 3 and F decreased by 0.1

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	2.076	2.750	3.086	3.095	2.918
0.200	0.882	1.316	1.713	1.973	2.083
0.300	0.440	0.713	1.028	1.313	1.520
0.400	0.249	0.422	0.654	0.906	1.135
0.500	0.152	0.269	0.439	0.645	0.860

Change in the yield-per-recruit of greasy prawns, *Metapenaeus bennettae* expressed as a percentage increase or decrease from the non-closure simulation. Yields for males and females have been combined and a sex ratio of 1:1 has been assumed

Hypothesis 1 and F decreased by 0.5
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	-1.804	-1.410	-0.742	0.049	0.842
0.200	-2.155	-1.934	-1.399	-0.757	-0.145
0.300	-2.692	-2.304	-1.824	-1.564	-1.182
0.400	-3.636	-3.125	-2.903	-2.208	-2.167
0.500	-4.483	-3.297	-3.247	-3.766	-3.284

Hypothesis 1 and F decreased by 0.25
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	-0.857	-0.673	-0.344	0.049	0.421
0.200	-1.006	-0.921	-0.666	-0.379	-0.097
0.300	-1.154	-0.922	-0.912	-0.782	-0.636
0.400	-1.818	-1.563	-1.290	-1.104	-0.833
0.500	-2.534	-2.198	-1.948	-2.092	-1.493

Hypothesis 1 and F decreased by 0.1
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	-0.316	-0.256	-0.132	0.025	0.173
0.200	-0.431	-0.368	-0.266	-0.108	0.000
0.300	-0.769	-0.230	-0.304	-0.335	-0.273
0.400	-0.909	-0.521	-0.645	-0.442	-0.333
0.500	-2.534	0.000	-0.649	-0.837	-0.597

Hypothesis 2 and F decreased by 0.5
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality				
	0.140	0.280	0.560	1.120	2.240
0.100	-4.420	-2.821	-1.245	-0.099	0.818
0.200	-4.598	-3.407	-2.132	-1.028	-0.193
0.300	-4.615	-3.687	-2.584	-1.899	-1.273
0.400	-4.545	-4.167	-3.226	-2.428	-2.333
0.500	-4.483	-4.396	-3.896	-3.766	-3.284

Change in the yield-per-recruit of greasy prawns, *Metapenaeus bennettae* expressed as a percentage increase or decrease from the non-closure simulation. Yields for males and females have been combined and a sex ratio of 1:1 has been assumed, continued...

Hypothesis 2 and F decreased by 0.25
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	-2.165	-1.346	-0.583	-0.025	1.561
0.200	-2.299	-1.657	-0.999	-0.487	-0.097
0.300	-2.308	-1.613	-1.216	-0.894	-0.636
0.400	-2.727	-2.083	-1.613	-1.104	-1.167
0.500	-4.483	-2.198	-1.948	-2.092	-1.791

Hypothesis 2 and F decreased by 0.1
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	-0.812	-0.513	-0.212	0.000	0.173
0.200	-0.862	-0.645	-0.400	-0.162	-0.048
0.300	-1.154	-0.461	-0.456	-0.335	-0.273
0.400	-0.909	-0.521	-0.645	-0.442	-0.333
0.500	-2.534	0.000	-0.649	-0.837	-0.597

Hypothesis 3 and F decreased by 0.5
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	0.631	-0.224	-0.371	0.123	0.867
0.200	0.144	-0.552	-0.799	-0.595	-0.097
0.300	-0.769	-1.152	-1.368	-1.341	-1.091
0.400	-1.818	-2.083	-2.258	-1.987	-2.167
0.500	-2.534	-3.297	-3.247	-3.766	-2.985

Hypothesis 3 and F decreased by 0.25
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	0.316	-0.064	-0.159	-0.099	0.396
0.200	0.144	-0.276	-0.333	-0.270	-0.048
0.300	-0.385	-0.461	-0.608	-0.670	-0.545
0.400	-0.909	-1.042	-0.968	-1.104	-1.167
0.500	-2.534	-1.099	-1.948	-2.092	-1.791

Hypothesis 3 and F decreased by 0.1
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	0.180	0.000	-0.053	0.049	0.173
0.200	0.000	-0.092	-0.133	-0.108	0.000
0.300	-0.385	0.000	-0.152	-0.335	-0.273
0.400	0.000	-0.521	-0.645	-0.442	-0.333
0.500	-2.534	0.000	-0.649	-0.837	-0.597

Change in the yield-per-recruit of greasy prawns, *Metapenaeus bennettae* expressed as a percentage increase or decrease from the non-closure simulation. Again, yields for males and females have been combined but a sex ratio of 0.7 has been assumed, since there is evidence of male dominance in the population.

