FISHERIES RESEARCH BULLETIN

No. 31, 2003

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**Fisheries Research Bulletin**

Titles in the Fisheries Research Bulletin series are scientific monographs independently refereed by specialists outside the Fisheries Research Division. They contain technical and scientific information that represents an important contribution to existing knowledge, but which may not be suitable for publication in national or international scientific journals.

Fisheries Research Bulletins may be cited as full publications. The full citation is:
Moran, M. and Kangas, M. 2003. *The effects of the trawl fishery on the stock of pink snapper,* **Pagrus auratus**, *in Denham Sound, Shark Bay,* Fisheries Research Bulletin No. 31, Department of Fisheries, Western Australia, 52 pp.

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Department of Fisheries
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Fish for the future

Published by Department of Fisheries, Perth, Western Australia. September 2003.
ISSN: 0155 - 9435 ISBN: 1 877098 35 3

**Fisheries Research in Western Australia**

The Fisheries Research Division of the Department of Fisheries is based at the Western Australian Marine Research Laboratories, PO Box 20, North Beach (Perth), Western Australia, 6920. The Marine Research Laboratories serve as the centre for fisheries research in the State of Western Australia.

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The primary function of the Fisheries Research Division is to provide scientific advice to government in the formulation of management policies for developing and sustaining Western Australian fisheries.

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# The effects of the trawl fishery on the stock of pink snapper, *Pagrus auratus*, in Denham Sound, Shark Bay

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## Summary

Snapper stocks in the inner gulfs of Shark Bay are in a depleted condition, both in trawled and non-trawled areas, with the main factor contributing to the depletion considered to be recreational fishing for adult snapper, including some mortality of undersized snapper returned to the water. The commercial prawn trawl fishery catches many small fish species, including small juvenile pink snapper, as part of its unintended bycatch. Some members of the local community believe that mortality of juvenile snapper due to trawling has also been a significant factor in depletion of the adult stock in Denham Sound, Shark Bay.

While the Department of Fisheries has undertaken extensive research on snapper and prawn fisheries including counting and measuring juvenile snapper in many research trawl surveys since the 1970s and observed commercial trawls since the 1990s, this information alone was insufficient for an assessment on the extent to which snapper stocks in Denham Sound are being affected by the trawl fishery. This bulletin provides the additional detailed information required and combines it with a range of historical data to complete a comprehensive assessment.

A series of dedicated snapper research vessel trawl surveys in 2000–2001 and snapper trapping surveys in 1998–2000 were combined with observer data from commercial trawling to estimate relative abundance of juvenile snapper both inside and outside the commercial trawl fishery boundaries. A series of experiments has estimated the vulnerability of juvenile snapper of various sizes to capture by trawl and, together with the research trawl surveys, enabled calculation of natural mortality rates, growth and duration of the life-stage vulnerable to trawling. Results of these experiments made it possible to calculate the fishing mortality rate of juvenile snapper resulting from an hour of commercial trawling (Note: adult snapper are rarely caught in prawn or scallop trawls). By applying the fishing mortality rates resulting from average annual prawn trawling effort on a one-minute (latitude and longitude) spatial scale, the proportion of juvenile snapper in Denham Sound which would survive the trawling season could be estimated. A number of scenarios for changes to the trawl fishery boundary were examined for their effects on survival of the juvenile snapper.

An alternative method of assessing the impact of pre-adult fishing mortality on yields to the fishery on adult snapper was also used. The number of juvenile snapper caught in a year by the trawl fishery was estimated from average catch per hour in observed commercial trawls multiplied by average hours per year of trawling. By applying growth and natural mortality rates, the weight of snapper that this number of juveniles would become as adults was calculated. A similar calculation was made on the number of undersized snapper inadvertently killed by recreational fishers. While these calculations give a useful “order of

magnitude” estimate of foregone yield due to pre-adult mortality, they are sensitive to the estimates used for natural mortality rates, which are not well known.

The main findings of the study are:

- Juvenile snapper are present on trawlable habitats in Denham Sound from approximately 6 to 18 months of age and most are between 10 and 15 cm in length.
- Snapper in this size range are retained by prawn trawl mesh but pass through the larger mesh used in scallop trawling.
- In this age range, snapper in Denham Sound are more widely distributed than the area trawled by the prawn fishery.
- The natural mortality rate of snapper in this age range (6–18 months), like the young of most fish species, is high, with an estimated average of 92% of the fish being consumed by natural predators in a 12-month period.
- The survival of juvenile snapper in Denham Sound is estimated to be reduced from 8% to approximately 6% per year due to the impact of the current level of trawling.
- The annual yield of the fishery (recreational and commercial) on adult snapper in Denham Sound is estimated to be reduced by between 2.5 and 4.2 tonnes as a result of the bycatch of juveniles in the trawl fishery.
- The annual yield to the fishery on adult snapper in Denham Sound is estimated to be reduced by between 3.8 and 4.4 tonnes as a result of 5% mortality of undersized snapper returned to the water by the recreational fishery.
- The impact of the prawn trawl fishery on survival of juvenile snapper could be reduced significantly by changes to the current trawl boundary to redirect effort away from juvenile snapper habitats. (Technology for management of complex trawl boundaries is now available and in use in the Shark Bay trawl fleet.)
- Some of the options examined for redirection of trawl effort are expected to have little impact on the value of the prawn catch as the prawns caught would be fewer in number but larger, with higher prices per kg.
- Reduction of the impact of the catch of undersized snapper in the recreational fishery may also be possible if hook types which minimise swallowing of the hook are used; this would require further research

# 1.0 Introduction

In the Shark Bay region of Western Australia (Figure 1), pink snapper (*Pagrus auratus*) is the target of commercial and recreational fishers. The commercial snapper fishery, which takes snapper using mechanised handlines, is confined to the outer bay and oceanic waters; it has been operating since the 1950s and has been managed by quota since 1988. The recreational fishery is unconfined but occurs mainly in the sheltered waters of the inner gulfs, which are more accessible from population centres and tourist accommodation in Denham, Nanga and Monkey Mia. Snapper in the ocean waters, and the eastern and western inner gulfs, have been shown by several research techniques including tagging, genetics, morphometrics, trace elements in otoliths and oceanography to exist as a number of separate stocks, independent of each other for fisheries management purposes (Edmonds et al., 1989, 1999; Gaughan et al., 2003; Johnson et al., 1986; Moran et al., 1998, 2003; Nahas et al., in press).

Serious declines in snapper abundance were first detected in the eastern gulf in 1996, following a sharp increase in recreational fishing effort and effectiveness (probably due to use of Global Positioning Systems) in the early and mid 1990s (Jackson & Stephenson, 2002). Subsequently, snapper breeding stock levels have also been estimated to be critically low in Freycinet Estuary, the southern part of the western gulf.

Recreational fishing within Shark Bay is mainly by hook and line, with boat fishers taking a variety of fish, of which the dominant species has historically been pink snapper. The recreational fishery has been the subject of a number of recent surveys, e.g. Sumner et al. (2002), which record information on both retained and discarded catches. This study showed that in Denham Sound, the number of snapper returned to the water, mainly because they are smaller than the minimum legal length, greatly exceeded the number of retained legal sized snapper. Recent research on the mortality rates of snapper released after capture by hook and line has shown that injuries due to hooks and handling result in a mortality of around 5% (St John & Moran, in prep).

Management measures to restrict inner bay snapper catches in response to the snapper stock declines in the inner gulfs have not been universally popular. Some members of the community do not accept that the declines are a result of recreational fishing effort at a level higher than the stocks can withstand. The local government authority (Shire of Shark Bay), in particular, has raised questions about the possible effect of trawl bycatch of juveniles in reducing snapper stocks and has lobbied for a change in the southern boundary of the trawl fishery in Denham Sound such that the “Torbay Line” (Figure 2b) would be the boundary all year, not just in March–April.

The commercial trawl fishery in Shark Bay for king prawns, *Penaeus latisulcatus,* and brown tiger prawns, *Penaeus esculentus*, and also for saucer scallops, *Amusium balotti* (Kangas & Sporer, 2002a,b), operates in the deeper parts of northern Shark Bay and Denham Sound. The incidental mortality of non-target species, commonly referred to as “bycatch”, is usually greater with bottom-trawl fishing methods than with more selective methods such as trapping or hook-and-line. In the last decade, awareness has grown of the responsibility of fisheries not only to maintain populations of target species at adequate levels to ensure future viability, but also to minimise adverse effects on non-target species. Subsequent action has resulted in the widespread adoption of “turtle exclusion devices” by trawler operators to enable large species like turtles and stingrays to escape from trawl nets, and extensive research into a range of bycatch reduction devices with the purpose of maximising the escape of the small species, mainly scalefish (Broadhurst, 2000). The effectiveness of such devices varies enormously from fishery to fishery and is dependent on such factors as whether the fishery operates during the day or night and, particularly in the Shark Bay situation, the presence of large amounts of drifting weed (usually dead seagrass).

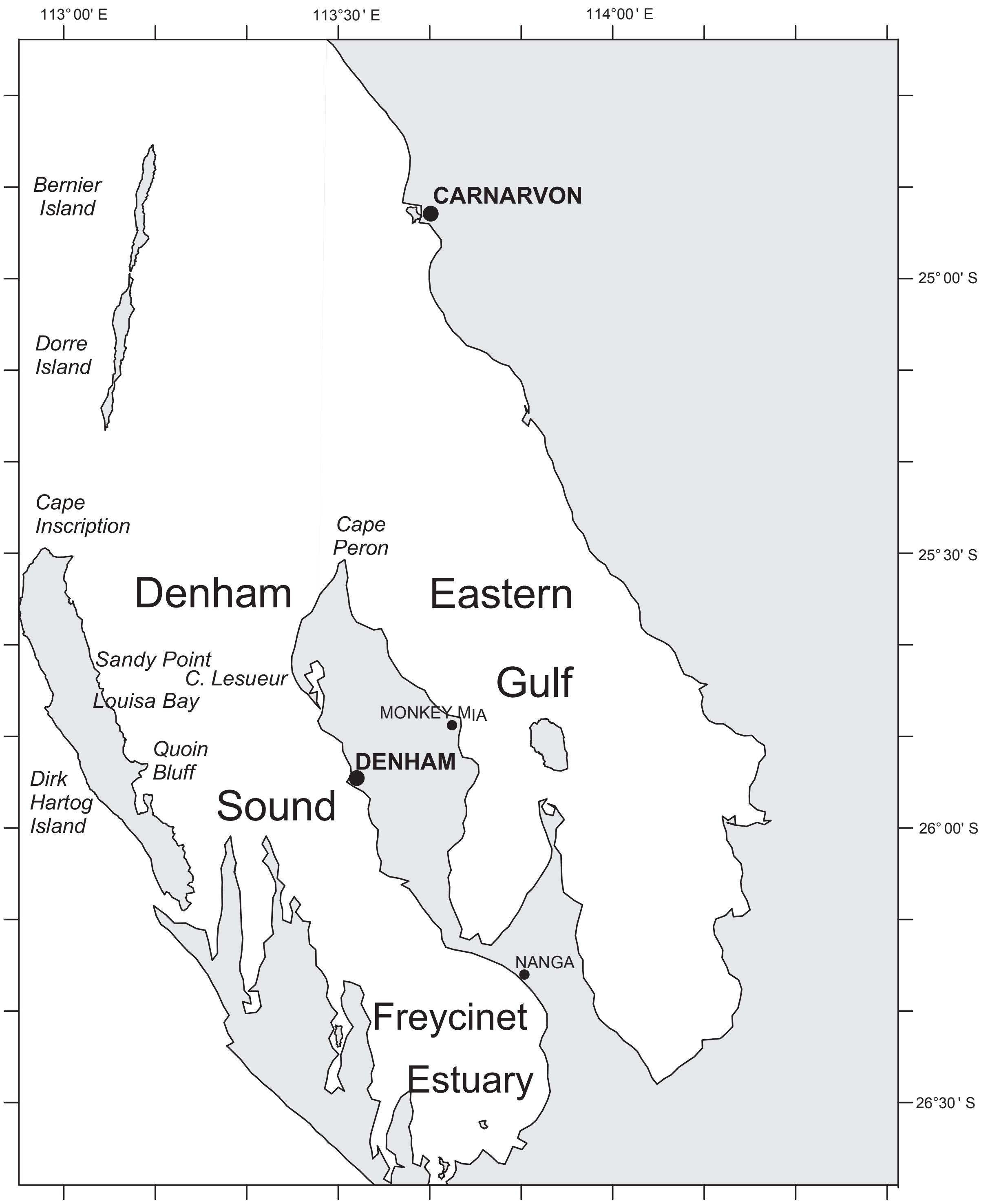


**Figure 1.** Shark Bay, Western Australia, with locations mentioned in the text.

Information on the bycatch of the Shark Bay trawl fishery has been collected in recent years during trials of bycatch reduction devices and from a current study of the biodiversity of species which are catchable by trawling in both the trawled and adjacent untrawled areas. Snapper makes up a very small and variable proportion of the total bycatch (Unsworth et al., 2000; M. Kangas, unpubl. data).

Large sections of Shark Bay have been closed to trawling since the 1960s, originally with the purpose of protecting young prawns and their habitat, but now the role of these closures in maintenance of bycatch species populations is also being examined. The two areas which have shown the most serious declines in snapper stocks, the eastern gulf and Freycinet Estuary, have been closed to trawling for over thirty years. The third inner bay area, Denham Sound, has been open to trawling since the fishery began, but with a recent reduction in the area available for trawling (Figure 3, Industry Closure Line).

The purpose of this bulletin is to bring together all relevant information on the trawl fishery and on pink snapper to assess the effect of capture of juvenile snapper by the trawl fishery in Denham Sound on adult snapper stocks and yields. For comparison with the effect of the trawl fishery on snapper yields, the effect of mortality of released undersize snapper from the recreational fishery is also estimated. Since reduction of the area available for trawling has been proposed as a means to lessen any possible effects of the trawl fishery on snapper stocks, a number of options for trawl boundary changes are examined to determine whether it is possible to increase snapper stocks by changing the trawl fishery boundary.

In this bulletin, the trawl fishery is described first, followed by a summary of relevant available information on snapper. This includes the vulnerability of snapper to capture by the trawl fishery and how this varies with size and age, estimation of the natural mortality rate of juvenile snapper and their spatial pattern of abundance in Denham Sound. The spatial pattern of intensity of trawling was combined with the information on snapper to estimate the snapper surviving in Denham Sound as a proportion of what there would be in the absence of trawling. In a second method, estimates from observations on commercial trawlers of the number of juvenile snapper caught in a year by the prawn fishery were used to calculate the additional yield there would be to the fishery on adult snapper if these juveniles had not been taken by trawling. A similar calculation was made on the estimated number of undersized snapper that die as a result of being caught and returned to the water by the recreational fishery. A number of options for minimising the pre-adult mortality of snapper are then examined.

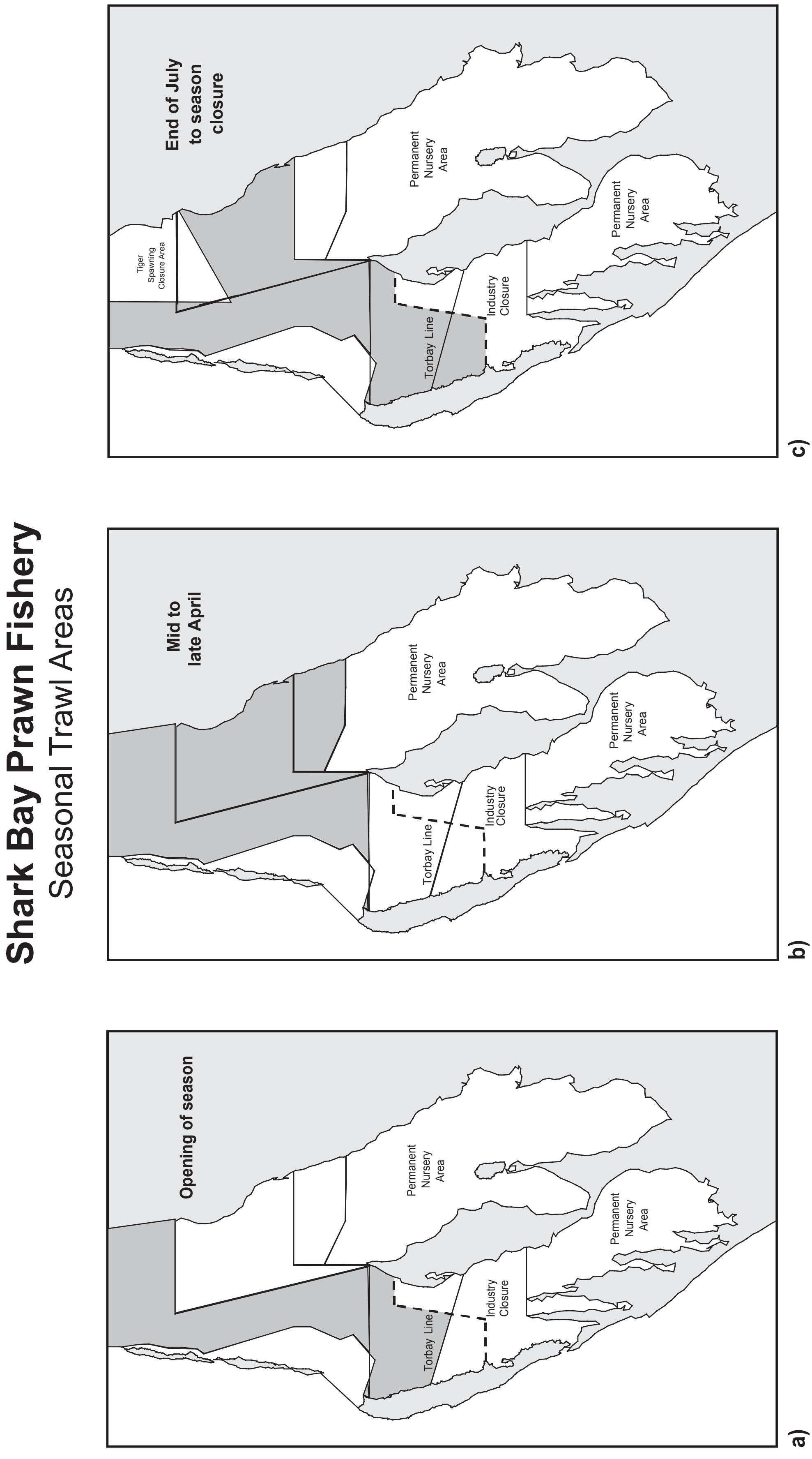


**Figure 2.** Generalised seasonal trawl areas in the Shark Bay Prawn Managed Fishery, indicated in dark grey.

# 2.0 Shark Bay prawn and scallop managed fisheries

## 2.1 Shark Bay Prawn Managed Fishery

Prawn fishing in Shark Bay commenced in 1962 with four trawlers, increasing gradually under a limited-entry regime to 35 vessels during the 1970s and 1980s. A buy-back scheme in 1990 reduced the number of vessels to 27 to compensate for increases in technological efficiency and to maintain economic efficiency. The fishery typically produces between 1,600 and 2,000 tonnes of prawns annually (Kangas & Sporer, 2002a). Since 1995 the value of the prawn fishery in Shark Bay has ranged between $27 and $33 million. The commercial fisheries in the Gascoyne region, of which the prawn fishery is the largest in value, provide significant employment for crew, processing and fleet maintenance workers.

Management of the Shark Bay prawn fishery is based on input controls to limit overall fishing effort, and hence catches, to sustainable levels. Trawling is undertaken using otter gear with two 8 fathom nets with 50 mm mesh in the body of the net and 45 mm mesh codends. Controls include vessel size and horsepower, headrope length and board size as well as closures by day, area, moon and season, and the permanent closure of prawn nursery areas. The main management changes in recent years have been in the development of a complex system of spatial and temporal closures aiming to optimise the separate management of king and tiger prawn stocks. This style of management has only become practical since the late 1990s when satellite-based vessel positioning and monitoring systems became available to the Shark Bay trawl fisheries.

### 2.1.1 *Sequence of area closures*

During a fishing season, areas of the Shark Bay Prawn Managed Fishery are opened and closed in a sequence to optimise the size of prawns caught and to maintain adequate breeding stocks of tiger prawns. The exact areas and the sequence have changed over time (opening and closing times of regions since 1990 are listed in Appendix A).