Hypothesis 1 and F decreased by 0.5
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	-2.205	-1.739	-0.964	-0.083	0.756
0.200	-2.502	-2.241	-1.623	-0.918	-0.260
0.300	-2.956	-2.619	-2.027	-1.742	-1.323
0.400	-3.885	-3.320	-3.112	-2.373	-2.313
0.500	-4.865	-3.697	-3.531	-3.989	-3.428

Hypothesis 1 and F decreased by 0.25
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	-1.063	-0.836	-0.449	-0.012	0.378
0.200	-1.160	-1.080	-0.771	-0.439	-0.150
0.300	-1.308	-1.065	-1.014	-0.871	-0.700
0.400	-1.943	-1.562	-1.357	-1.186	-0.945
0.500	-3.161	-2.328	-2.166	-2.250	-1.588

Hypothesis 1 and F decreased by 0.1
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	-0.398	-0.318	-0.171	0.003	0.162
0.200	-0.489	-0.425	-0.303	-0.131	-0.017
0.300	-0.824	-0.288	-0.319	-0.368	-0.295
0.400	-0.800	-0.456	-0.678	-0.458	-0.342
0.500	-3.161	0.000	-0.802	-0.869	-0.613

Hypothesis 2 and F decreased by 0.5
Percent change in yield from no closure

Natural Mortality	Maximum Monthly Fishing Mortality 0.140	0.280	0.560	1.120	2.240
0.100	-4.514	-2.966	-1.394	-0.208	0.735
0.200	-4.661	-3.528	-2.255	-1.148	-0.300
0.300	-4.653	-3.829	-2.685	-2.028	-1.400
0.400	-4.685	-4.232	-3.391	-2.562	-2.454
0.500	-4.865	-4.657	-4.093	-3.989	-3.428

Change in the yield-per-recruit of greasy prawns, *Metapenaeus bennettae* expressed as a percentage increase or decrease from the non-closure simulation. Again, yields for males and females have been combined but a sex ratio of 0.7 has been assumed, since there is evidence of male dominance in the population, continued...

Hypothesis 2 and F decreased by 0.25
Percent change in yield from no closure

	Maximum Monthly Fishing Mortality				
Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.100	-2.217	-1.421	-0.653	-0.074	1.328
0.200	-2.303	-1.724	-1.058	-0.531	-0.150
0.300	-2.327	-1.670	-1.277	-0.966	-0.700
0.400	-2.743	-2.018	-1.636	-1.186	-1.227
0.500	-4.865	-2.328	-2.166	-2.250	-1.840

Hypothesis 2 and F decreased by 0.1
Percent change in yield from no closure

	Maximum Monthly Fishing Mortality				
Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.100	-0.836	-0.541	-0.239	-0.018	0.162
0.200	-0.870	-0.667	-0.418	-0.177	-0.058
0.300	-1.163	-0.489	-0.451	-0.368	-0.295
0.400	-0.800	-0.456	-0.678	-0.458	-0.342
0.500	-3.161	0.000	-0.802	-0.869	-0.613

Hypothesis 3 and F decreased by 0.5
Percent change in yield from no closure

	Maximum Monthly Fishing Mortality				
Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.100	-0.055	-0.707	-0.646	-0.020	0.776
0.200	-0.470	-1.033	-1.106	-0.780	-0.219
0.300	-1.259	-1.611	-1.633	-1.551	-1.246
0.400	-2.284	-2.408	-2.553	-2.184	-2.313
0.500	-3.161	-3.697	-3.531	-3.989	-3.175