Currently, at the start of the season in March, residual 1+ age prawns can be harvested by the fishery in the north and west of northern Shark Bay and in the northern part of Denham Sound (Figure 2a). Although the Denham Sound area is open to fishing from the start of the season (usually mid-March) until mid-April or early May, the fishery at that stage is primarily focused north of Cape Peron (Figures 1, 2a) such that low prawn trawling effort occurs in Denham Sound at this time. Other areas in the eastern part of Shark Bay are then opened after April/May to allow the capture of prawns as they migrate out from permanently closed nursery areas (Figure 2 b,c).

An additional voluntary industry closure line in Denham Sound (Figure 3) was adopted in 1998 and reduced the overall area open to prawn trawling in Denham Sound while focusing the fleet in areas of prawn concentrations.

For the 2000 season, a typical recent season (Figure 3), the season commenced on 13 March with fishing taking place north and west of the Carnarvon-Peron line and in areas of Denham Sound north of the Torbay line (and west of the industry closure line). On 27 April, Denham Sound (south of a line due west from Cape Peron) was closed. Denham Sound both north and south of the Torbay line, down to the voluntary industry line, re-opened on 1 August and remained open until the end of the season on 4 November.

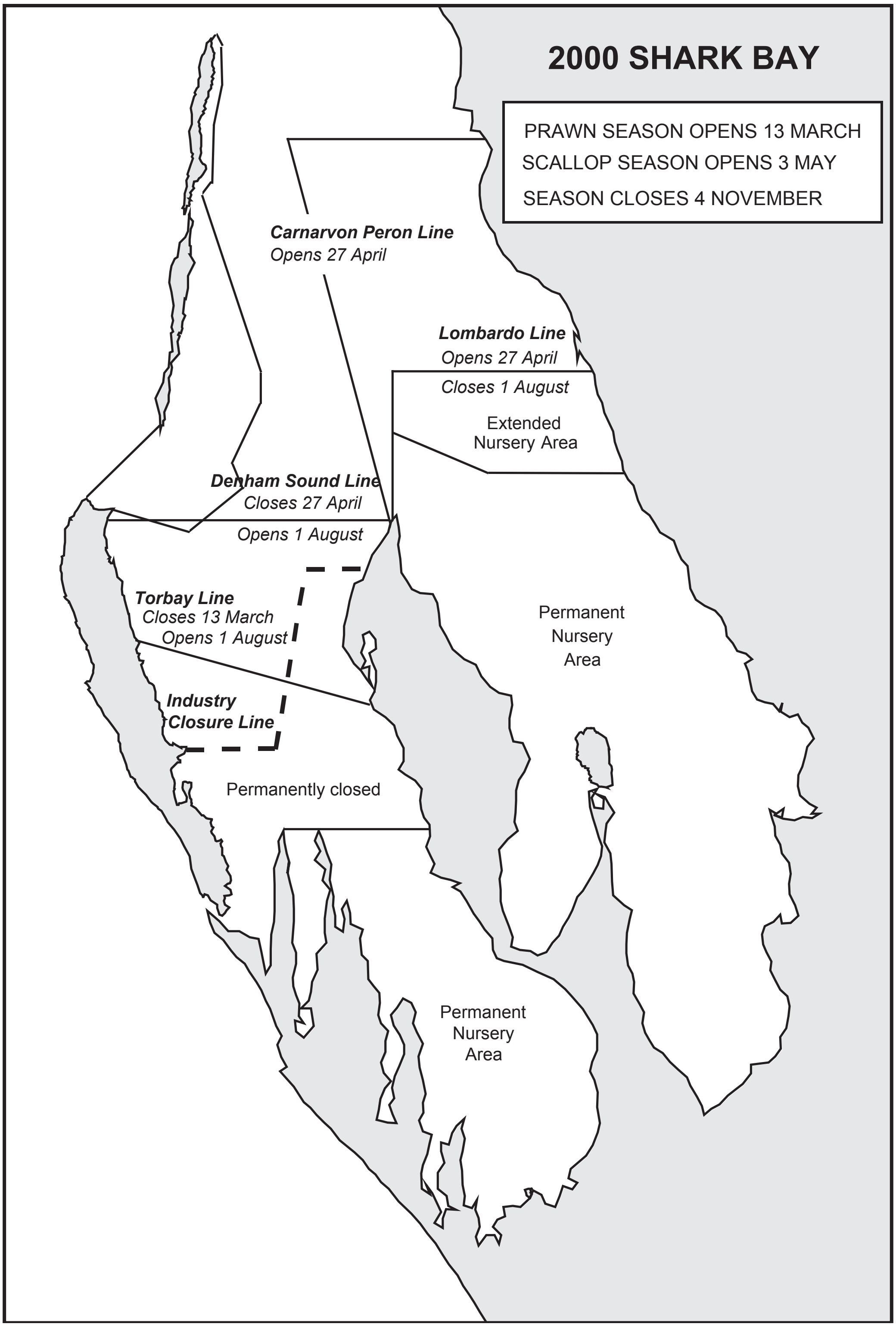


**Figure 3.** Opening sequence for the 2000 season in the Shark Bay prawn/scallop fishery.

### 2.1.2 Effort distribution in the Shark Bay prawn fishery in 2001

The general pattern of fishing effort expended by trawlers in the Shark Bay prawn fishery in recent years is illustrated for the 2001 season. Some areas are more intensively fished than other areas (Figure 4) in response to the abundance of prawns which is closely related to fishing effort. These include the Extended Nursery Area (ENA) east of Peron Flats, the area north-west of Cape Peron and areas of Denham Sound east of Sandy Point and Louisa Bay (Figures 1, 3).

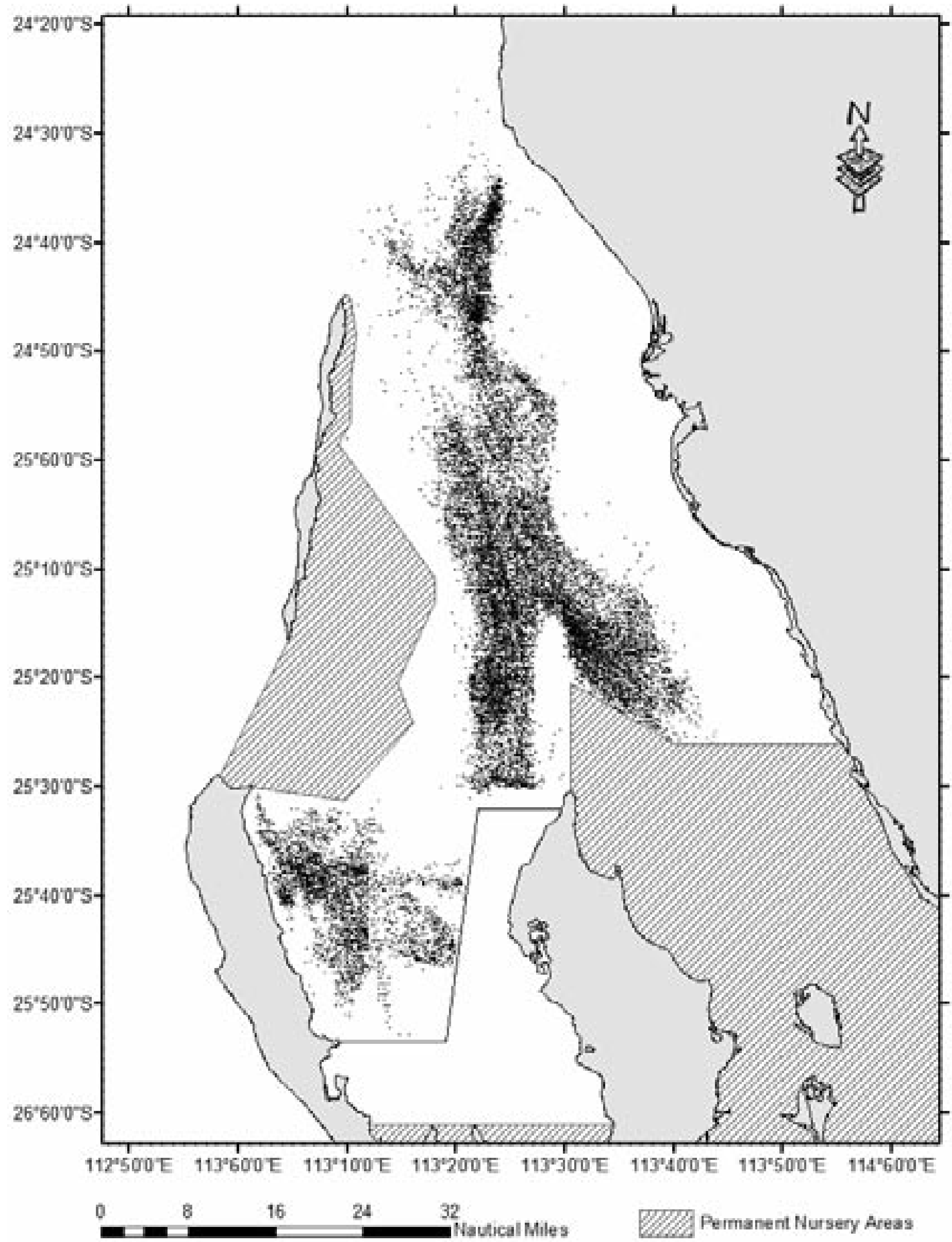


**Figure 4.** Prawn trawling effort distribution in Shark Bay during the 2001 fishing season. Each point is the starting position of a trawl shot.

### 2.1.3 Effort trends in Denham Sound

Prawn trawling in Denham Sound has been a part of the seasonal fishing pattern of the Shark Bay Prawn Managed Fishery since it began in 1962 and particularly since the 1970s (Figure 5). Total fishing effort in the fishery has shown some variation but remained relatively constant between the mid-1970s and late 1980s. There was a reduction in effort in the late 1980s through an industry licence buy-back scheme to enhance profitability. Also in the late 1980s and early 1990s there was a period of exceptional scallop abundance which diverted some of the prawn fleet's effort away from prawns and into catching scallops. During the period from the mid-1970s to the late 1980s, the Denham Sound effort contributed between 5% and 20% of total effort in the fishery. However, as a result of effort reduction in the rest of the fishery since 1990, effort in Denham Sound now comprises a higher proportion of the total effort of the fishery (25–40%).

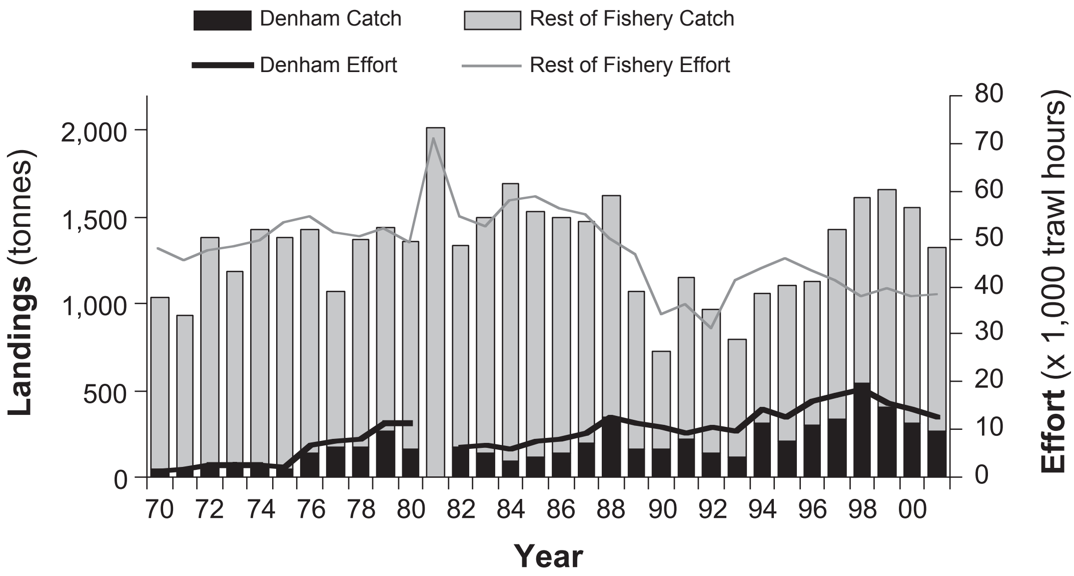


**Figure 5.** Annual catch (tonnes) and effort (hours) expended in Denham Sound compared to the rest of the fishery (data by region not available in 1981).

### 2.1.4 Movement of prawns in Denham Sound

Tiger prawns living as juveniles in the extensive seagrass banks on the north-western side of Peron Peninsula move northwards as they grow and are taken in the northern part of the fishery rather than in Denham Sound. The size of king prawns increases from south-east to north-west in Denham Sound, indicating a movement of prawns in this direction (Penn & Stalker 1979, Penn 1988). Using catch data from periods when Denham Sound was not closed in winter, Penn (1988) showed that the catch rates in Denham Sound peak in spring, indicating a recruitment peak into the fishery around this period (Figure 6).

Catches of king prawns in the March–April fishing period are dominated by large and medium prawns in the north-west of the trawled area in Denham Sound and by small prawns in the south-east. The large prawns are survivors from the year-class which recruited in the previous fishing season which, over summer, have concentrated in the deeper waters nearer the ocean. The small prawns are the vanguard of the current season's recruits moving from the south-east into the fished area. In the August–November part of the fishing season the current season's recruits are caught throughout the area, but are again concentrated in the north-west as larger prawns at the end of the season.

These fishery data support the conclusion from research surveys that the prawns are moving to the north-west of Denham Sound as they grow. This pattern is the same as that for king prawns in northern Shark Bay, where they move north-westerly from the eastern gulf to the main spawning grounds between the mainland and Dorre and Bernier Islands.

The controls on prawn fisheries, particularly king prawns, tend to focus on ensuring prawns grow to marketable sizes before capture. In this context, growth overfishing is the term used for catching too many fish at an early part of their lives when gains to the population biomass due to growth exceed losses due to natural mortality; that is, allowing the fish to live longer increases the yield available to the fishery. In many fisheries, a minimum size at which fish can be caught is set, partly to prevent growth overfishing and partly to ensure that the fish live long enough to spawn one or more times, thus maintaining an adequate stock of mature animals to provide future recruitment. In prawn fisheries, because prawns move into the deeper waters of the fishery as they grow, it has been found to be more practical to close the shallow inshore areas to fishing where young prawns live. The Shark Bay fishery has had such nursery area closures almost since it began in 1962 but as knowledge of the biology of the prawns and experience of fleet behaviour have increased, it has been possible to augment the permanent closures with a complex set of seasonal closures which have proved successful in maintaining the prawn stocks and the fishery at economically viable levels.

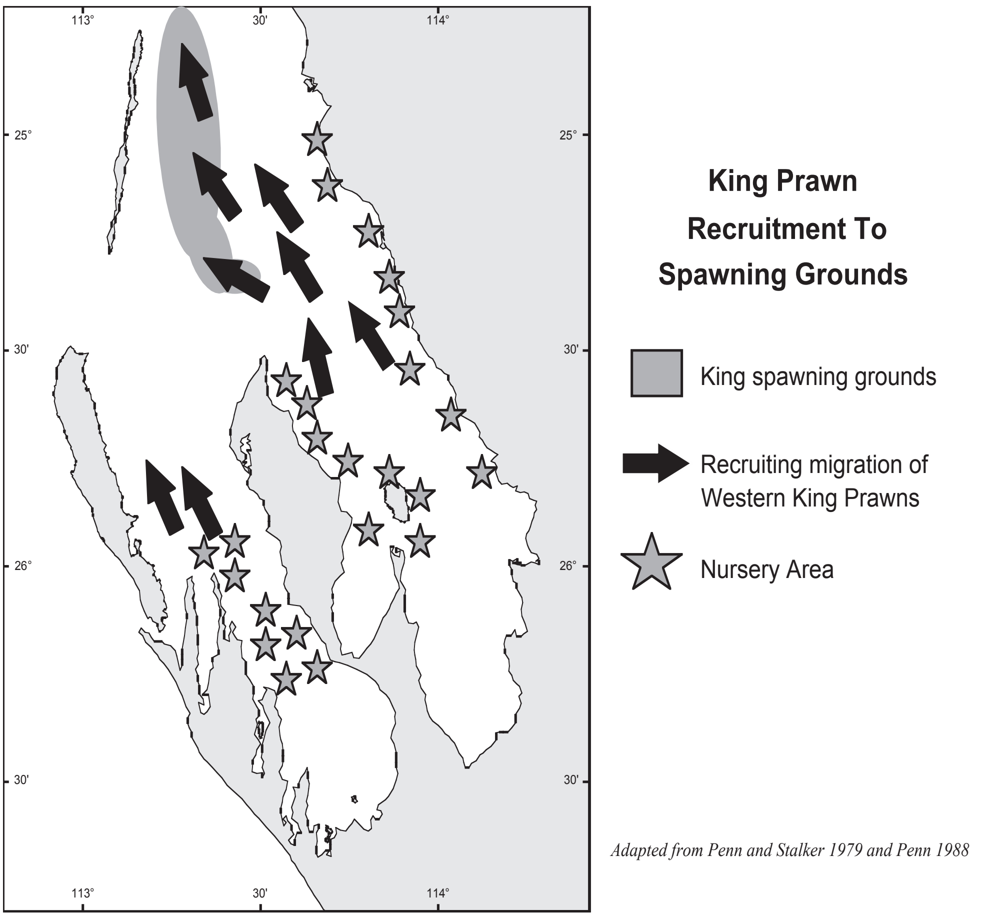


**Figure 6.** King Prawn recruitment within Shark Bay.

### 2.1.5 Preliminary bycatch reduction trials

Preliminary trials of bycatch reduction devices (BRDs), primarily aimed at reducing large elasmobranchs (sharks and rays) and turtles in trawls were conducted in 1998 (Unsworth et al., 2000). During this study, information on bycatch of snapper showed low numbers of snapper caught overall and high variability in catches from trawl to trawl. The number of snapper caught in nets was reduced with various kinds of BRDs by between 9% and 33% even though these BRDs were not primarily designed to reduce catches of small fish species. Preliminary trials of square-mesh escape panels, designed to increase escapement of small fish, reduced catches of most fish species, including snapper, by around 30% (M. Moran, unpubl. data). Further trials of such devices are occurring as part of an ongoing program of technology improvement to reduce bycatch and raise prawn quality. Greater reductions in small fish catches may well be achieved, possibly as high as 50% (Broadhurst et al., 2002).

## 2.2 Shark Bay Scallop Managed Fishery

Commercial scallop trawling commenced in the late 1960s with moderate catches recorded (Harris et al., 1999). Following a period of low catches in the mid-1970s, landings increased significantly during the late 1970s and early 1980s. After peaking at 26 vessels in 1983, the size of the scallop fleet was reduced to 14 vessels pending a four-year biological review of the fishery. Following review recommendations, the Shark Bay scallop fishery was declared a limited entry fishery in 1987 and restricted to 14 dedicated scallop vessels operating alongside the prawn fleet. All prawn vessels in Shark Bay can take scallops during prawn trawling operations. The scallop fleet take 70–80% of the overall catch of scallops in Shark Bay with the remainder being taken by the prawn vessels during prawn trawling operations.

The fishery is managed by similar input controls to the prawn fishery, except that there are no moon closures and scallop trawlers can operate over a 24 hour period compared with prawn trawlers that can only operate at night. However, the mesh size used by scallop boats is much larger (100 mm) to avoid the capture of prawns. Controls include vessel size and horsepower, headrope length and otter-board size as well as area and season closures and the permanent closure of prawn nursery areas.

Annual catches of scallops can be highly variable, reflecting the extreme natural variability in recruitment. Catches in the Shark Bay fishery have ranged from 121 to 4414 tonnes (meat weight) with an average of 938.4 tonnes since 1984. The fishery has an annual value ranging between $2 million and $58 million.

### 2.2.1 Seasonal closures

The timing and duration of the scallop season in Shark Bay has been influenced by the adjacent Shark Bay prawn fishery. Since 1983, the scallop season has been set to close on the same date as the Shark Bay prawn season in November; however, dedicated scallop vessels usually cease fishing well before the end of the defined season as catch rates for scallops alone become uneconomical. The opening date, however, is set independently to ensure breeding stock maintenance and is set using the results of a research vessel survey in November each year which forecasts abundance.

### 2.2.2 Distribution of scallop trawling effort

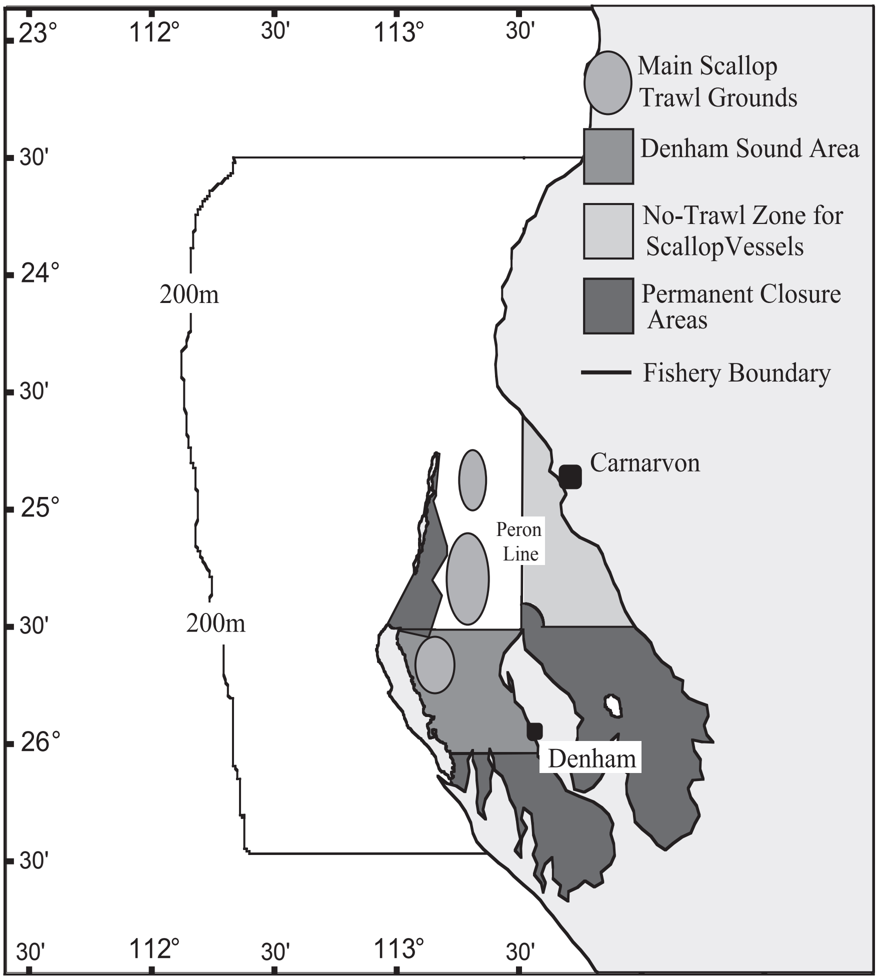


**Figure 7.** Map showing the general boundaries and fishing grounds of the Shark Bay Scallop Managed Fishery.

Two main trawl grounds exist for scallops within Shark Bay, i.e. to the east of Dorre and Bernier Islands off Red Cliff and north-west of Cape Peron. Occasionally scallops are also taken in the north-western area of Denham Sound (Figure 7). The Shark Bay scallop vessels' catches in Denham Sound, however, have not been significant since 1995 due to low natural recruitment of scallops in this region (Figure 8) although there was a small increase in 2002. The November 2002 survey again indicated scallops at harvestable abundance and the area was opened for scallop fishing for six days in mid-May 2003.

### 2.2.3 Bycatch

The occurrence of small fish in the bycatch of the scallop fishery is very low. Most of the fish that occur in the prawn fishery bycatch, including snapper up to 15 cm in fork length, would escape through the large mesh of scallop trawl nets.

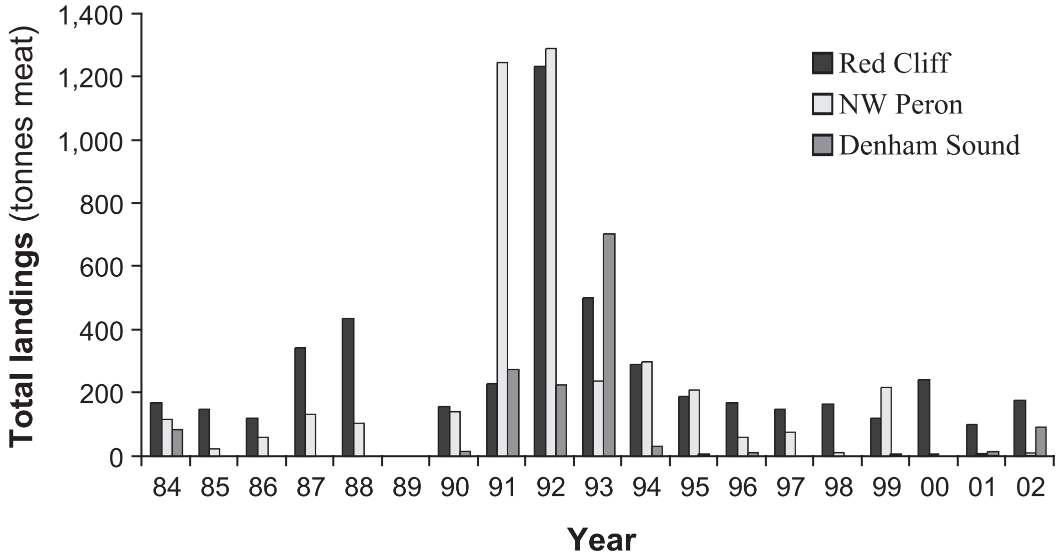


**Figure 8.** Historical annual catches from dedicated scallop trawlers for each area of Shark Bay.

## 3.0 Information on snapper

The purpose of this section is to present relevant information on the biology of snapper from the scientific literature and the results of research by the Western Australian Department of Fisheries that is pertinent to the issue of pre-adult mortality. This research includes the vulnerability of juvenile snapper to trawling, the age, growth, natural mortality rate and the distribution and abundance patterns of juvenile snapper in inner Shark Bay.

### 3.1 Background

Snapper, *Pagrus auratus*, is a widely distributed species in warm temperate waters, extending slightly into tropical waters, of the eastern Indian Ocean and western Pacific Ocean (Kailola et al., 1993). Adults are fished in Australia, New Zealand, China and Japan from the edge of the continental shelf to the coast and in marine embayments. Juveniles are common in marine embayments and coastal lagoons but also are sometimes found in the lower reaches of estuaries and inshore ocean waters. The species is demersal, i.e. it generally lives close to the sea bed. Snapper eat a very wide variety of animals, mainly crustaceans and molluscs living on the sea bed, but are also occasionally observed to eat mid-water species such as squid and pilchards. Adults form aggregations at spawning time, with offshore populations migrating inshore to spawn (Moran et al., 2003).

There are numerous spawning events in each season for each individual, probably once daily for a number of days around the new moon and less frequently or not at all around full moon (G. Jackson, unpubl. data). Spawning seasons are usually three or four months in duration and occur in spring-summer at the cold end of the species' latitudinal range and in winter at the warm end of the range, which includes Shark Bay. Age at maturity in this region is around four years but these smaller spawners contribute far fewer eggs than the larger, older fish, up to 30 years of age, with egg production being approximately proportional to body weight.

The female snapper spawn by swimming rapidly upwards and broadcast the unfertilised eggs into the sea (Smith, 1986). Males follow the female on her spawning rush, broadcasting sperm into the water to fertilise the eggs. The fertilised eggs tend to float, rather than sink, as they contain an oil globule (Kitajima et al., 1993). After one to two days of passive dispersal by water currents, the eggs hatch into free-swimming larvae, which again are thought to be dispersed more by water currents than by their own swimming efforts. At three to four weeks of age the tadpole-like larvae settle to the sea-bed and metamorphose into tiny fish which are recognisable as juvenile snapper.

### *3.1.1 Relationships among snapper populations in the various parts of the Shark Bay region*

There are many lines of evidence that, in the Shark Bay region, the ocean snapper and inner bay snapper either do not mix with each other at all or have extremely low rates of mixing, at least from the age of three years (Edmonds et al., 1989, 1999; Johnson et al., 1986; Moran et al., 1998, 2003; Nahas et al., in press). There is less information on the younger juveniles as techniques such as tagging are much less successful. However a recent research project using the advanced stock discrimination tool of otolith microchemistry found that there is no mixing between ocean and inner bay snapper from the time of settlement (Gaughan et al., 2003). There is also minimal mixing between snapper populations occupying the three inner bay areas of Denham Sound, Freycinet Estuary and the eastern gulf. Of 493 recaptures of inner bay tagged snapper (Moran et al., 2003), with times at liberty of up to 15 years, only two fish were recaptured in an area other than the one where they were tagged (moved from Denham Sound to Freycinet).

Since 1997, there have been annual egg surveys used as part of the daily egg production method for estimating the size of the spawning biomass in the three inner bay areas (Jackson & Cheng, 2001). An additional benefit of this research is information on the distribution and abundance of snapper eggs indicating the locations of the key spawning areas. In the eastern gulf, the major spawning area is in a deep channel between Hopeless Reach and Disappointment Reach and was marked by buoys and closed to all fishing from 1997 to 2003. In Freycinet Estuary spawning is apparently more spread out over the deepest parts of the basin, and in Denham Sound the major spawning area is off Dirk Hartog Island between Quoin Bluff and Sandy Point (Figure 1).

Studies of the effects of wind, tide and the Leeuwin Current on water movements inside Shark Bay indicate that while passive movement of the eggs and larvae by the currents disperses them to some extent away from the different spawning grounds, it does not result in mixing between the three inner bay areas, nor would eggs and larvae be transported from the inner bay to the ocean (Nahas et al., in press). There remains, however, a possibility that eggs and larvae from spawning by ocean snapper may sometimes be swept into the northern parts of Denham Sound.

## 3.2 Fisheries biology of juvenile snapper

Although there is a great deal of data on snapper numbers and sizes in trawl surveys and observations of commercial trawling, additional information was required to make an assessment of the effects of the trawl fishery on snapper abundance. Research was undertaken from 1998 to 2001 partly with the purpose of addressing this issue. An experiment to estimate catchability of snapper in trawl nets was carried out in November 2000. Trapping surveys to estimate distribution and abundance of juvenile snapper in both trawlable and non-trawlable areas were conducted in 1998, 1999 and 2000.

A dedicated multi-purpose series of quarterly research trawl surveys in both Denham Sound and Freycinet Estuary from November 2000 to December 2001 was designed to estimate:

- effects of snapper size on retention in a trawl net;
- the sizes, ages and growth of snapper on trawl grounds throughout the year;
- the natural mortality rate of juvenile snapper; and
- the pattern of distribution and abundance of juvenile snapper on trawlable grounds.

Since they are relevant to several of the sections below, the quarterly surveys are described in detail here. The same set of trawl gear was used throughout: twin otter trawls in the same configuration as commercial trawlers in Shark Bay. The nets used were similar to commercial prawn trawl nets in having 50 mm mesh in the body of the net and 45 mm mesh in the codend. They differed in having 6 fathom headropes (width of the front opening of the net) compared with 8 fathoms in commercial nets. In the first four surveys, one of the twin nets was fitted with a fine mesh (20 mm) codend cover. All trawl shots were 20 minutes in duration and at a speed of 3 knots. All snapper caught on all surveys were counted and measured (fork length), with the fish passing through the main net and retained by the fine-mesh cover recorded separately. The aim was to have the surveys at three-monthly intervals but vessel availability caused some deviations from this.

**Table 1.** Details of the quarterly research trawl surveys for snapper in Denham Sound and Freycinet Esturary from November 2000 to December 2001.

| Dates | Area | No. of shots | Codend cover used |
|---|---|---|---|
| 24-25/11/2000 | Denham Sound | 16 | Yes |
| 26-30/11/2000 | Freycinet Estuary | 12 | Yes |
| 25-26/02/2001 | Denham Sound | 13 | Yes |
| 26-27/02/2001 | Freycinet Estuary | 13 | Yes |
| 26-27/05/2001 | Denham Sound | 16 | Yes |
| 23-25/05/2001 | Freycinet Estuary | 14 | Yes |
| 16-19/09/2001 | Denham Sound | 45 | Yes |
| 18/09/2001 | Freycinet Estuary | 13 | Yes |
| 10-11/12/2001 | Denham Sound | 15 | No |
| 12-13/12/2001 | Freycinet Estuary | 13 | No |

### 3.2.1 The effect of snapper size on vulnerability to trawling

Although most snapper taken in commercial prawn trawls are in the 10–15 cm length range, this could be due to the absence of other sizes of snapper in the trawled area or to a low catchability of snapper outside this size range. Knowing the catchability of snapper at different sizes is important when using catch or catch-rate data for estimating absolute population sizes, growth rates, natural and fishing mortality rates. Two experiments were carried out to investigate this: one measured the proportion of snapper of various sizes that were retained by the codend of the trawl net after entering it (i.e. mesh selectivity) while the other estimated the proportion of snapper in the path of the net which were actually caught (trawl efficiency).

### 3.2.2 Retention of snapper which enter the trawl net – the effect of snapper size

#### 3.2.2.1 Methods

A series of four research trawl surveys for juvenile snapper was conducted in Denham Sound and Freycinet Estuary approximately quarterly from November 2000 to September 2001 (152 20-minute trawls in total). The trawl nets used were similar in all respects to those used by commercial prawn trawlers except that the headrope length (width of the mouth of the net) was 6 fathoms instead of 8 fathoms. A 20 mm fine-mesh cover was attached around the trawl codend to retain fish passing through the codend which is made of 45 mm stretched mesh. For each 1 cm size-class the ratio of the total number of snapper retained by the main codend to the total number retained by both the codend and the fine-mesh cover was calculated to give the proportion retained for each size of snapper.

#### 3.2.2.2 Results

The sizes of snapper caught in the main net and fine mesh codend cover ranged from 3 cm to 20 cm in length. Snapper smaller than 4 cm were not retained at all by the main net, and a very small proportion was retained at 4 cm, increasing in a typical sigmoid manner until they were fully retained at 10 cm and above (Figure 9). The proportions retained at different sizes can be used to calculate what the length-frequency of snapper in a trawl catch would be if **all** fish entering the net were retained.

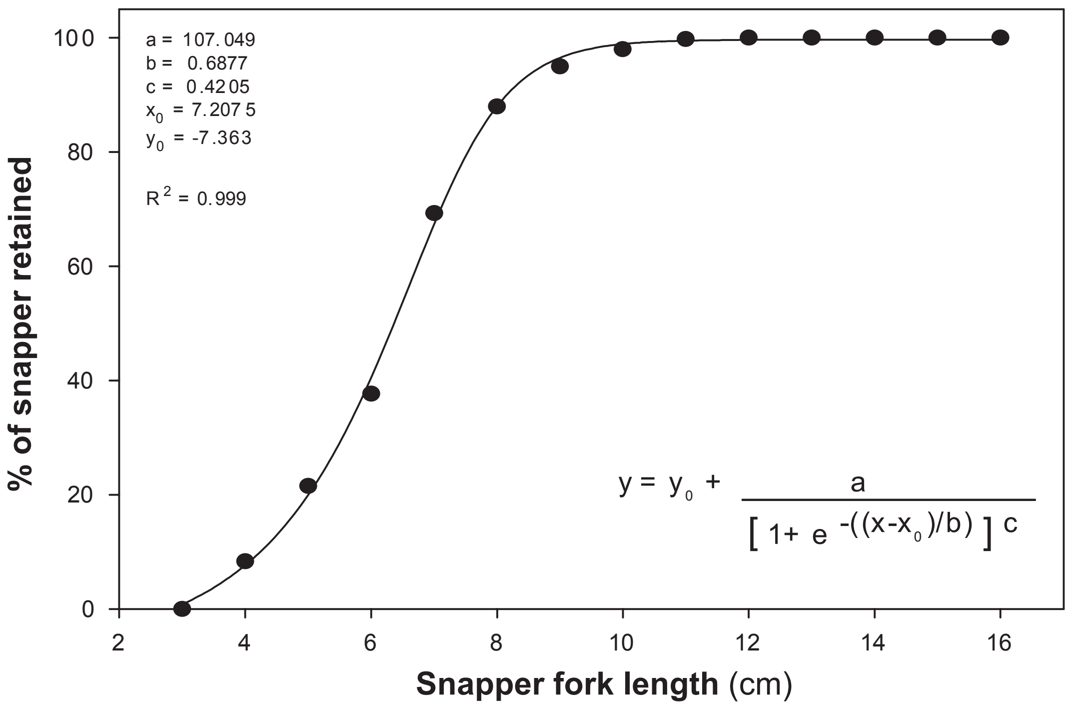


**Figure 9.** Codend selectivity for snapper: percentage retained in the codend by fork length.

### 3.2.3 The proportion of snapper in the path of the net that is caught

In addition to small fish passing through the trawl mesh, fish of all sizes escape trawl capture by passing under, over or around the side of the net. It is commonly assumed that only around 50% of the fish in the path of a trawl net actually enter the mouth of the net. A depletion experiment can be used to estimate the proportion of the fish in the path of the net that are caught. This involves repeated trawling of the same area and calculating the catchability from the rate of decline in catches as the fish are depleted. Such experiments can only work effectively if the species is of very low mobility. For specific details on the assumptions underlying this method see Joll & Penn (1990).

#### 3.2.3.1 Methods

A depletion experiment was conducted in November 2000 in an area of Freycinet Estuary where juvenile snapper were known (from November surveys between 1996 and 1999) to be abundant. The aim was to completely trawl a rectangular area four times, over four consecutive nights, and record the decline in numbers of snapper caught on successive trawls. The area to be repeatedly fished and the 12 vessel paths required to cover the area completely were marked out on the GPS plotter. The marked area was totally covered by the trawl once on each of four successive nights. Due to overlap of adjacent trawl paths the swept area was 1.09 times the area of the marked rectangle. All snapper caught were counted and measured. Catch numbers declined for all size groups over the four nights, with the rate of decline increasing with fish size. Since the same amount of fishing effort was applied on each night, catchability was calculated as the slope of a plot of catch per night against cumulative catch prior to that night. To obtain sufficient numbers in a size group to make this calculation reliable, it was necessary to aggregate fish from several 1 cm size-classes.

#### 3.2.3.2 Results

The smallest snapper had very low catchability (Figure 10). This would be expected as any that entered the net had a high probability of escaping through the mesh as shown in Figure 9. Catchability increased with increasing size, levelling off above 10–15 cm. These catchability estimates refer to a single fishing event and for the 10–15 cm size group, the estimate of catchability was 0.46. An adjustment needed to be made to correct for the total area swept in each fishing event being 1.09 times the area of the marked block due to overlap between adjacent trawl runs. For example, for 10–15 cm snapper, the number of snapper caught in a single trawl pass, as a proportion of the number of snapper in the path of the trawl, is estimated to be 0.46 / 1.09 = 0.42. In other words, an estimated 42% of the small snapper (10–15 cm) in the path of a trawl are caught and retained.

As part of this experiment, all snapper caught were sorted from the remainder of the catch as soon as possible at the end of a trawl run, placed in aerated seawater, and live ones were returned to aerated seawater after being measured. A small piece of fin was clipped at the time of measuring as a means of marking the fish with minimal harm. At the end of the night, all the snapper were returned to the sea in the middle of the experimental area. Only a handful (less than 1%) were recaptured on subsequent nights of the depletion experiment, indicating that survival was extremely low, even for fish which had been handled so carefully. This, combined with the results of several other tagging studies of juvenile snapper (e.g. N. Tapp, MSc thesis, 2003), indicates that a juvenile snapper that has been trawled, emptied onto a sorting table and returned to the sea has very little chance of surviving. For the purposes of this study, the worst-case scenario of no survival after trawl capture has been assumed.