Hypothesis 3 and F decreased by 0.25
Percent change in yield from no closure

	Maximum Monthly Fishing Mortality				
Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.100	-0.027	-0.306	-0.291	-0.136	0.357
0.200	-0.144	-0.517	-0.483	-0.348	-0.110
0.300	-0.629	-0.662	-0.751	-0.776	-0.623
0.400	-1.142	-1.107	-1.077	-1.186	-1.227
0.500	-3.161	-1.369	-2.166	-2.250	-1.840

Hypothesis 3 and F decreased by 0.1
Percent change in yield from no closure

	Maximum Monthly Fishing Mortality				
Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.100	0.040	-0.095	-0.103	0.024	0.162
0.200	-0.109	-0.184	-0.188	-0.131	-0.017
0.300	-0.484	-0.086	-0.188	-0.368	-0.295
0.400	0.000	-0.456	-0.678	-0.458	-0.342
0.500	-3.161	0.000	-0.802	-0.869	-0.613

Appendix 3b

Simulation results for the yield-per-recruit model

Effects of the seasonal closure on yield-per-recruit for king prawns, *Penaeus plebejus*.

Yield-per-recruit for king prawns, *Penaeus plebejus*, assuming the smallest size of migrating kings is 13 mm Cl.

Yield Per Recruit (grams)

No closure

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.040	2.080
0.333	1.863	2.615	2.921	2.603	2.061
0.667	0.541	0.855	1.148	1.279	1.224
1.000	0.215	0.363	0.543	0.694	0.762
1.333	0.102	0.180	0.288	0.405	0.493
1.666	0.054	0.099	0.166	0.250	0.332

With Closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	1.833	2.592	2.921	2.621	2.088
0.667	0.540	0.854	1.150	1.285	1.235
1.000	0.214	0.362	0.542	0.694	0.765
1.333	0.101	0.179	0.287	0.403	0.492
1.666	0.054	0.098	0.165	0.248	0.329

With Closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	1.848	2.604	2.921	2.612	2.074
0.667	0.541	0.854	1.149	1.282	1.230
1.000	0.214	0.362	0.543	0.694	0.763
1.333	0.102	0.179	0.287	0.404	0.493
1.666	0.054	0.098	0.165	0.249	0.330

With Closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	1.857	2.611	2.921	2.607	2.066
0.667	0.541	0.854	1.149	1.280	1.226
1.000	0.215	0.363	0.543	0.694	0.762
1.333	0.102	0.179	0.288	0.404	0.493
1.666	0.054	0.098	0.166	0.250	0.331

Yield-per-recruit for king prawns, *Penaeus plebejus*, assuming the smallest size of migrating kings is 19 mm Cl.

Yield Per Recruit (grams)

No closure

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	2.391	3.355	3.744	3.330	2.621
0.667	0.889	1.402	1.879	2.081	1.966
1.000	0.449	0.757	1.127	1.426	1.530
1.333	0.269	0.472	0.752	1.039	1.225
1.666	0.179	0.324	0.538	0.793	1.004

With closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	2.352	3.325	3.745	3.354	2.658
0.667	0.887	1.401	1.883	2.092	1.989
1.000	0.448	0.756	1.128	1.430	1.543
1.333	0.268	0.471	0.751	1.041	1.232
1.666	0.178	0.322	0.537	0.792	1.006

With closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	2.372	3.340	3.745	3.342	2.639
0.667	0.888	1.402	1.881	2.087	1.977
1.000	0.448	0.756	1.127	1.428	1.536
1.333	0.268	0.472	0.751	1.040	1.229
1.666	0.179	0.323	0.537	0.793	1.005

With closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	2.383	3.349	3.744	3.335	2.628
0.667	0.889	1.402	1.880	2.083	1.971
1.000	0.449	0.757	1.127	1.427	1.533
1.333	0.269	0.472	0.752	1.040	1.227
1.666	0.179	0.323	0.538	0.793	1.004

Yield-per-recruit for king prawns, *Penaeus plebejus*, assuming the smallest size of migrating kings is 25 mm Cl.