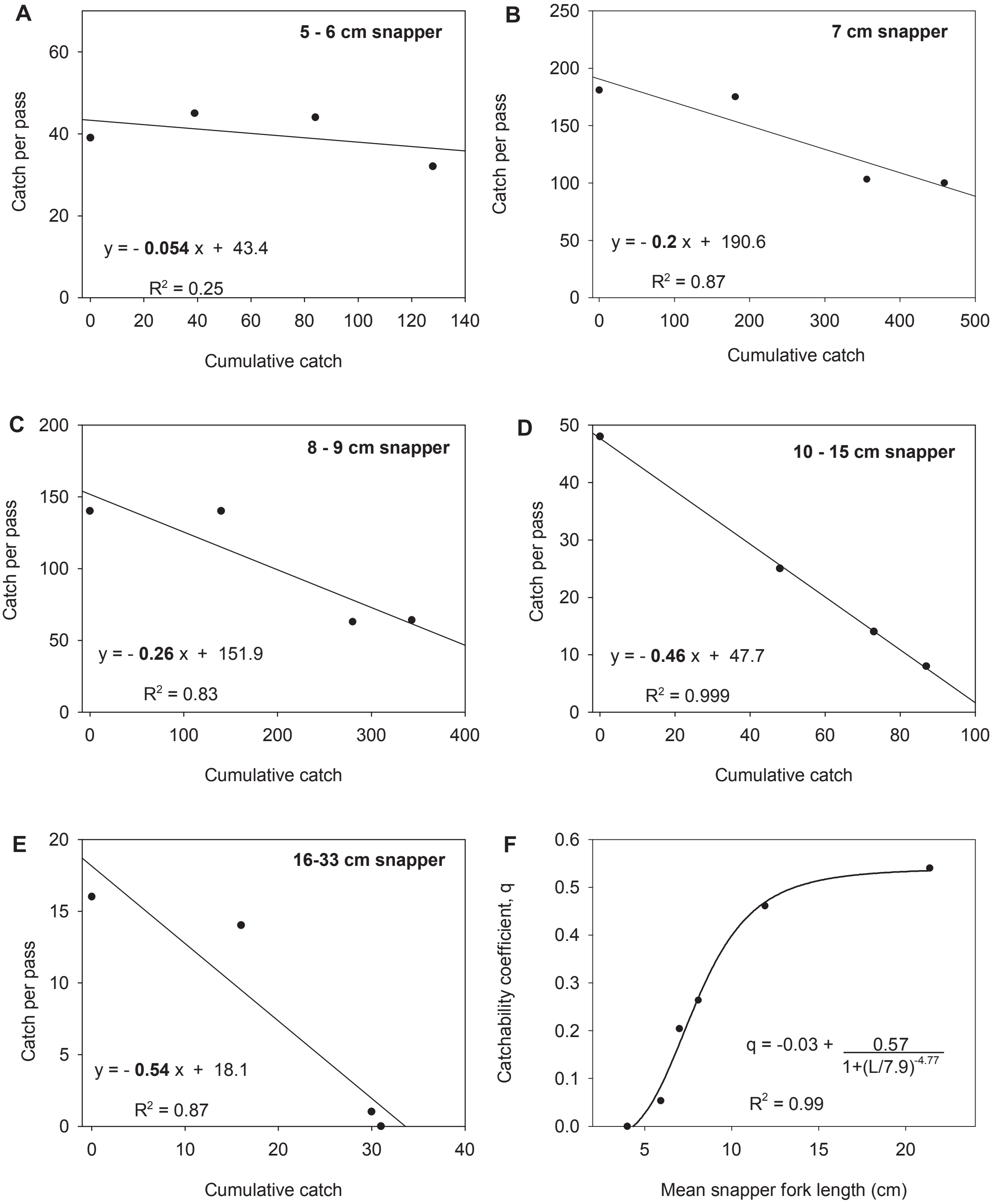


**Figure 10.** Results of the depletion experiment: (A-E) slopes of the linear regressions for various size groups of snapper give the catchability coefficient q; (F) catchability coefficient plottted against snapper length with fitted sigmoid equation.

## 3.2.4 Size, age and growth of juvenile snapper in trawlable areas

### 3.2.4.1 Methods

A series of five dedicated snapper trawl surveys at approximately quarterly intervals was conducted in both Denham Sound and Freycinet Estuary from November 2000 to December

2001. Lengths of all snapper (snout to caudal fork) to the nearest cm were recorded immediately after sorting the catch from each shot to generate length-frequencies at various times of year. The fine-mesh codend cover was used in the quarterly snapper surveys from November 2000 to September 2001 to determine whether there were snapper on the grounds that were too small to be captured by the normal prawn trawl mesh. All snapper were also measured in scallop trawl surveys in Denham Sound from 1996 to 1999.

#### 3.2.4.2 Results

The trawl surveys with the fine-mesh covered codend give a more accurate indication than trawls without the codend cover of the sizes of snapper available in the survey areas at different times of year. The length frequencies for the quarterly surveys in 2000/2001 in Denham Sound and Freycinet Estuary are shown in Figure 11. These show that in Freycinet in November-December, catches were dominated by the 5–10 cm snapper which had been spawned 3–7 months earlier (i.e. less than one year old or 0+ age-class), with a less numerous group of 11–15 cm snapper a year older (i.e. 1+ age-class). In Denham Sound in November-December, the 1+ snapper dominated the catch, with the 0+ either totally absent or in very low numbers. This pattern has been consistently found every year in November–December trawl surveys.

By February, although the 1+ snapper were still present on the trawl grounds in Denham Sound, they are greatly outnumbered by the 0+ which have come into the trawl grounds since November. In May, the 1+ snapper were absent from the survey area. They are almost two years old at this stage, as the spawning season is May–August. Snapper older than this have not been found on the trawlable grounds of Denham Sound in any of our trawl surveys. This is strong evidence for their absence as the depletion experiment showed that the 2+ snapper approximately 20 cm in length are slightly more catchable than the 10–15 cm 1+ snapper. The 2+ snapper are commonly caught by hook and line on rocky reefs, around coral patches and in channels.

In September, the new 0+ cohort was detectable as 3–7 cm snapper in Freycinet but not in Denham Sound. The snapper in Denham Sound spawn at the same time or slightly earlier than those in Freycinet (G. Jackson, unpubl. data). Also, 0+ snapper in Denham Sound have had a mean size about 2 cm greater than those in Freycinet in all our surveys (Figure 12) due to faster growth in the warmer waters of Denham Sound in the first few months of life (N. Tapp, MSc thesis, 2003). The larger 0+ snapper in Denham Sound would be more catchable than those in Freycinet. The absence of 0+ snapper in trawl surveys in Denham Sound in September cannot therefore be due to the 0+ snapper in Denham Sound being too small to catch but must be due to their absence from the trawl grounds at this time of year.

The conclusion from the quarterly surveys, supported by numerous other surveys over many years, is that some of the 0+ snapper in Denham Sound move onto the deeper, trawlable sand-mud habitat during summer (December–February) when they are around 6 months old; they remain there until the following summer, then leave this habitat when they are around 18 months old in their second summer. The situation in Freycinet is different in that the young snapper are present in the deep central sand-mud area at least from a size of 3 cm (about 2 months old) and can be caught in research trawl surveys until around two years of age when they become abundant in shallow rocky areas around the edges of the basin.

From the point of view of vulnerability to commercial trawling, each cohort of snapper occurs on the trawl grounds in Denham Sound for approximately one year and is subject to

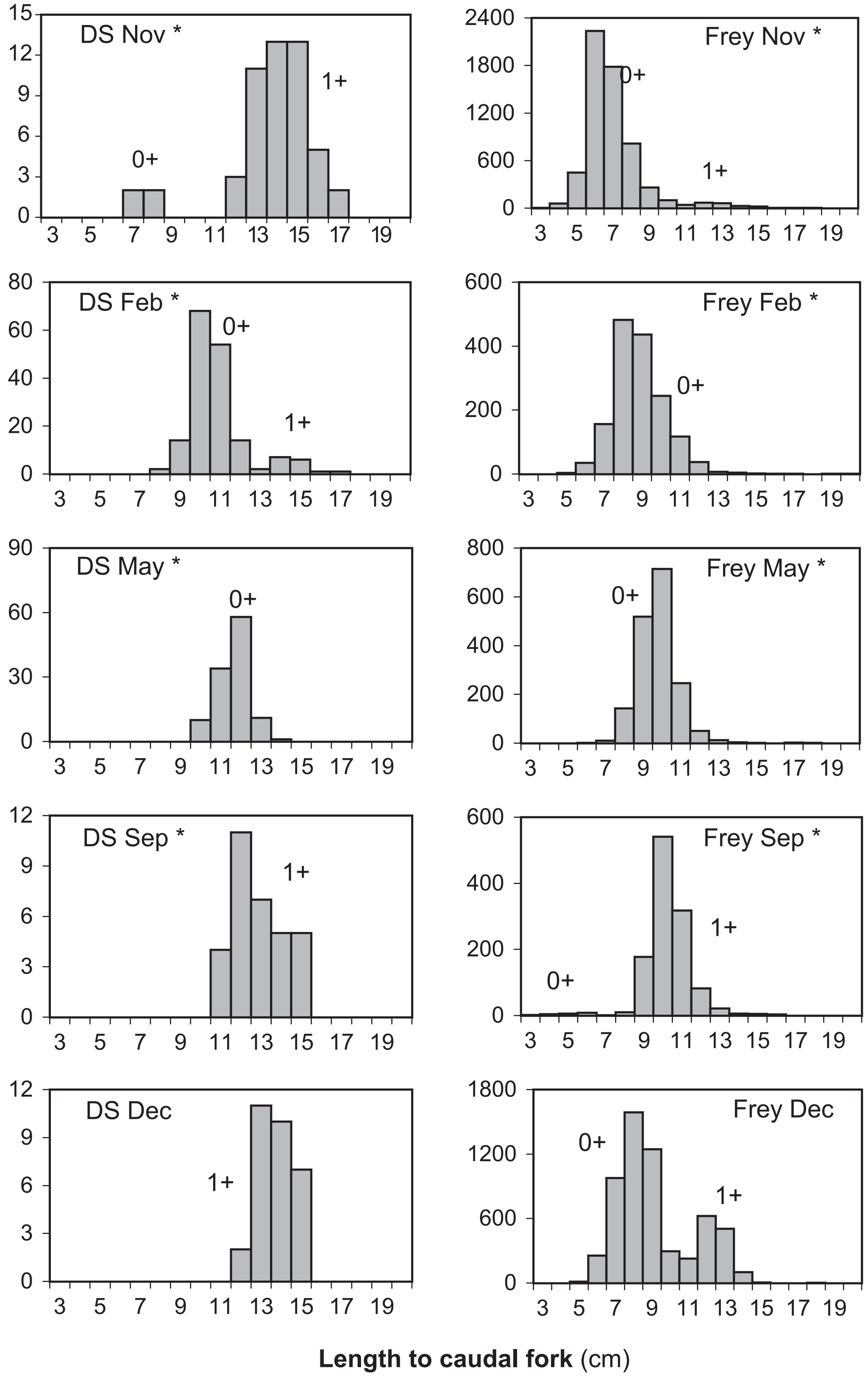


**Figure 11.** Length-frequencies of snapper in research trawls by time of year in Denham Sound (DS) and Freycinet (Frey), November 2000–December 2001.

*Indicates fine-mesh codend cover used.

trawling from March to November, excluding the trawling closure from May to July. During this exposure to trawling the snapper are approximately 9 to 17 months old and mainly in the 10–15 cm size range (Figure 12). If the young snapper were present on the trawl grounds in Denham Sound at ages less than 6 months, i.e. during their first August–November period, they would have been seen in our research trawl surveys with the fine mesh codend cover in September and November. As will be shown in the section on distribution (Figure 18), young snapper also occur in many parts of Denham Sound that are not trawlable.

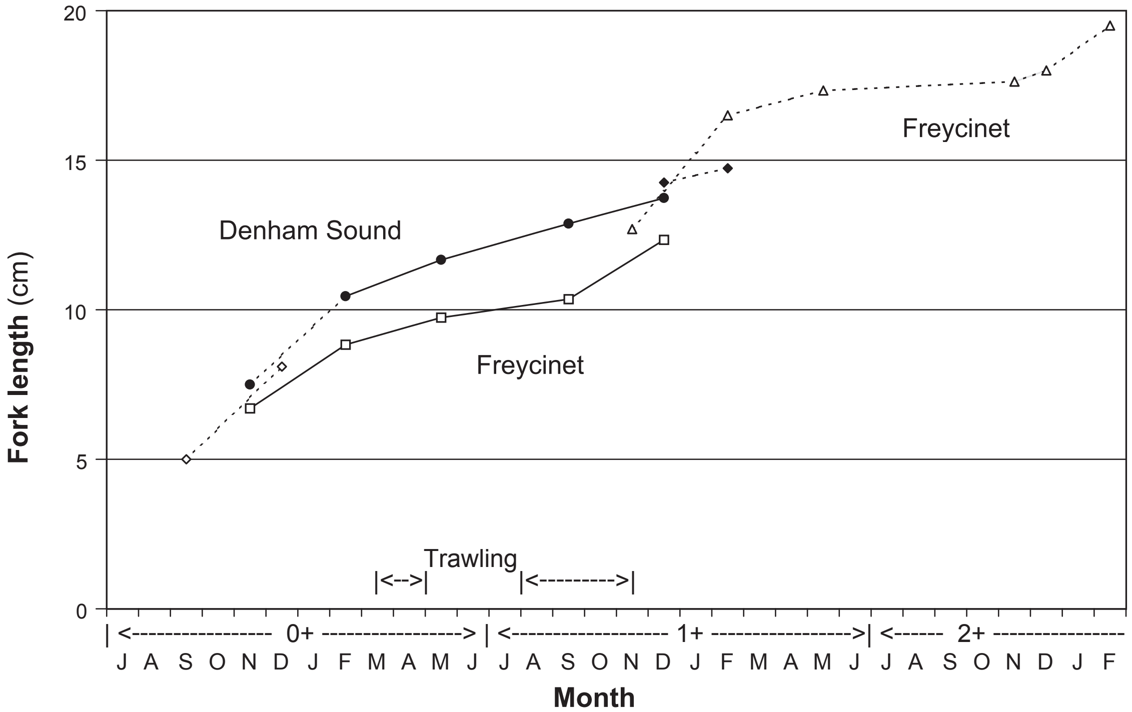


**Figure 12.** Mean lengths of cohorts of trawled snapper in Denham Sound (filled symbols) and Freycinet (open symbols) by time of year, arranged to indicate a growth curve. The prawn trawling seasons and age-classes of snapper are indicated.

### 3.2.5 *Natural mortality rate of juvenile snapper*

It is rare to be able to reliably estimate natural mortality rates for exploited finfish species (Hoenig, 1983). However, it was possible for juvenile snapper in Shark Bay because there are large areas protected from fishing and we have been able to estimate abundance with reasonable accuracy and economy based on standard trawl surveys in Freycinet Estuary. Estimates of abundance of the younger snapper using normal trawl survey gear are biased downwards due to their lower vulnerability to the standard trawl gear. To overcome this problem, the standard survey trawl data needed to be adjusted to take into account the rate of escapement which varies with size.

#### 3.2.5.1 Methods

To convert the CPUE to measures of abundance, the catches of snapper in each 1 cm length-class in all trawl surveys in Freycinet Estuary from November 1996 to November 2002 were adjusted for the proportion of that size-class retained by the net. For example, if 50% of the 7 cm snapper which enter the net are retained, the number of 7 cm snapper caught was multiplied by 2, whereas since 100% of the 12 cm snapper are retained, the number of 12 cm snapper was multiplied by 1, i.e. is unchanged.

Following these adjustments, length-frequency distributions were analysed. The modes of the distributions representing the year-classes were either completely separate or showed a clear minimum allowing separation into year-classes (Figure 11). The mean numbers of snapper caught per standard 20-minute shot in the 0+, 1+ and 2+ year-classes for each survey were calculated. From November 1998 to November 2002, there were three or more surveys per year and mortality rates could be calculated using linear regression of the natural logarithm of the mean number caught per shot, against time in years. The slope of the regression line gives the estimate of natural mortality rate.

In addition to the estimates of natural mortality rate made for the four year-classes (1998–2001) using regression slopes, natural mortality rates were also estimated for the 1996 and 1997 year-classes by comparing the adjusted mean catch per shot from a 0+ cohort in the year of its birth with that of the same cohort as 1+ snapper a year later.

#### 3.2.5.2 Results

Estimates of the natural mortality rate using regression analysis were made for the 1998, 1999, 2000 and 2001 year-classes (Figure 13). For the 1999 and 2000 year-classes, there were enough surveys to see that the same rate of decline in abundance applied from ages of approximately 4 months to 2 years, indicating a constant natural mortality rate over that part of the life. The sharper decline in abundance after 2 years was expected due to snapper leaving the trawlable habitat at that age and is not thought to reflect an increase in mortality. Sub-adult snapper, 2+ and older, are numerous over shallower rocky habitats around the edges of Freycinet Estuary.

The estimates of natural mortality rate for the six year-classes were fairly consistent (Table 1), ranging from 1.95 (i.e. 86% die per year) to 3.07 (i.e. 95% die per year) and are similar to the rates found for other fish species in this age group (e.g. Rooker et al., 1998; Schneider et al., 1999). The weighted mean estimate of natural mortality rate of juvenile snapper over all these year-classes was 2.58, corresponding to around 92% dying per year.

**Table 2.** Estimates of the instantaneous annual rate of natural mortality (M) for juvenile snapper for year-classes from 1996 to 2001, with the weighted mean (weighted on degrees of freedom for the M estimate).

| Year-class | M | df | $R^2$ | % Annual Mortality |
|---|---|---|---|---|
| 1996 | 2.25 | 1 | | 0.90 |
| 1997 | 1.95 | 1 | | 0.86 |
| 1998 | 2.12 | 2 | 0.98 | 0.88 |
| 1999 | 3.07 | 3 | 0.99 | 0.95 |
| 2000 | 2.72 | 5 | 0.99 | 0.93 |
| 2001 | 2.44 | 2 | 0.75 | 0.91 |
| Weighted mean M | **2.58** | | | **0.92** |

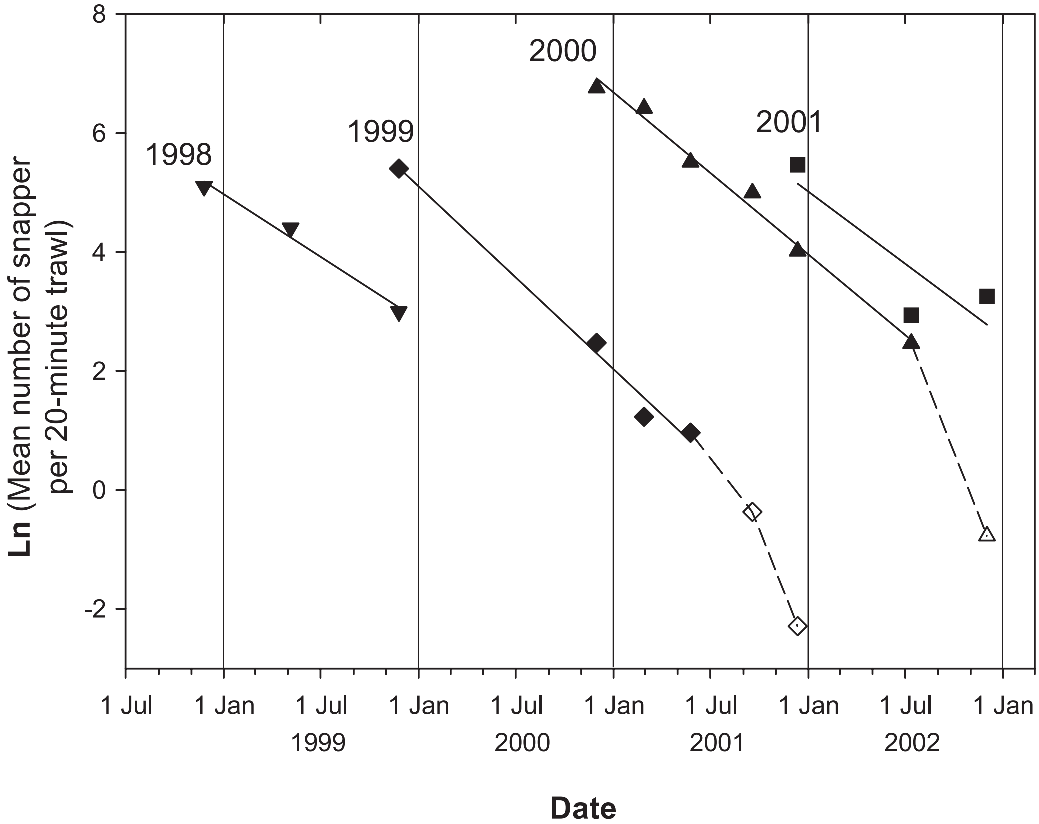


**Figure 13.** Regressions of natural logarithms of catch-rate of four year-classes of juvenile snapper against time. The regression slopes multiplied by -1 are estimates of the annual exponential rate of mortality.

## 3.2.6 *Distribution and abundance of juvenile (0+ and 1+) snapper*

The Fisheries Research Division, using its own vessel or chartered commercial vessels, conducts trawl surveys in Shark Bay in relation to monitoring current status of stocks or predicting the next recruitment of prawns and scallops. In recent years there have also been research trawls in relation to tests of bycatch reduction devices, studies of biodiversity in the trawlable habitats and the biology of juvenile snapper. Snapper have been counted and measured on many of these surveys even when they were primarily directed at prawns or scallops. Snapper were also counted occasionally on surveys since 1975 for northern Shark Bay and 1981 for Denham Sound, and annually in Denham Sound from 1996 to the present (2002). Research staff have also been present as observers on a number of commercial vessels during their normal fishing operations and have counted and measured snapper on some occasions. The information collected is useful in showing what sizes of snapper are taken by trawling and provides general data on the distribution and abundance of juvenile snapper over the trawling areas at different times of year.

### 3.2.6.1 *Standard scallop trawl survey data*

Many of the research trawls have been carried out as part of an ongoing standard scallop and prawn survey, which occurs annually in late November and early December, at the end of the trawling season (Figure 14). The abundance of snapper on the main trawl grounds at this time of year is very low, averaging less than 3 snapper per 20-minute shot, although a lightly fished location to the north-east of the main grounds occasionally has 1+ snapper.

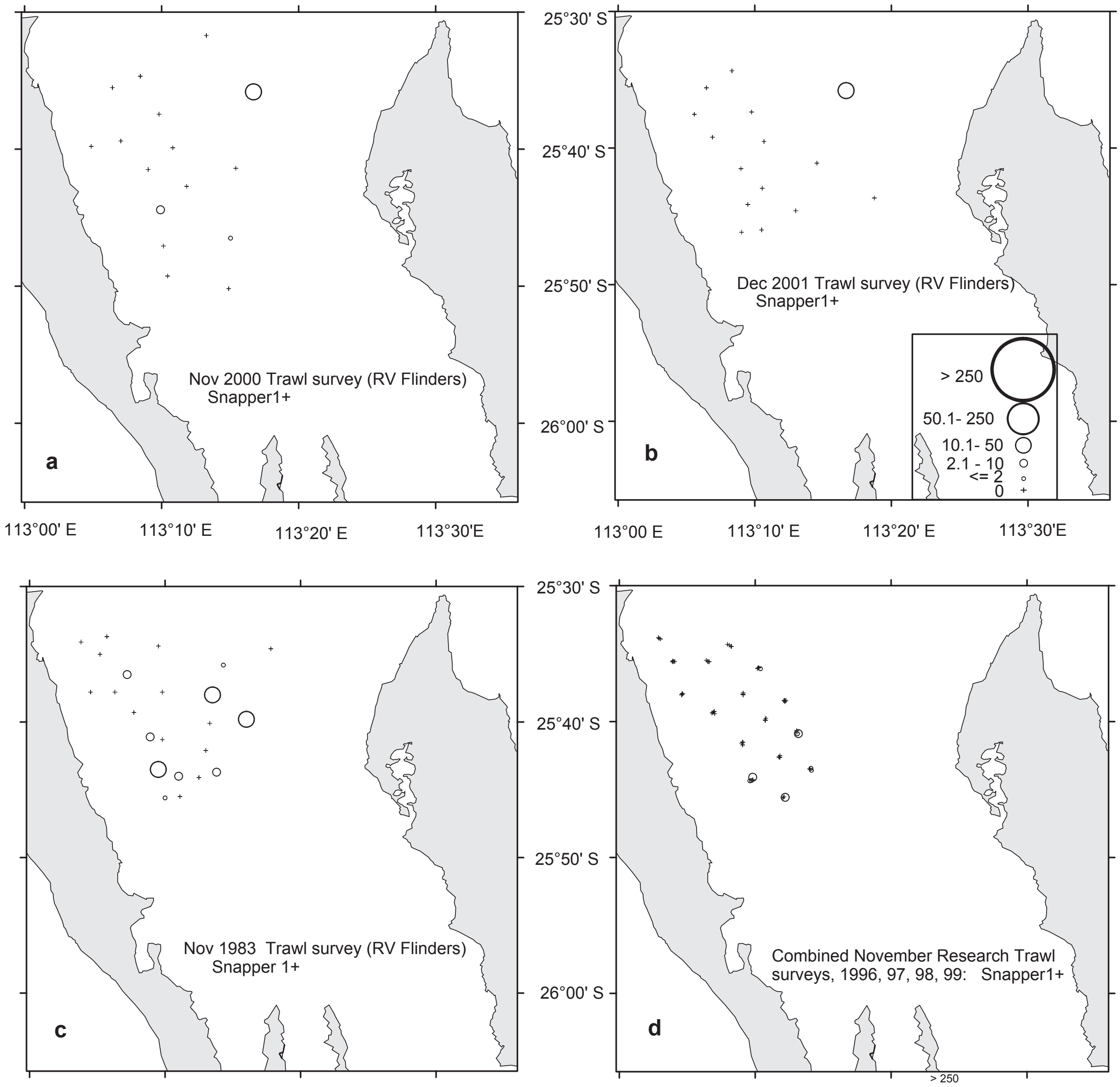


**Figure 14.** November–December research trawl surveys in Denham Sound. Numbers of 1+ snapper per 20-minute shot: a) November 2000; b) December 2001; c) November 1983; d) November 1996–99 combined.

The November 1983 survey was exceptional in that three shots caught 10–50 snapper and four shots caught 2–10 snapper (Figure 14b). All but one of these snapper were 1+. As abundances of snapper were also unusually high at this time on the grounds north-west of Cape Peron, it is likely that recruitment of 0+ was high in 1982 in this region. Occasional exceptionally strong year-classes of snapper are known to occur in snapper populations, e.g. in Freycinet Estuary in 2000 when juveniles were six times more abundant than the average for 1996–2001 year-classes and four times as abundant as the next strongest year-class. The main information which can be deduced from the November trawl series is that snapper are usually rare on the trawl grounds in Denham Sound at this time of year and that those present are predominantly the 1+ age-class.

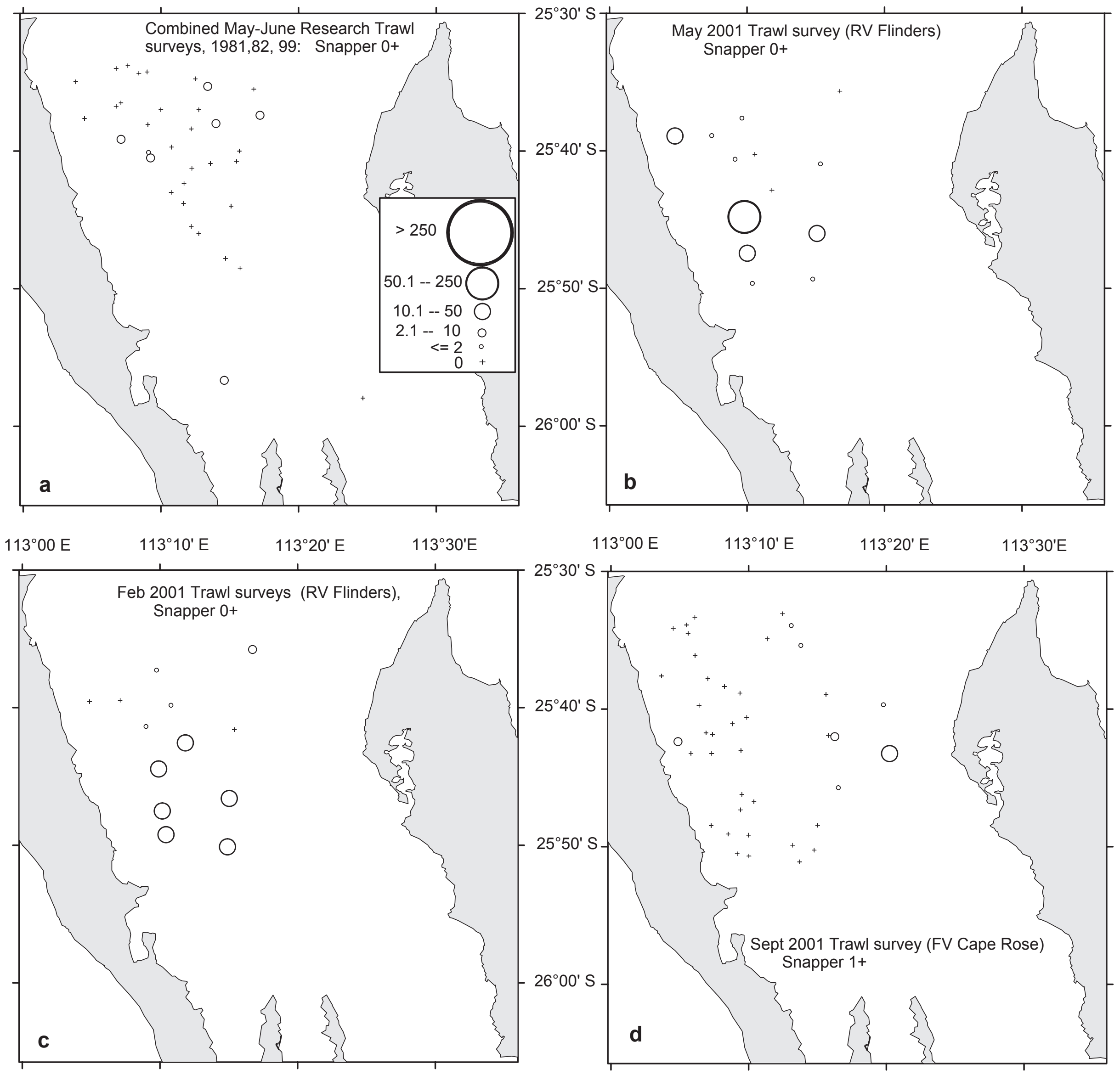


**Figure 15.** Juvenile snapper in research trawl surveys in Denham Sound. Numbers of 0+ snapper per 20-minute shot: a) combined May–June surveys 1981, 1982, 1999; b) May 2001; c) February 2001; d) number of 1+ snapper per 20-minute shot in September 2001.

### 3.2.6.2 Dedicated *snapper surveys*

Mid-year surveys in May–June were carried out in 1981, 1982, 1999 and 2001 (Figure 15). In the first three of these years, few snapper were caught in Denham Sound; most shots caught none, although there were two shots with 2–10 snapper in each year. In contrast, the May 2001 survey caught snapper in ten out of thirteen shots, with three shots of between 10 and 50 and one shot with more than 50 snapper. It appears from this that the 2000 year-class was stronger than usual in Denham Sound as well as in Freycinet. All the snapper on the trawl grounds were the 0+ age-class (approximately 9–12 months old) and thus would be 1+ fish (15–18 months old) in November–December of the same year.

To better understand the information from the earlier surveys, a series of quarterly trawl surveys was planned for Denham Sound and Freycinet Estuary from November 2000 to November 2001, using the same standard set of trawl gear for the whole series. The results for this series (Figure 15) show that the surveys in February 2001, before the prawn trawl fishery opened, and May 2001, caught greater numbers of snapper in Denham Sound than were usual in the May–June and November–December trawl surveys.

An additional survey using a commercial vessel with commercial gear (without a fine-mesh codend cover) was included in early August 2001 at the beginning of the second part of the trawling season. In this survey, five shots caught no snapper, five caught less than 10, two shots caught between 10 and 50 and one shot caught over 250 snapper per 30-minute shot (Figure 16). All the large catches were taken on the edge of the shallow bank near Sandy Point (Figure 1) in areas not covered by the standard research trawl surveys. This indicated a much more uneven distribution of juvenile snapper than was previously apparent and identified an area of habitat where juvenile snapper appear to aggregate.

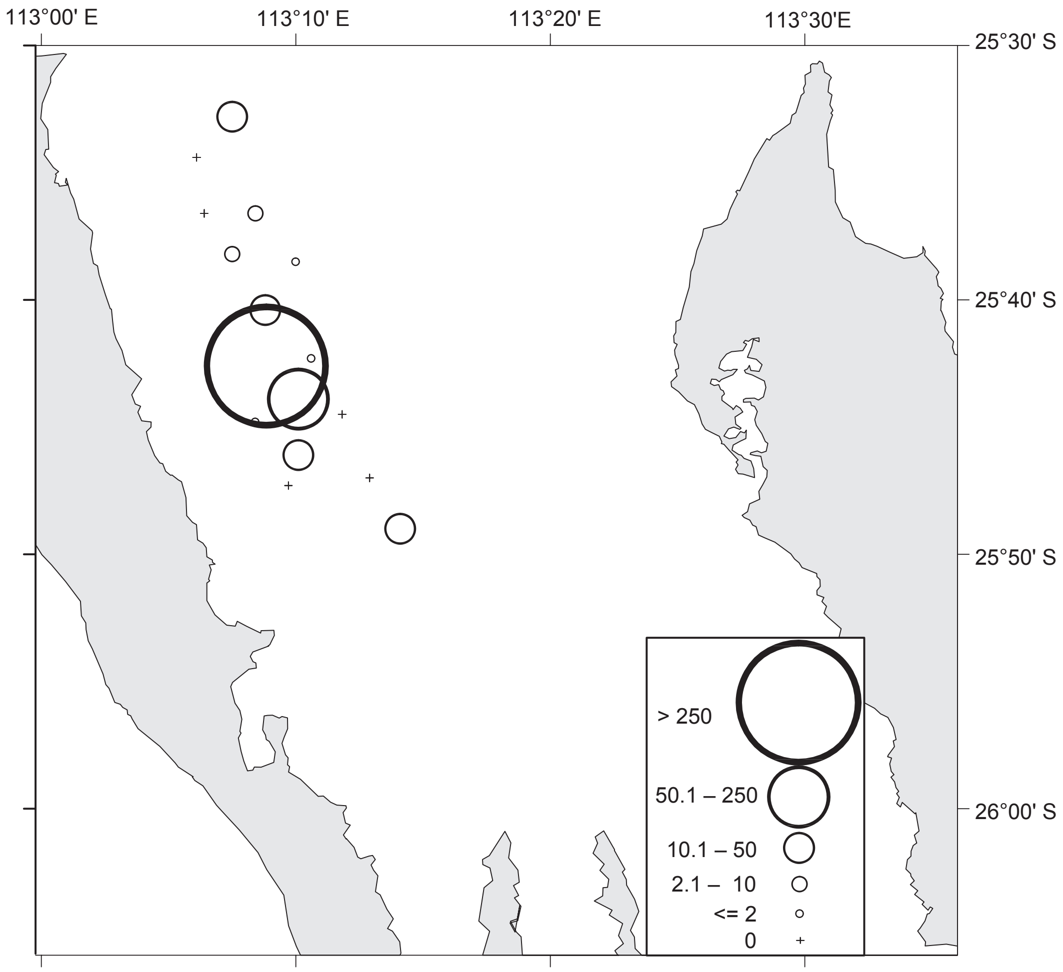


**Figure 16.** August 2001 survey trawling (commercial trawler, 30-minute shots), snapper 1+.

A commercial trawler was again used for the juvenile snapper survey in September 2001 (one of the planned quarterly series) fishing with the research trawl gear. This survey, with 45 shots in Denham Sound, covered a wider area than the other surveys with 12–16 shots, with extra shots targeted on the area around Sandy Point (Figure 15). However, on this occasion, all catches of snapper were zero or very low except for one shot off Cape Lesueur (Figure 1) in a shallow area to the east which is not usually trawled commercially or in the standard trawl surveys.

### 3.2.6.3 Observed commercial trawls

Department of Fisheries observers were present on commercial trawlers in most months of the trawling seasons in 2000–2002 as part of the BRD research project. The data from this source, taken over the whole year, cover a slightly wider area than the scallop and snapper research surveys, and have a greater number of shots (Figure 17). The observed commercial trawls confirm the patchy distribution of juvenile snapper and indicate that the slope of the shallow bank off Sandy Point is an area which produces the most consistent high snapper catches.

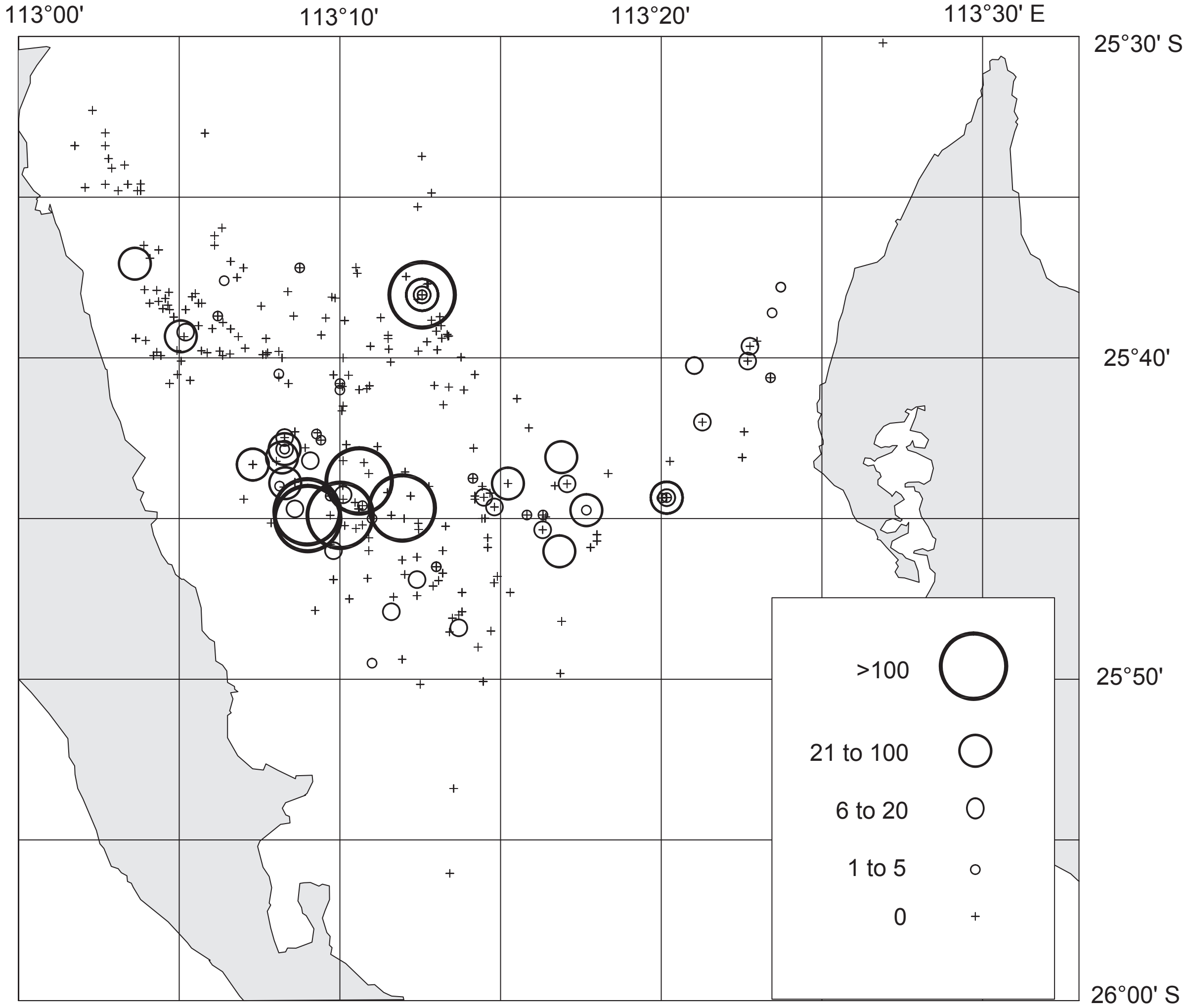


**Figure 17.** The number of snapper per hour caught in commercial trawls observed by Department of Fisheries staff.

### 3.2.6.4 Research trap surveys for juvenile snapper.

Trap surveys for juvenile snapper were initiated as a means of sampling untrawlable areas, in response to the low numbers of snapper in trawl surveys in the eastern gulf of Shark Bay in late 1996 and early 1997. The possibility existed that snapper were more plentiful in untrawlable areas and that trawl surveys would not provide a good index of juvenile abundance. These surveys were conducted in 1998, 1999 and 2000 in the eastern gulf, Denham Sound and Freycinet Estuary.

Juvenile snapper (0+ and 1+) were caught in all three regions, generally in low numbers, i.e. fewer than 5 per trap-hour (Figure 18). In Denham Sound there is an area of deep water corresponding to the centre of the commercial trawl fishery where no snapper were caught in either 1999 or 2000, although 0+ snapper were caught around the edges of this trawled area in depths of 5 to 18 m. In Freycinet and the eastern gulf, where the maximum depths are less than 18 m, 0+ snapper were found throughout waters deeper than 5 m.

In all three areas, 1+ snapper catches were less plentiful in deep waters. As the trap surveys were conducted at a time of year (March–June) when these snapper were almost two years old, these results confirm that snapper migrate out of the deeper basins around this age. The similarity of the pattern of distribution and abundance of 0+ and 1+ snapper in Denham Sound to that in the two untrawled areas (eastern gulf and Freycinet) suggests that the pattern of low abundance in waters deeper than 18 m may not be solely an effect of commercial trawling.

An important result of the trap surveys is that 0+ snapper in Denham Sound are not confined to the sandy and muddy-bottom trawlable area, in contrast to Freycinet and the eastern gulf where they do occur mainly in such areas. This may be due to a greater range of suitable habitat types occurring in Denham Sound. Habitat requirements of juvenile snapper are not well understood but recent research in New Zealand has shown a preference for some stucture in the habitat such as seabed ripples, sponges, etc over plain flat sand (Thrush et al., 2002).