Yield Per Recruit (grams)

No closure

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	3.028	4.228	4.662	4.032	3.013
0.667	1.383	2.154	2.811	2.946	2.532
1.000	0.828	1.369	1.957	2.291	2.161
1.333	0.569	0.973	1.471	1.848	1.865
1.666	0.422	0.739	1.158	1.528	1.623

With closure F reduced by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	2.978	4.190	4.664	4.063	3.059
0.667	1.381	2.154	2.820	2.968	2.568
1.000	0.828	1.369	1.962	2.305	2.189
1.333	0.568	0.974	1.474	1.859	1.887
1.666	0.421	0.738	1.159	1.535	1.641

With closure F reduced by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	3.004	4.210	4.663	4.047	3.035
0.667	1.382	2.154	2.815	2.957	2.550
1.000	0.828	1.369	1.960	2.298	2.175
1.333	0.568	0.973	1.473	1.853	1.876
1.666	0.422	0.739	1.159	1.532	1.632

With closure F reduced by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	3.018	4.221	4.663	4.038	3.022
0.667	1.383	2.154	2.813	2.950	2.539
1.000	0.828	1.369	1.958	2.293	2.166
1.333	0.569	0.973	1.472	1.850	1.869
1.666	0.422	0.739	1.158	1.530	1.627

Yield-per-recruit for king prawns, *Penaeus plebejus*, assuming the smallest size of migrating kings is 13 mm Cl. Change in yield represented as a percentage of the yield-per-recruit in the absence of the closure.

Percentage change in yield per recruit

With closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-1.642	-0.887	0.006	0.688	1.320
0.667	-0.280	-0.096	0.147	0.448	0.898
1.000	-0.279	-0.208	-0.091	0.094	0.397
1.333	-0.554	-0.517	-0.454	-0.352	-0.183
1.666	-0.948	-0.935	-0.914	-0.883	-0.836

With closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-0.807	-0.426	0.015	0.342	0.645
0.667	-0.138	-0.046	0.074	0.222	0.440
1.000	-0.139	-0.103	-0.045	0.047	0.196
1.333	-0.277	-0.257	-0.225	-0.173	-0.087
1.666	-0.473	-0.466	-0.454	-0.436	-0.406

With closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-0.319	-0.166	0.008	0.136	0.255
0.667	-0.055	-0.018	0.030	0.089	0.174
1.000	-0.056	-0.041	-0.018	0.019	0.078
1.333	-0.111	-0.103	-0.090	-0.069	-0.034
1.666	-0.189	-0.186	-0.181	-0.173	-0.160

Yield-per-recruit for king prawns, *Penaeus plebejus*, assuming the smallest size of migrating kings is 19 mm CI. Change in yield represented as a percentage of the yield-per-recruit in the absence of the closure.

Percentage change in yield per recruit

With closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-1.638	-0.879	0.021	0.723	1.409
0.667	-0.248	-0.055	0.209	0.561	1.136
1.000	-0.179	-0.089	0.067	0.342	0.848
1.333	-0.330	-0.262	-0.136	0.102	0.557
1.666	-0.525	-0.469	-0.361	-0.151	0.262

With closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-0.805	-0.422	0.022	0.359	0.689
0.667	-0.122	-0.025	0.106	0.278	0.556
1.000	-0.089	-0.044	0.034	0.170	0.417
1.333	-0.165	-0.131	-0.067	0.052	0.275
1.666	-0.261	-0.233	-0.179	-0.073	0.132

With closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-0.319	-0.165	0.011	0.143	0.272
0.667	-0.049	-0.009	0.042	0.110	0.220
1.000	-0.035	-0.017	0.014	0.068	0.165
1.333	-0.066	-0.052	-0.027	0.021	0.109
1.666	-0.104	-0.093	-0.071	-0.029	0.053

Yield-per-recruit for king prawns, *Penaeus plebejus*, assuming the smallest size of migrating kings is 25 mm Cl. Change in yield represented as a percentage of the yield-per-recruit in the absence of the closure.

Percentage change in yield per recruit

With closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-1.649	-0.881	0.041	0.788	1.546
0.667	-0.207	0.005	0.308	0.732	1.430
1.000	-0.049	0.066	0.273	0.645	1.313
1.333	-0.085	0.013	0.201	0.554	1.197
1.666	-0.146	-0.053	0.125	0.464	1.081

With closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-0.810	-0.423	0.032	0.391	0.755
0.667	-0.102	0.005	0.154	0.362	0.699
1.000	-0.024	0.033	0.136	0.319	0.642
1.333	-0.043	0.007	0.101	0.274	0.586
1.666	-0.073	-0.026	0.063	0.230	0.530

With closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	-0.320	-0.165	0.015	0.156	0.298
0.667	-0.040	0.002	0.062	0.144	0.276
1.000	-0.009	0.013	0.054	0.127	0.254
1.333	-0.017	0.003	0.040	0.109	0.231
1.666	-0.029	-0.010	0.025	0.091	0.209

Appendix 3c

Simulation results for the yeild-per-recruit model

Effects of the seasonal closure on the number of emigrating prawns-per-recruit for eastern king prawns, *Penaeus plebejus*.