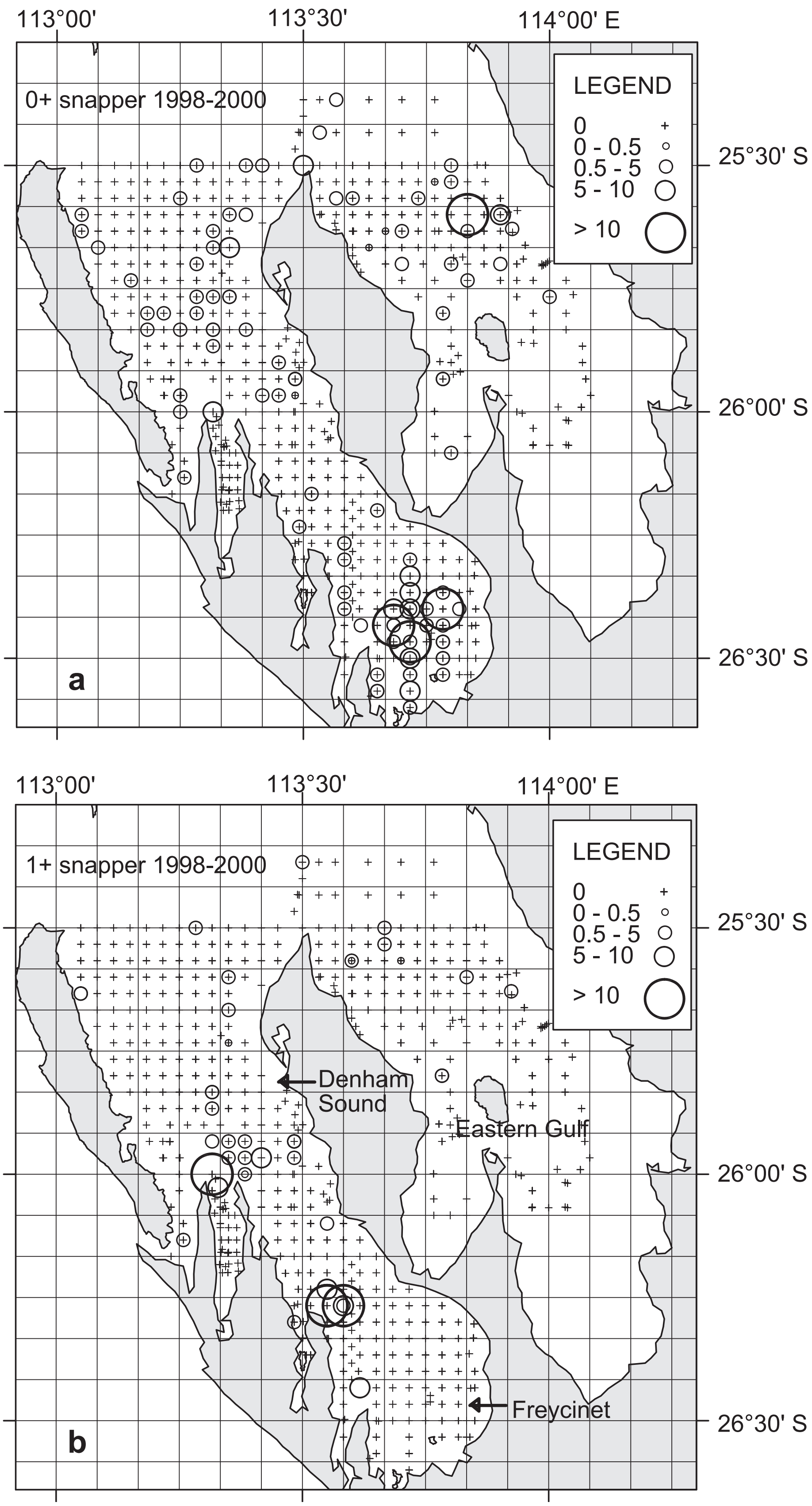


**Figure 18.** a) Trap surveys 1998, 1999, 2000 combined: number of 0+ snapper per trap-hour.
b) Trap surveys 1998, 1999, 2000 combined: number of 1+ snapper per trap-hour.

# 4.0 Interactions between the trawl fishery and juvenile snapper in Denham Sound

## 4.1 Estimating the effect of the current trawl fishery on juvenile snapper abundance

One approach to evaluating the potential effect of the trawl fishery on juvenile snapper, and hence subsequent adult snapper abundance, is based on estimating the abundance of snapper on a fine spatial scale throughout Denham Sound at the beginning of the fishing season, and then estimating fishing mortalities from trawl fishing effort on the same small spatial scale. The number of snapper that survive the fishing season can then be expressed as a proportion of the number there would have been if there had been no trawling. This approach is simplified by our finding that each year-class of snapper is effectively exposed to only one March–November trawling season.

### 4.1.1 Methods

#### 4.1.1.1 Fine-scale patterns of distribution of juvenile snapper and prawn trawling effort

We had three sources of information on the distribution and abundance of snapper (research trawl surveys, snapper catches during commercial trawling and research trap surveys) which together provide an adequate data set for this evaluation. To combine the three sources, however, they must be expressed in common units. Commercial trawl CPUE (number of snapper per hour) was used as the common index of abundance.

#### 4.1.1.2 Trawl CPUE standardisation

Standardising between commercial trawls and research trawls was straightforward because the nets used are similar, except that commercial trawling uses twin 8 fathom nets whereas the research vessel uses twin 6 fathom nets. Research catches per hour were therefore standardised with commercial catches per hour by multiplying by 8/6. There is no necessity to convert this to absolute numbers of snapper per unit area as the purpose is to compare relative survivorships with and without the effect of the trawl fishery.

#### 4.1.1.3 Trap CPUE standardisation

Converting trap catch per hour to trawl catch per hour was more complex. In Freycinet Estuary, each trap survey was preceded by a trawl survey several months earlier. Catches of 0+ snapper in the trawl survey were corrected for the effect of fish size on retention by the trawl net, then adjusted for natural mortality (M=2.58) to estimate what the catch per hour would have been if the trawl survey and trap survey had been carried out at the same time. For each 5-minute latitude and longitude block, the mean trawl catch per hour was divided by the mean trap catch per hour for the same block. The mean of the ratios of research trawl to trap catch rates over all blocks was calculated to be 32.5 and this was used as a conversion factor to enable trap catch rates to be expressed in units of numbers of 0+ snapper per research trawl hour and thence to snapper per commercial trawl hour.

#### 4.1.1.4 Adjusting estimates of abundance for time of year

To evaluate the effect of trawling on snapper, estimates of snapper abundance prior to the start of the trawling season are required. All abundance indices, therefore, were adjusted to estimate what they would have been on 1 March. In areas with no trawling, estimates of the snapper abundance index at one time of year were estimated from data at another time of year by applying the natural mortality rate (M=2.58).

Since in parts of Denham Sound where there is commercial trawling, snapper are subject to fishing mortality as well as natural mortality, snapper abundance data for the later part of the year could be significantly affected by commercial trawling. Ideally, all snapper catch-rate data would be obtained from surveys before the start of the commercial trawling season. However, as there was only one February trawl survey, this would not provide sufficient information to generate a reliable pattern of distribution and abundance at the start of the trawl season. To overcome this limitation of the data, only catch-rate data for February–July, i.e. prior to the onset of intensive trawling effort in August, were used, with corrections for natural mortality, to project back to what the catch rate would have been on 1 March. This standardised data set (Figure 19) was used as the initial abundance index for the fine spatial scale trawl assessment. This procedure gave at least one data point for most of the one-minute blocks in Denham Sound. Estimated abundance indices for the few blocks with no CPUE data were interpolated by averaging the adjacent blocks for which there were data (Figure 20a). For example, for the centre block in the diagram below, there are seven adjacent blocks with data so (1+5+0+2+1+2+0) / 7 = 1.57 is the interpolated value used for that block.

| | | |
|---|---|---|
| 1 | 5 | |
| 0 | | 2 |
| 1 | 2 | 0 |

#### 4.1.1.5 Fine-scale trawl fishing effort and calculation of fishing mortality

The annual trawl fishing effort on the same spatial scale was calculated from latitude and longitude of the starting points of trawl shots and duration of shots from the skippers' logs, averaged over four years (Figure 20b). Trawl logbook coverage is 100% in this fishery.

The trawl fishing mortality on juvenile snapper in each block was estimated from the hours of trawl fishing effort in each block and the catchability coefficient for 10–15 cm snapper derived from the depletion experiment. The proportion surviving in each block was then estimated from the fishing mortality and multiplied by the initial abundance index in the block to give a final abundance index. The resulting final abundance indices were summed over all blocks to give an overall final abundance index. The ratio of the final abundance index to initial index was the estimated number of snapper surviving the trawl fishing season as a proportion of the number there would be if there was no trawl fishery.

### 4.1.2 Results

The combined juvenile snapper abundance index data for the one-minute blocks are shown in Figure 19. Figure 20a shows the spatial pattern of abundance generated from these data but also including an interpolated abundance index for those blocks for which there were no catch-rate data.

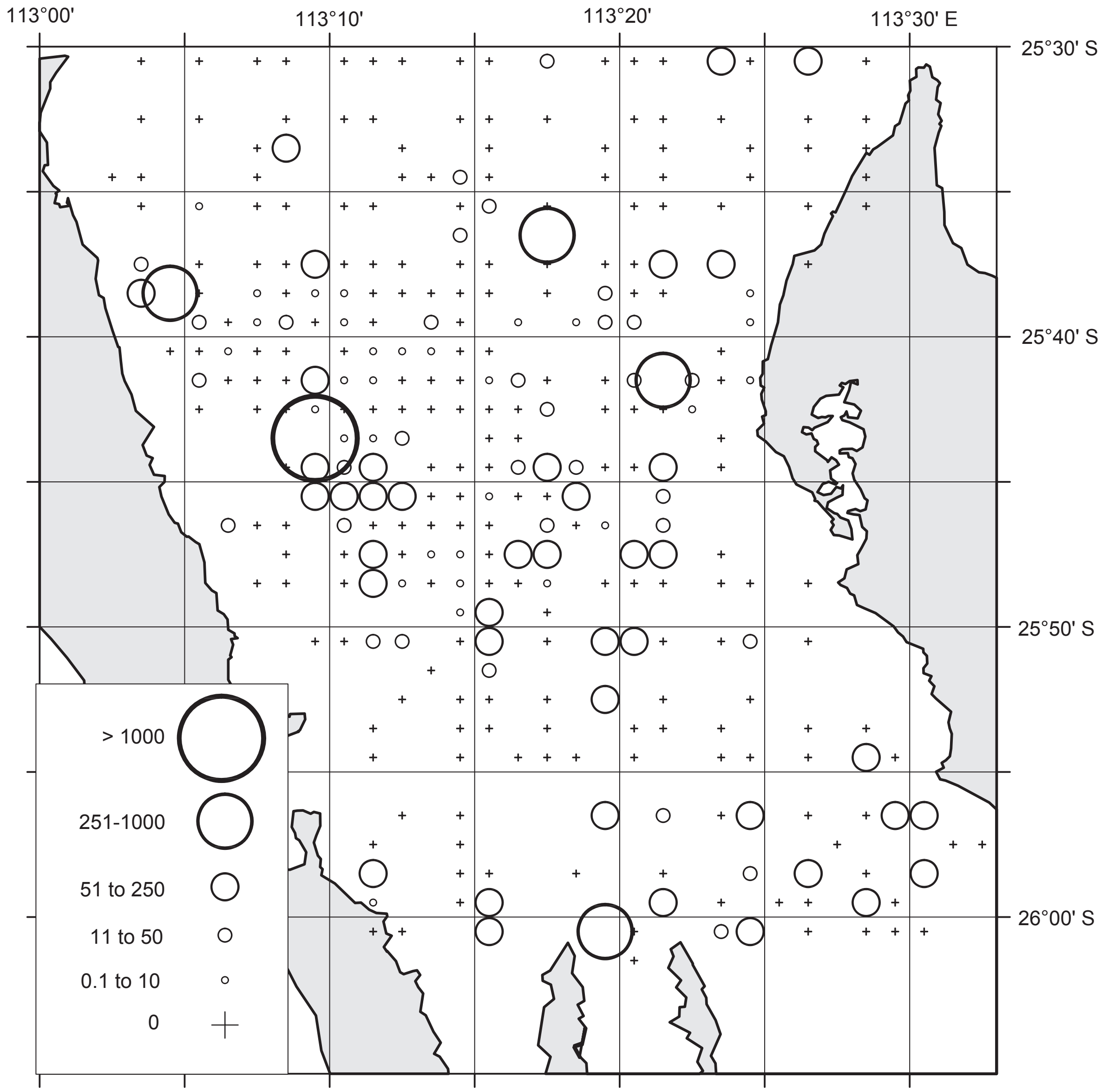


**Figure 19.** Estimated abundance of snapper, expressed as mean number per commercial trawl hour on a one-minute grid, estimated at 1 March by adjusting for natural mortality between 1 March and date of sample. Data are from research trap and trawl surveys and observed commercial trawls.

The four-year average trawling effort distribution pattern by one-minute blocks is shown in Figure 20b. After applying fishing mortality rates in each block calculated from the fishing effort, the abundances of the surviving juvenile snapper in each block were summed to give an overall snapper abundance index. For the whole of Denham Sound, the ratio of the overall snapper abundance index after applying the trawl fishing mortality to that before applying the mortality was calculated to be 0.75, i.e. we estimated that the effect of the trawl fishery was to reduce the number of juvenile snapper in Denham Sound at the end of the year by 25%.

In simple terms, around 60% of the juvenile snapper in Denham Sound occur in the area which is not subject to trawling, and around 60% of those in the trawled area that do not die due to natural predation survive the trawling season, then migrate to non-trawled areas.

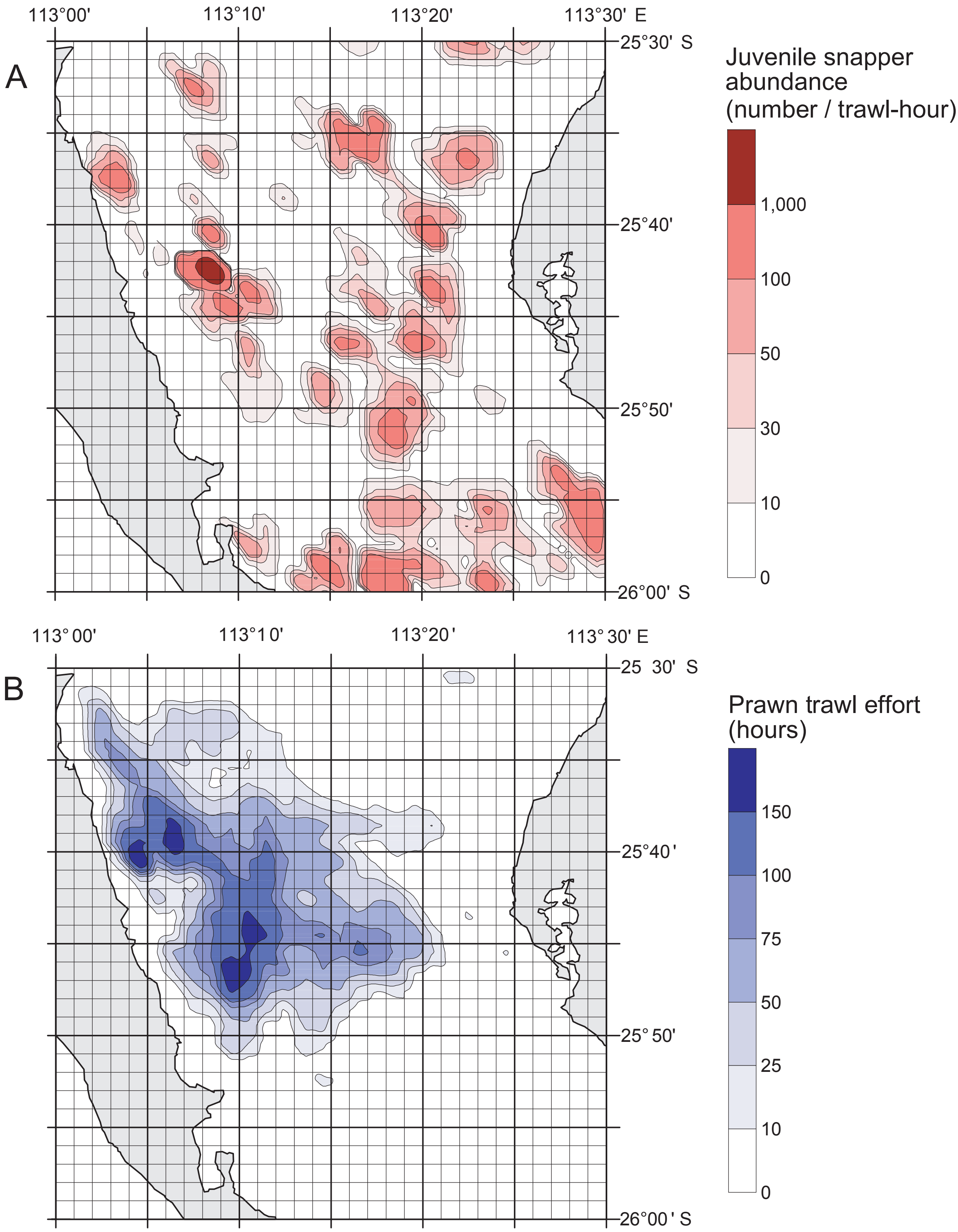


**Figure 20.** (A) Distribution and abundance of 0+ juvenile snapper in Denham Sound, interpolated from combined trap and trawl survey data and observed commercial trawls, at 1 March. (B) Prawn trawl fishing effort in Denham Sound, average of four years, 1998–2001.

## 4.2 A yield-per-recruit method for estimating the effect of the trawl fishery and of discards from recreational fishers on stocks and yield to the snapper fishery

Yield-per-recruit is a technique for tracking growth and mortality of young fish as they age and enter the exploited fishery and can enable calculation of numbers and weight of fish surviving to each age as well as catch (yield). This method as used here estimated the number of juvenile snapper caught by the trawl fishery and calculates what weight of snapper this would become at the time of entering the snapper fishery when those fish reach minimum legal size, using known parameters (growth curve, length–weight relationship, 0+ and 1+ natural mortality rate) and making some assumptions of values of unknown parameters (fishing mortality rate (F) and natural mortality rates (M) of older age-classes). The yield to the snapper fishery that would be caught in the absence of fishing on juveniles can also be calculated, making an assumption that the fishing mortality rate in the snapper fishery would be kept to a sustainable level (F=M).

A similar calculation can be done on the numbers of undersized snapper returned to the water by the recreational fishery. A creel survey in 2001–2002 estimated the number of undersized snapper returned in the year in Denham Sound to be 70,000 (N. Sumner, pers. comm.). Recent research (St John & Moran, in prep.) has estimated the mortality rate of snapper caught in shallow water and returned after capture at 5%. The loss of potential yield due to this recreational mortality on sub-adults was estimated for comparison with the loss due to trawling.

### 4.2.1 Methods

The yield-per-recruit calculations use a growth equation (G. Jackson, unpubl. data) and length–weight relationship (Moran & Burton, 1990) for snapper in this region from previous and current snapper research projects. The instantaneous natural mortality rate (M) value of 2.58 per year for the for 1+ snapper is from the work in this report (Section 3). The sensitivity of the results to the value assumed for adult (> 5+) snapper natural mortality rate was tested by using values of 0.1 and 0.15 per year (Jackson & Stephenson, 2002). Although it can be assumed that the natural mortality rate for 2+, 3+ and 4+ snapper is less than that for 0+ and 1+ juveniles and greater than that for adults, there is no equivalent information on how quickly natural mortality declines to adult levels.

Because of the uncertainty around natural mortality levels, four scenarios were evaluated, i.e. with adult natural mortality set at 0.1 and 0.15, and natural mortality of 2+ juveniles set at 1.0 and 0.5. The natural mortality rate of 1+ juveniles was kept at 2.58 and that of 3+ fish at 0.2 for all scenarios. The number of snapper at around one year of age caught by the trawl fishery in Denham Sound in a year was estimated at 81,000 from observer data on average number of snapper caught per hour and the average annual trawl effort, in hours, over the four years to 2001. Fishing mortality, F, on adult snapper from age 6 was set equal to natural mortality, M, since the target catch has been set by management for sustainability and F should not exceed M in a sustainable fishery. Fishing mortality on the 5+ snapper was set at 0.65 x M as they are not fully recruited to the fishery, i.e. only 65% of 5+ fish are above legal minimum size.

The calculation for undersized fish returned to the water by the recreational fishery used the above method with the assumption that 5% of the 70,000 returns died, and that equal numbers of 3+ and 4+ snapper died (1750 fish of each age). The same M values were used as above and F was set equal to M.

### 4.2.2 Results

The results of the calculations for the trawl-caught juvenile snapper are shown in Table 3 and indicate the sensitivity of the estimates to the values used for adult and sub-adult natural mortality rates. There is a 2.5–4.2 tonne estimated reduction in yield of adult snapper in Denham Sound due to the trawl catch of juvenile snapper. The sensitivity of these results to the values assumed for mortality rates is apparent and the results should be taken only as indicative of the order of magnitude of the foregone yield.

**Table 3.** Estimates of the reduction in recruitment to the adult stock and reduction in yield to the fishery on adult snapper in Denham Sound, as a result of capture of 81,000 one-year-old juveniles by the trawl fishery, showing the variability due to assumed values of natural mortality rate (M).

| 2+ M | Adult M | Reduction in recruitment (tonnes) | Reduction in yield (tonnes) |
|---|---|---|---|
| 1 | 0.1 | 2.7 | 2.6 |
| 0.5 | 0.1 | 4.5 | 4.2 |
| 1 | 0.15 | 2.6 | 2.5 |
| 0.5 | 0.15 | 4.3 | 4.0 |

Using the same method as used above for the effect of trawling, the loss in yield due to mortality of returned undersized snapper by the recreational fishery was estimated to be 3.8 and 4.4 tonnes for assumed natural mortality values of 0.15 and 0.1 respectively. While this is the same order of magnitude as the estimated loss due to trawling, it must be remembered that the ages of the returned snapper are assumed because there are no data on their actual ages. If the returned snapper really consisted of a substantial number of 2+ fish, for example, the estimated loss in yield would be lower.

That 3500 sub-adult fish result in a yield to the fishery of a similar order of magnitude to 81,000 one-year-olds can be understood when it is realised that 81,000 one-year-old snapper, subject to the values of natural mortality used here, would have declined in number to 2,000–4,000 fish by the time they reach three years of age.

# 5.0 Evaluation of alternative management scenarios

## 5.1 Effects of alternative trawl fishery boundaries on juvenile snapper survival and prawn trawl effort distribution

Using the method of estimating the effect of the trawl fishery on juvenile snapper from spatial patterns of trawling effort and snapper abundance, the effects on snapper of a number of alternative trawl fishery boundaries could also be evaluated. Community representatives have suggested a change in the southern boundary of the trawl fishery such that the 'Torbay Line' (Figure 3) would be the boundary all year, not just in March–April. To provide a starting point for discussions regarding the trawl–snapper interactions, the 'Torbay Line' and a number of other possible boundary lines were therefore evaluated. The potential boundaries to be evaluated were selected for likely increased survival of snapper and minimal detriment to the profitability of the trawl fishery.

A number of types of bycatch reduction devices (BRDs) are under trial in the fishery, to enhance escape of small fish from the nets. Such devices frequently achieve a reduction in catch of around 30% in a shot for snapper and most other species, though better results may be possible with modified designs (Moran, unpubl. data; Broadhurst et al., 2002). The additional benefit to snapper of using BRDs together with the potential boundary changes were also evaluated.

### 5.1.1 Methods

The described procedure of estimating survivorship of juvenile snapper was repeated for a number of alternative closure lines to evaluate the effect on the survival of the juvenile snapper. This was achieved by modification of the original trawl effort data as follows: trawl effort was assumed to be zero in all blocks outside the new boundary and effort was multiplied by 1/p for all blocks inside the boundary, where p is the average proportion of the original fishing effort which was inside the new boundary. That is, this approach assumed that all effort displaced from outside the boundary will be expended inside the boundary in Denham Sound.

For each of the potential new boundaries evaluated, the additional effect of implementation of bycatch reduction devices was also calculated by multiplying the fishing mortality rate in each block by 0.7 to apply a 30% reduction in snapper catch per shot.

### 5.1.2 Results

Five potential boundary lines were evaluated in this manner including the 'Torbay Line' and a boundary that approximately follows a line separating areas with large and small prawns (Figure 25). These lines are illustrated in figures as follows: Lines 1–4 (Figures 21–24) and Line 5 (Figure 26). For each boundary, the estimated number of snapper surviving the trawling season, expressed as a proportion of the number there would be in the absence of trawling, is presented in Table 4. The proportion if BRDs are used is shown for comparison. Table 4 also shows the proportion of the 0+ snapper population in Denham Sound that is outside each boundary and the proportion of the current trawl effort that is inside each boundary.

**Table 4.** Comparison of various possible boundary options for the Shark Bay prawn fishery in Denham Sound.

| Boundary option | Proportion of snapper outside the trawl area | Proportion of current trawl effort inside the area | Surviving snapper as a proportion of survivors if there was no trawling* | Survivors if BRD reduces snapper/ shot by 30% |
|---|---|---|---|---|
| Current trawled area | 0.40 | 1 | 0.75 | 0.80 |
| Line1 | 0.90 | 0.66 | 0.95 | 0.96 |
| Line2 | 0.86 | 0.81 | 0.92 | 0.93 |
| Line3 | 0.86 | 0.49 | 0.96 | 0.96 |
| Line4 (Torbay Line) | 0.43 | 0.73 | 0.76 | 0.80 |
| Line 5 (Small prawn line) | 0.85 | 0.64 | 0.94 | 0.95 |

* Assumes the same distribution of effort within the boundary as there is currently and that all the effort previously outside the boundary would be deployed inside the boundary rather than in a different part of the fishery, e.g. off Carnarvon.

One finding from this evaluation is that the ‘Torbay Line’ (Line 4) is of no great benefit to the protection of juvenile snapper, giving 76% survival of Denham Sound juvenile snapper compared with 75% from the current fishery boundary. Lines 1 and 3 both give substantial increases in survival of snapper (95% and 96%) but Line 1 causes less displacement of trawling effort with 66% of the current effort inside the boundary compared with 49% for Line 3. Line 2 gave snapper survival of 92% and caused least displacement of effort with 81% of the existing trawl effort inside the new boundary.

Line 5, based on the distributions of large and small prawns, gave snapper survival of 94% and had 64% of the existing trawl effort within its boundary.

The relatively small improvements in snapper survival attributable to a BRD reducing catch per shot by 30% show that although the catch in a single shot may be reduced by 30%, the reduction of the whole season’s catch is less than 30% as fish that escape from one shot have a chance of being caught in subsequent shots in that area. If the boundary to the fishery remains unchanged, such BRDs were estimated to result in juvenile snapper survival of 80% compared to the current 75%.

The reduction in prawn catch, and particularly the value of that catch, as a result of any boundary change is, however, much less than the percentage of trawling effort displaced. Firstly, the effort displaced from closed areas will be utilised somewhere in the trawl fishery, increasing the exploitation rate and catches of prawns in the areas open to trawling. Secondly, the movement of prawns to the north-west (Penn 1988) allows for the protected prawns to be caught later in the season as they migrate into open areas. In this case the actual number of prawns caught will decrease due to natural mortality occurring before they migrate across the boundary into open areas, however this is offset by growth in weight and higher values of larger prawns. As a result of interactions of the re-configured effort with the spatial and temporal occurrence of larger prawns, the value of the catch with the potential boundary changes is likely to be similar to the current value.

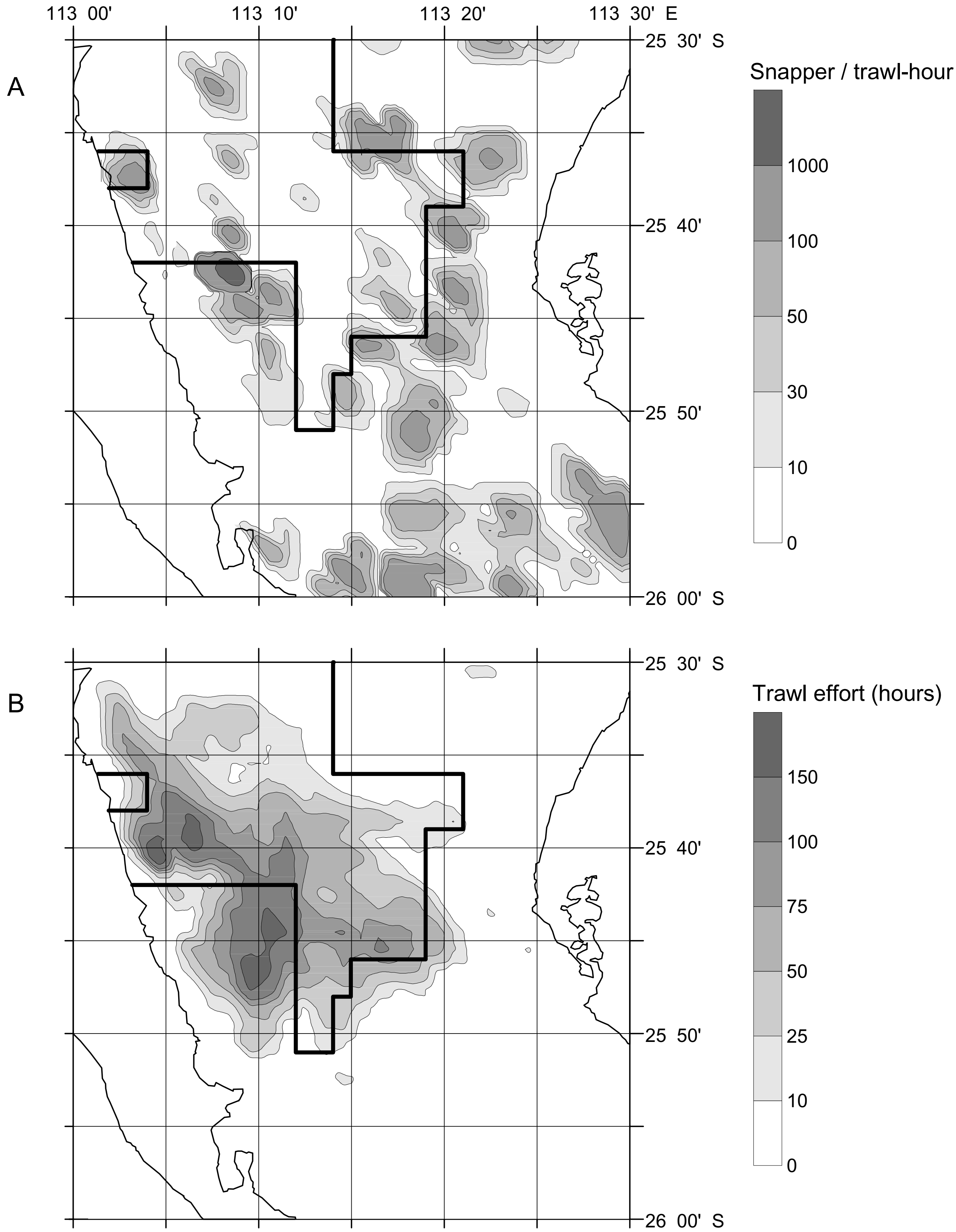


**Figure 21.** Evaluation of a potential new boundary for trawl fishing in Denham Sound (Line 1) in relation to (A) the distribution and abundance of snapper, and (B) prawn trawl effort.

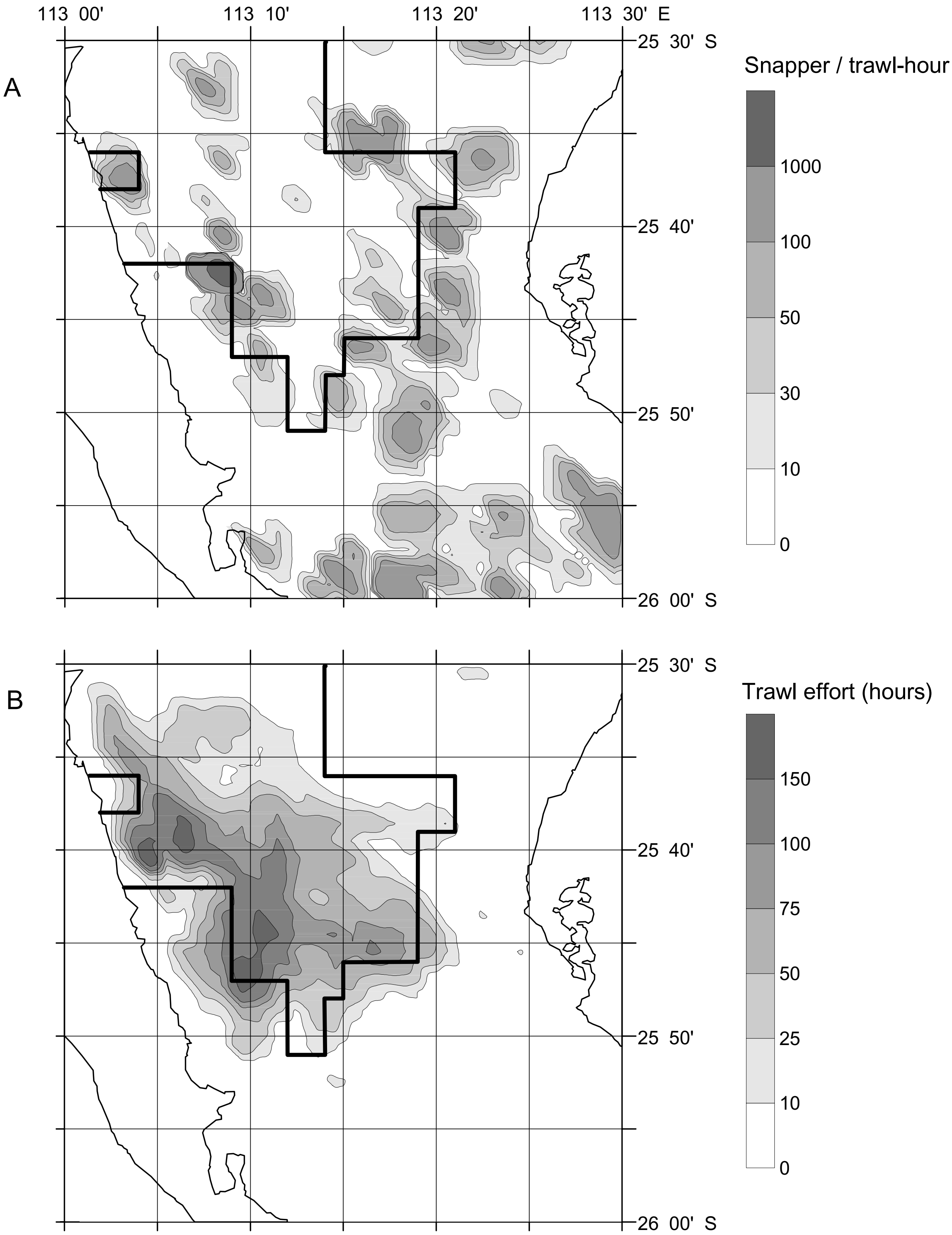


**Figure 22.** Evaluation of a potential new boundary for trawl fishing in Denham Sound (Line 2) in relation to (A) the distribution and abundance of snapper, and (B) prawn trawl effort.

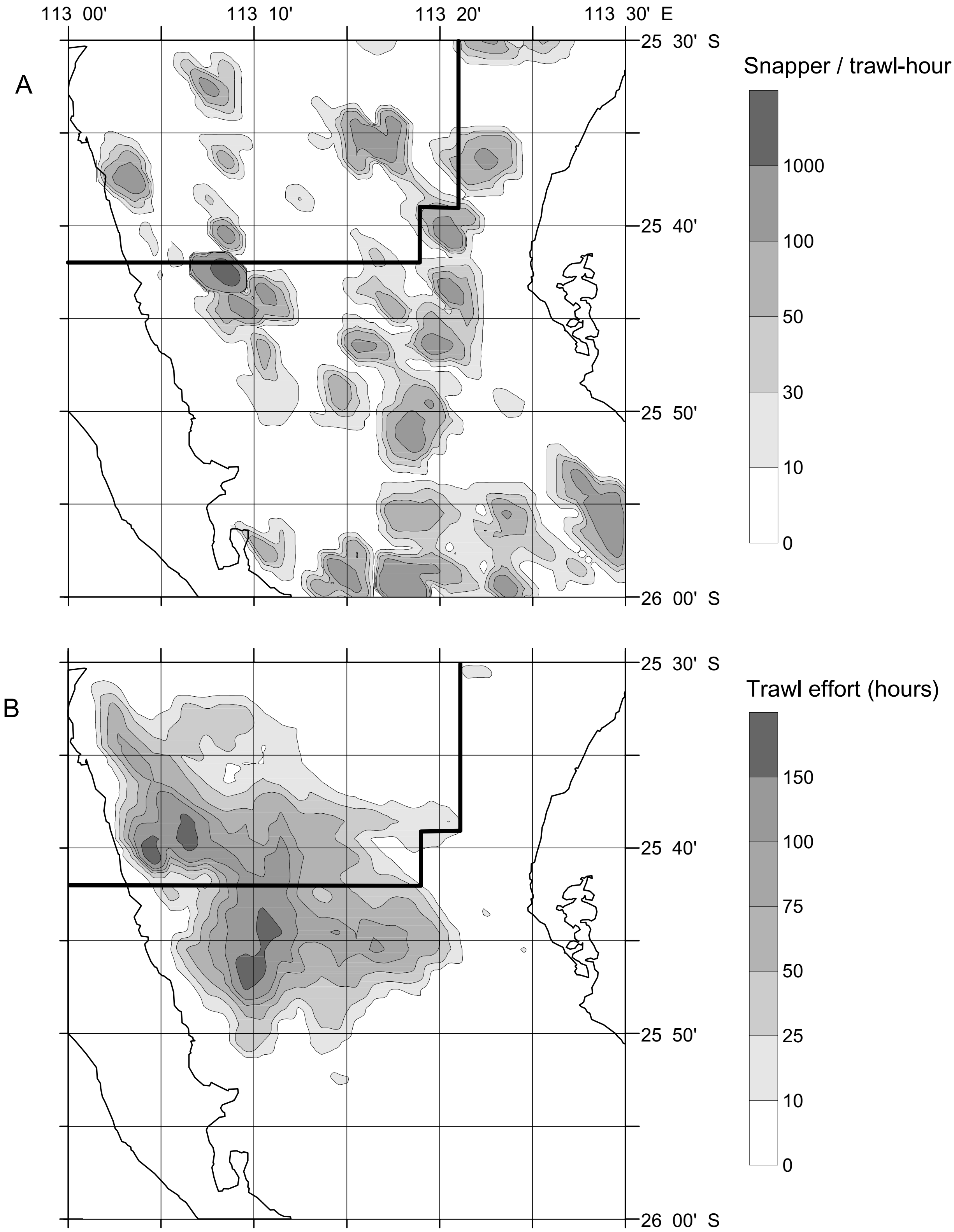


**Figure 23.** Evaluation of a potential new boundary for trawl fishing in Denham Sound (Line 3) in relation to (A) the distribution and abundance of snapper, and (B) prawn trawl effort.