Number of emigrating prawns-per-recruit for eastern king prawns, *Penaeus plebejus*, assuming the smallest size of migration is 13 mm Cl.

Emigrants Per Recruit

No closure

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.396	0.316	0.221	0.134	0.071
0.667	0.326	0.282	0.221	0.151	0.088
1.000	0.245	0.221	0.183	0.133	0.082
1.333	0.180	0.166	0.142	0.108	0.070
1.666	0.131	0.122	0.107	0.084	0.056

With Closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.396	0.317	0.222	0.136	0.073
0.667	0.327	0.283	0.222	0.153	0.090
1.000	0.246	0.221	0.184	0.135	0.084
1.333	0.180	0.166	0.143	0.109	0.072
1.666	0.131	0.122	0.107	0.085	0.058

With Closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.396	0.316	0.221	0.135	0.072
0.667	0.326	0.282	0.222	0.152	0.089
1.000	0.246	0.221	0.183	0.134	0.083
1.333	0.180	0.166	0.142	0.109	0.071
1.666	0.131	0.122	0.107	0.085	0.057

With Closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.396	0.316	0.221	0.135	0.071
0.667	0.326	0.282	0.221	0.152	0.088
1.000	0.245	0.221	0.183	0.134	0.083
1.333	0.180	0.166	0.142	0.108	0.070
1.666	0.131	0.122	0.107	0.084	0.057

Number of emigrating prawns-per-recruit for eastern king prawns, *Penaeus plebejus*, assuming the smallest size of migration is 19 mm CI.

Emigrants Per Recruit

No closure

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.324	0.232	0.130	0.051	0.011
0.667	0.247	0.191	0.119	0.053	0.013
1.000	0.170	0.137	0.091	0.043	0.011
1.333	0.116	0.095	0.065	0.032	0.009
1.666	0.077	0.065	0.045	0.023	0.007

With closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.325	0.233	0.131	0.051	0.012
0.667	0.247	0.191	0.120	0.053	0.013
1.000	0.171	0.138	0.092	0.044	0.012
1.333	0.116	0.095	0.066	0.033	0.009
1.666	0.078	0.065	0.046	0.024	0.007

With closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.325	0.233	0.130	0.051	0.012
0.667	0.247	0.191	0.120	0.053	0.013
1.000	0.171	0.138	0.091	0.043	0.012
1.333	0.116	0.095	0.065	0.033	0.009
1.666	0.077	0.065	0.046	0.023	0.007

With closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.324	0.232	0.130	0.051	0.011
0.667	0.247	0.191	0.120	0.053	0.013
1.000	0.171	0.137	0.091	0.043	0.012
1.333	0.116	0.095	0.065	0.032	0.009
1.666	0.077	0.065	0.045	0.023	0.007

Number of emigrating prawns-per-recruit for eastern king prawns, *Penaeus plebejus*, assuming the smallest size of migration is 25 mm Cl.

Emigrants Per Recruit

No closure

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.265	0.171	0.076	0.018	0.001
0.667	0.186	0.128	0.063	0.017	0.002
1.000	0.118	0.085	0.044	0.013	0.001
1.333	0.073	0.054	0.029	0.009	0.001
1.666	0.045	0.033	0.018	0.006	0.001

With closure F reduced by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.266	0.171	0.077	0.018	0.001
0.667	0.187	0.129	0.064	0.017	0.002
1.000	0.118	0.085	0.044	0.013	0.001
1.333	0.074	0.054	0.029	0.009	0.001
1.666	0.045	0.033	0.018	0.006	0.001