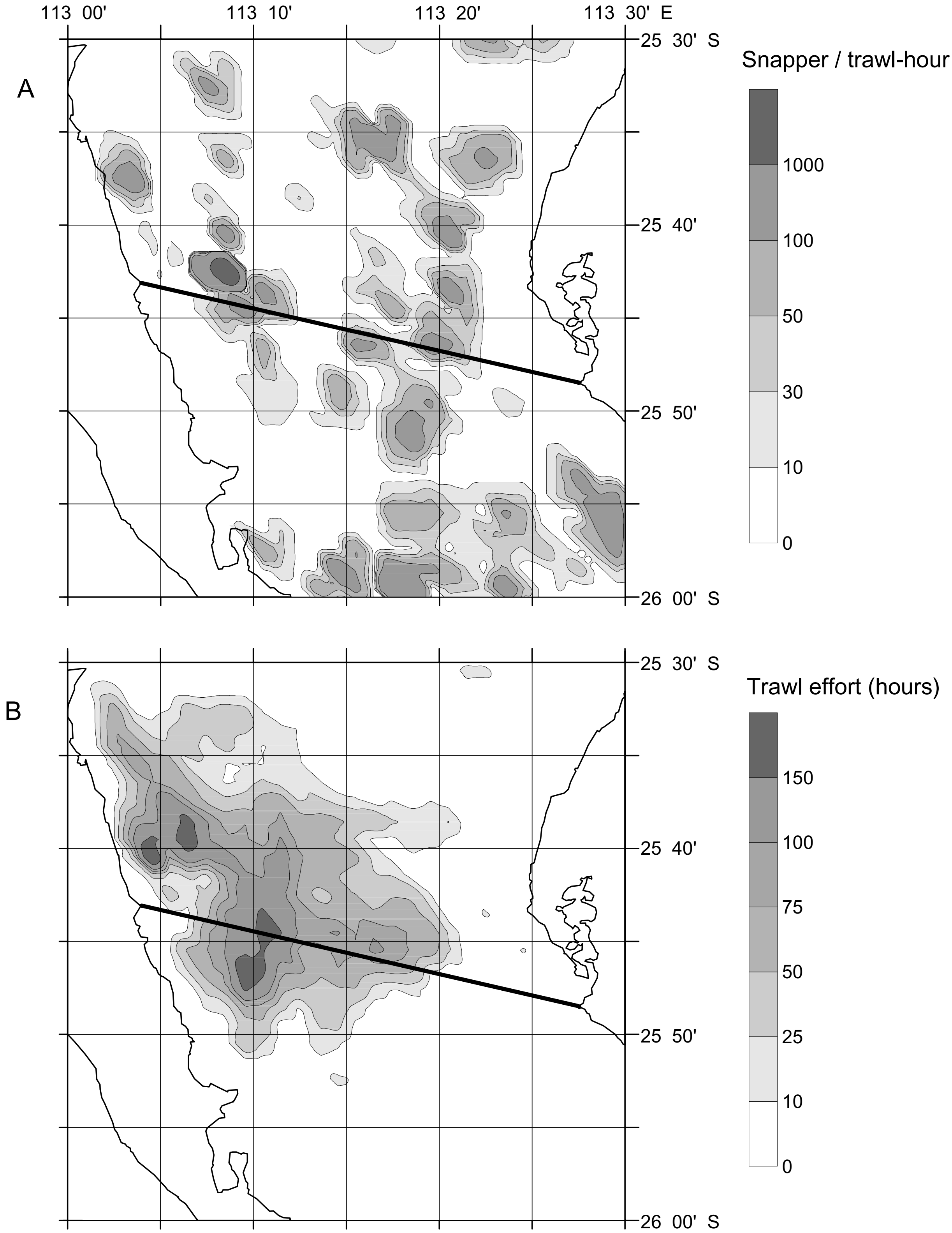


**Figure 24.** Evaluation of a potential new boundary for trawl fishing in Denham Sound (Line 4, the Torbay Line) in relation to (A) the distribution and abundance of snapper, and (B) prawn trawl effort.

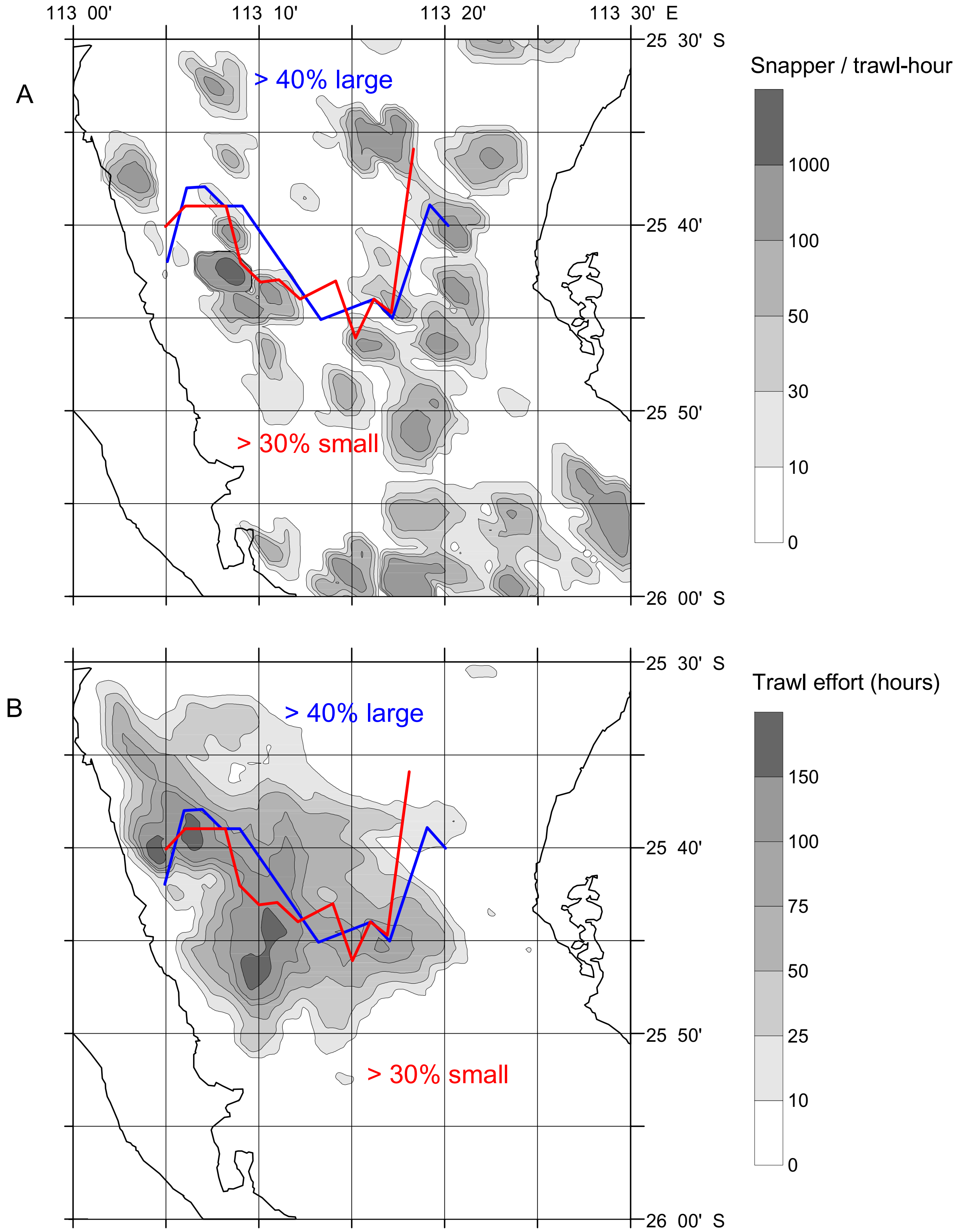


**Figure 25.** Indication of locations of large and small prawns in August–October (red and blue) in Denham Sound in relation to (A) the distribution and abundance of snapper, and (B) prawn trawl effort.

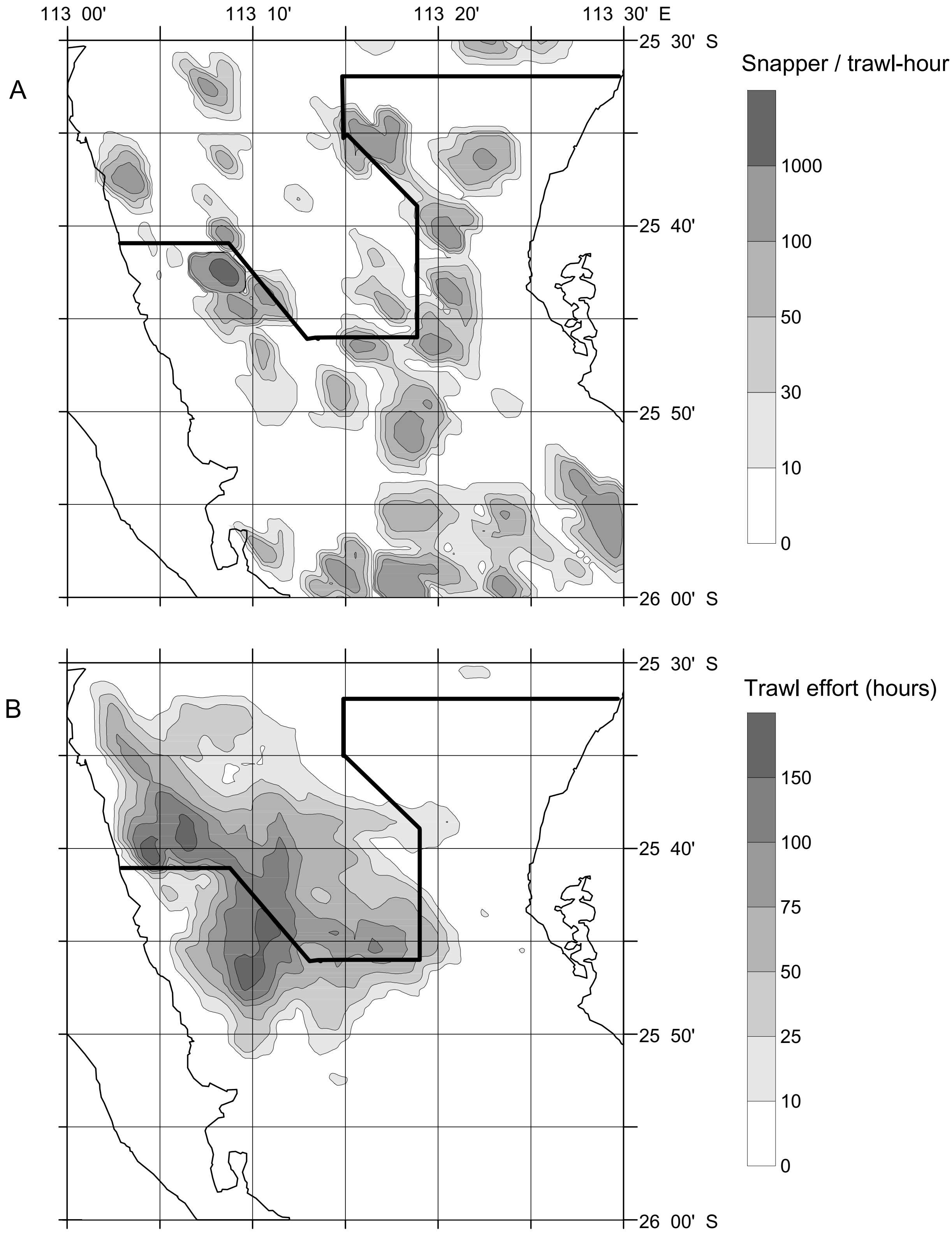


**Figure 26.** Evaluation of a potential new boundary for trawl fishing in Denham Sound (Line 5) in relation to (A) the distribution and abundance of snapper, and (B) prawn trawl effort.

# 6.0 Discussion

While the Department of Fisheries has counted and measured juvenile snapper in many trawl surveys and observed commercial trawls in Shark Bay since the 1980s, this information alone was insufficient for an assessment of the extent to which snapper in Denham Sound are affected by the trawl fishery.

These historical snapper trawl data were combined with more recent information from a series of dedicated snapper trawl surveys and experiments in 2000–2001, and trapping surveys in 1998–2000. The trap surveys estimated juvenile snapper abundance both in areas which are trawled and those which are not trawled (outside commercial fishery boundaries or in untrawlable habitat). The experiments estimated the vulnerability of snapper of various sizes to capture by trawl and, together with results of quarterly trawl surveys from November 2000 to December 2001, enabled calculation of natural mortality rates, growth, and duration of the life-stage vulnerable to trawling. Snapper living on the commercial trawl grounds in Denham Sound are approximately 6–18 months old, this makes them around 9–17 months old and mostly in the 10–15 cm size range during the months of the trawling season (March–November). Average exponential natural mortality rate of snapper in this age-range was estimated as 2.58 per year, which equates to 92% of snapper dying per year. The experiments also enabled calculation of the mortality rate of snapper per hour of commercial trawling.

To match information from fishers' log books on the trawl fishing effort in each one-minute latitude and longitude block, a pattern of distribution and abundance of juvenile snapper in Denham Sound at the beginning of the trawling season was derived by combining the results of the trap surveys, research trawl surveys and observed commercial trawls. By calculating fishing mortality in each one-minute block from the trawl fishing effort data, the proportion of juvenile snapper in Denham Sound which survive the trawling season could be estimated. On this basis, the number of 1+ snapper in Denham Sound at the end of the season was estimated to be 75% of what there would be if there were no trawling; that is, taking into account a natural mortality rate of 92% per year, trawling is reducing the overall survival rate from 8% to 6% per year.

Community representatives have argued the case for changes to the southern boundary of the trawl fishery to enhance the survival of juvenile snapper in Denham Sound. A number of options for a new trawl fishery boundary were assessed, and the survival of juvenile snapper under each scenario was estimated. Several scenarios resulted in estimates of snapper abundance over 90% of what there would be in the absence of a trawl fishery. Of these, the scenario which caused least displacement of trawling effort (Line 2) resulted in abundance of snapper at 92% of that in the absence of the fishery and displaced 19% of the trawling effort.

Since much of the trawling in the southern part of the Denham Sound trawl fishery, in areas of high juvenile snapper abundance, is on small prawns which are expected migrate to within the open area defined by the new boundary as they grow, lost catches of small prawns would be replaced by catches of larger prawns which would be lower in terms of weight than the lost catch, but approximately equal in value as large prawns attract a higher price. The scenario with a boundary line separating the areas with large and small prawns (Line 5) performed slightly better than the Line 2 scenario in terms of snapper survival (94%).

An alternative method of assessing the effect of the trawl fishery is to calculate the weight of adult snapper that would result from the young snapper in the trawl bycatch had they not been caught, based on a yield-per-recruit analysis. On these calculations, the trawl fishery was estimated to result in a loss of yield to the snapper fishery of 2.5–4.2 tonnes per year, however this estimate is very sensitive to the values assumed for the natural mortality rate. The total allowable catch for the snapper fishery in Denham Sound during the current stock-rebuilding phase has been set at 10 tonnes for 2003 but could possibly be in the region of 20 tonnes when the stock is fully recovered.

Mortality of undersized snapper caught by recreational fishers and returned to the water was estimated to result in a loss of yield and biomass of adult snapper similar to that caused by prawn trawling. Much of the mortality of returned undersized fish is due to hooking in the gut and gills. Some modified hooks have been found to reduce gut-hooking in New Zealand snapper (K. Sullivan, NZ Ministry of Fisheries, pers. comm.). While exploring ways of minimising this mortality is beyond the scope of the present study, further research into hook types aimed at reducing catches of undersized snapper or reducing fatal injuries appears to be warranted.

## Acknowledgements

We wish to thank skipper Theo Berden and crew of the Fisheries Research Vessels *Flinders* and *Naturaliste* for their assistance with much of the work in this bulletin, also the technical officers in the trawl and snapper sections of the Fisheries Research Division.

Neil Sumner and his team in the recreational fishing section provided information on catches of undersized snapper. The trawler fishermen of Shark Bay provided invaluable information through their log books, and in accommodating observers on their vessels and operating their trawlers for some of the surveys. Tony Fowler, Brent Wise, Lindsay Joll, Gary Jackson and Jim Penn improved the manuscript with their comments.

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# APPENDIX A

## Summarised history of the management of the Shark Bay prawn trawl fishery since 1990

### 1990

| | |
|---|---|
| 11 April | Prawn fishery open north of the Carnarvon line |
| 18 April | All areas open except permanent nursery areas open |
| 27 April | Part of the ENA closed due to small prawns caught |
| 15 May | All of ENA open |
| 1 August | ENA closed |
| 2 November | Season closed |

- Buy-back implemented - the prawn trawl fleet was reduced by 8 vessels ( from 35 to 27 vessels).

### 1991

| | |
|---|---|
| 7 March | Prawn fishery open (ENA and Carnarvon) |
| 20 April | Scallop season open |
| 6 May | Carnarvon/Peron line open |
| 5 June | ENA open |
| 1 August | ENA closed |
| 23 October | Season closed |

- The Carnarvon line was modified this year. The new line introduced from Peron Point (25°30.2' S, 113°30.6' E) bearing 345° to intersect a line due west from Carnarvon 25°52.75' S 113°19.4' E then due east to the mainland (Carnarvon/Peron line).
- Moon closure implemented.
- Prawn trawler crews were limited to 6 (maximum) for the 1991 season.
- Scallop vessel crew limited to 14 (maximum). Prior to 1991 there were no crew limits for scallop or prawn vessels.
- Full moon 3 day closure implemented for the prawn fleet.

### 1992

| | |
|---|---|
| 10 March | Prawn season open. Fishing north and west of a line 345° from Cape Peron to the intersection of a line due west from Carnarvon (Carnarvon /Peron line) |
| l7 March | Scallop season commenced |
| 25 April | Carnarvon/Peron line open |
| 25 May | ENA open (down to the 9 n mile arc only) |
| 1 August | ENA closed |
| 22 October | Season closed |

- The Dorre Island Recreational Zone - commercial fishing closure was implemented.

### 1993

| | |
|---|---|
| 13 March | Opening of season. Fishing outside the line 345° from Cape Peron to the intersection with the Carnarvon line. 25°30.2' S 113°30.6' E to 24°52.75' S, 113°19.4' E then due east to the mainland |

| | |
|---|---|
| 7 April | First moon closure extended to 12 April, rest of the moon closures were three days as was previously implemented |
| 13 April | Carnarvon/Peron line open to the extended nursery area |
| 17 May | Extended nursery area open |
| 15 May | at 0800 to 1 August at 1700 - closure of Denham Sound |
| 1 August | ENA closed |
| 29 October | Season closed |

**1994**

| | |
|---|---|
| 5 March | Season open |
| 11 April | Carnarvon/Peron line opened, allowing fishing down to the 9 mile arc |
| 3 May | Scallop season opened |
| 10 May | The opening of the southern ENA |
| 15 May to 1Aug | Denham Sound closed to fishing |
| 1 August | Extended nursery area closed |
| 11 November | Season closed |

**1995**

| | |
|---|---|
| 7 March | Season open |
| 21 April | Carnarvon/Peron line and extended nursery line open |
| 1 May | Denham Sound closed |
| 10 May | Scallop season open |
| 1 Aug | Denham Sound closed |
| 6 Nov | Season end |

**1996**

| | |
|---|---|
| 12 March | Season commenced |
| 12 April | Carnarvon Line and ENA open |
| 1 May | Denham Sound area opened |
| 9 May | Scallop season open |
| 15 July | Introduction of tiger spawning area closure |
| 28 Oct | Tiger spawning area re-opened |
| 18 November | Season closed |

**1997**

| | |
|---|---|
| 12 March | Season commenced. Fishing north and west of Carnarvon line |
| 17 April | Scallop season commenced |
| 28 April | Carnarvon Line and ENA open |
| 1 May | Denham Sound closed |
| 19 July | Tiger prawn area closed |
| 9 October | Tiger prawn closed area re-opened |
| 13 November | 0800hrs season closed |

**1998**

| | |
|---|---|
| 17 March | Season commenced. Fishing north and west of Carnarvon/Peron line |
| 17 March | Introduction of the Torbay line closure area |
| 16 May | Scallop season commenced |
| 16 April | Carnarvon Line and ENA open |
| 1 May | Denham Sound closed |
| 12 July | Tiger Prawn area closed |
| 1 August | Denham Sound and Torbay Line closure area re-open |
| 8 October | Tiger prawn closured area re-opened |
| 3 November | 0800hrs season closed |

**1999**

| | |
|---|---|
| 10 March | Season commenced. Fishing north and west of Carnarvon Line |
| 10 March | Torbay line closure area closed |
| 5 May | Scallop season commenced |
| 16 April | Carnarvon Line and ENA open |
| 16 April | Denham Sound closed |
| 1 July | Tiger Prawn area closed |
| 26 July | ENA closed |
| 31 July | Denham Sound and Torbay Line closure area reopen |
| 5 October | Tiger prawn closed area re-opened |
| 25 October | 0800hrs season closed for scallop and prawn |

- 24 hr trawling not undertaken this season
- 3 day moon periods March April May June
- 5 day moon periods 26 to 30 July, 25 to 29 August, 23 to 27 September

**2000**

| | |
|---|---|
| 13 March | Season commenced. Fishing north and west of Carnarvon line |
| 13 March | Torbay line closure area closed |
| 18-22 March | March moon closure |
| 3 March | Scallop season commenced |
| 27 April | Carnarvon Line and ENA open |
| 18 April | Denham Sound closed |
| 20 July | Tiger Spawning Area closed |
| 1 August | ENA closed |
| 1 August | Denham Sound and Torbay Line closure area reopen |
| | Tiger Spawning Area to remain closed |
| 4 November | 0800hrs season closed for scallop and prawn |

- 24 hr trawling not undertaken this season
- 9 mile arc modified to a straight line and southern ENA boundary raised 1.4 nm
- VMS mandatory for prawn and scallop fleet 3 May
- 3 day moon closures - April, May, June
- 5 day moon periods 26 to 30 July, 25 to 29 August, 23 to 27 September