With closure F reduced by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.265	0.171	0.076	0.018	0.001
0.667	0.186	0.129	0.064	0.017	0.002
1.000	0.118	0.084	0.044	0.013	0.001
1.333	0.074	0.054	0.029	0.009	0.001
1.666	0.045	0.033	0.018	0.006	0.001

With closure F reduced by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.265	0.171	0.076	0.018	0.001
0.667	0.186	0.129	0.064	0.017	0.002
1.000	0.118	0.085	0.044	0.013	0.001
1.333	0.074	0.054	0.029	0.009	0.001
1.666	0.045	0.033	0.018	0.006	0.001

Number of emigrating prawns-per-recruit for eastern king prawns, *Penaeus plebejus*, assuming the smallest size of migration is 13 mm CI. Change in emigration represented as a percentage of emigrants-per-recruit in the absence of the closure.

Percentage change in emigrants per recruit

With closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.173	0.312	0.565	1.123	2.423
0.667	0.134	0.268	0.540	1.122	2.417
1.000	0.131	0.265	0.539	1.123	2.409
1.333	0.131	0.265	0.540	1.122	2.401
1.666	0.131	0.265	0.540	1.120	2.394

With closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.086	0.155	0.280	0.554	1.180
0.667	0.067	0.133	0.268	0.554	1.177
1.000	0.065	0.132	0.268	0.554	1.173
1.333	0.066	0.132	0.269	0.554	1.169
1.666	0.065	0.132	0.268	0.553	1.166

With closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.034	0.062	0.111	0.220	0.465
0.667	0.027	0.053	0.107	0.220	0.463
1.000	0.026	0.052	0.107	0.220	0.462
1.333	0.026	0.053	0.107	0.220	0.461
1.666	0.026	0.053	0.107	0.219	0.459

Number of emigrating prawns-per-recruit for eastern king prawns, *Penaeus plebejus*, assuming the smallest size of migration is 19 mm Cl. Change in emigration represented as a percentage of emigrants-per-recruit in the absence of the closure.

Percentage change in emigrants per recruit

With closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.198	0.347	0.593	1.112	2.460
0.667	0.138	0.271	0.538	1.115	2.489
1.000	0.131	0.264	0.537	1.126	2.511
1.333	0.131	0.264	0.540	1.135	2.527
1.666	0.131	0.265	0.543	1.141	2.540

With closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.098	0.172	0.293	0.548	1.197
0.667	0.069	0.135	0.268	0.550	1.212
1.000	0.065	0.131	0.267	0.556	1.222
1.333	0.065	0.132	0.268	0.560	1.231
1.666	0.065	0.132	0.269	0.563	1.237

With closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.039	0.068	0.116	0.217	0.471
0.667	0.028	0.054	0.107	0.218	0.478
1.000	0.026	0.053	0.106	0.220	0.481
1.333	0.026	0.053	0.107	0.222	0.485
1.666	0.026	0.053	0.107	0.223	0.487

Number of emigrating prawns-per-recruit for eastern king prawns, *Penaeus plebejus*, assuming the smallest size of migration is 25 mm Cl. Change in emigration represented as a percentage of emigrants-per-recruit in the absence of the closure.

Percentage change in emigrants per recruit

With closure F decreased by 0.5

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.235	0.408	0.650	1.034	1.902
0.667	0.146	0.278	0.523	0.990	1.934
1.000	0.131	0.259	0.508	0.995	1.964
1.333	0.129	0.257	0.509	1.001	1.990
1.666	0.129	0.258	0.512	1.015	2.011

With closure F decreased by 0.25

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.117	0.201	0.319	0.506	0.925
0.667	0.073	0.138	0.259	0.488	0.941
1.000	0.065	0.129	0.252	0.492	0.956
1.333	0.064	0.128	0.253	0.496	0.969
1.666	0.065	0.129	0.254	0.501	0.979

With closure F decreased by 0.1

Maximum Monthly Fishing Mortality

Natural Mortality	0.140	0.280	0.560	1.120	2.240
0.333	0.047	0.080	0.126	0.200	0.364
0.667	0.029	0.055	0.103	0.194	0.370
1.000	0.026	0.051	0.100	0.194	0.377
1.333	0.026	0.051	0.101	0.197	0.381
1.666	0.026	0.051	0.101	0.199	0.385