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Distribution and abundance of juvenile pink snapper, *Pagrus auratus*, in the gulfs of Shark Bay, Western Australia, from trap surveys

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Government of Western Australia

Fish for the future

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Distribution and abundance of juvenile pink snapper, *Pagrus auratus*, in the gulfs of Shark Bay, Western Australia, from trap surveys

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Abstract

Trap surveys using Antillean-Z fish traps were carried out across a range of depths and habitat-types in the gulfs of Shark Bay between 1998 and 2000. Objectives of the study were (i) to evaluate the efficiency of the fish traps in catching 0+ and 1+ pink snapper (Pagrus auratus)*, (ii) to investigate the distribution and abundance of juvenile pink snapper in both gulfs using trap surveys, (iii) to investigate the influence of environmental factors including habitat-type on the distribution of juvenile pink snapper and, (iv) to develop trap indices of 0+ relative abundance and assess their use for monitoring of juvenile pink snapper recruitment. During the three year study, a total of 1,020 trap-sets were made and 24,248 individual fish representing more than 34 species were caught. Pink snapper were ranked 5th numerically with a total of 782 caught. Mean catch rates of 0+ and 1+ pink snapper were between 0.08-1.57 and 0.01-0.32 fish per trap hour, respectively. The distribution of 0+ pink snapper was most closely correlated with latitude and depth. Habitat-type at the majority of sites surveyed in 2000 was either seagrass meadow or sand. 0+ pink snapper were not strongly associated with any particular habitat-type based on the habitat classification system used in this study and the spatial scale at which sampling was undertaken. Although the presence/absence of 0+ pink snapper followed some predictable pattern, the variation in 0+ abundance was much less predictable. Trawl indices of 0+ relative abundance are recommended in preference to trap indices for future monitoring of juvenile pink snapper recruitment in the gulfs of Shark Bay.*

1.0 Introduction

Shark Bay on the central coast of Western Australia is a large, semi-enclosed marine embayment, covering approximately 14,000 km^2. The Bay is bounded by three large islands to the west (Dirk Hartog Is., Bernier Is. and Dorre Is.), with open, deeper waters to the north (maximum depth ~ 20 m) and two shallower gulfs to the south (average depth ~ 10 m) (Figure 1). The region received World Heritage status in 1991 principally for the high conservation value of its marine environment (Shaw 2000).

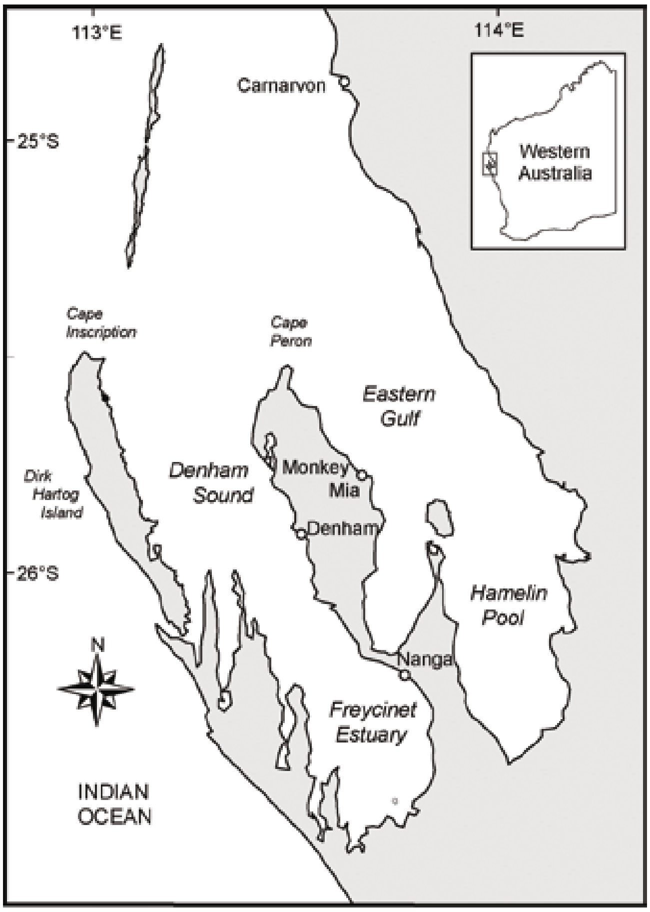

Figure 1. Map of Shark Bay, Western Australia, showing gulf waters surveyed during trap surveys 1998-2000. Denham Sound and the Freycinet Estuary are collectively referred to as the Western Gulf. Hamelin Pool is a Marine Reserve and closed to fishing.

The region's climate is arid with minimal terrestrial runoff. Annual levels of evaporation (average 2000–2200 mm yr-^{1}) are much greater than rainfall (average 200-220 mm yr-^{1}) (Logan and Cebulski 1970). Water temperatures inside the Bay range between winter minima of 15-18°C and summer maxima of 26-30°C (Logan and Cebulski 1970). Salinities consistently exceed the oceanic level (35) with metahaline conditions in the Eastern Gulf and southern regions of Denham Sound (38-48) and the Freycinet Estuary (45-48), and hypersaline (50-65+) in Hamelin Pool (Logan and Cebulski 1970).

Shark Bay is near the northern limit of a transition zone between temperate and tropical fish faunas on the west coast of Australia; gulf waters contain a higher proportion of temperate species while the more exposed, oceanic waters are dominated by tropical taxa (Black et al. 1990, Hutchins 1990, 1994).

Although Shark Bay has had a varied history since the arrival of Europeans (Edwards 1999), the region's economy is now based on fishing, aquaculture, solar salt production and tourism (Shaw 2000). Important commercial fisheries today include line-fishing for pink snapper (*Pagrus auratus*) in oceanic waters outside Shark Bay, and trawling for prawns (*Penaeus latisulcatus, P. esculentus, Metapenaeus* spp.) and scallops (*Amusium balloti*), and beach seining for whiting, mullet, tailor and yellowfin bream (*Sillago* spp., *Mugil cephalus, Pomatomus saltatrix, Acanthopagrus latus*) in gulf waters (Shaw 2000). The region has been one of the state's most important recreational fishing destinations since the 1970s at least (Jackson et al. 2003). Pink snapper have traditionally been a major attraction and remain the key target species for recreational boat fishers in gulf waters (Sumner and Malseed 2001, Jackson et al. 2005).

Stock structure of pink snapper in the Shark Bay region is complex with little or no mixing apparent between local populations separated in some cases by only tens of kilometres (Johnson et al. 1986, Edmonds et al. 1989, 1999, Moran et al. 1998, 2003, Whitaker and Johnson 1998, Baudains 1999, Bastow et al. 2002, Gaughan et al. 2003, Nahas et al. 2003). Management now recognises four discrete pink snapper stocks in the region: an oceanic stock found along the continental shelf outside Shark Bay, and three inner gulf stocks found in the Eastern Gulf, Denham Sound, and Freycinet Estuary, respectively.

Community concern regarding the exploitation of pink snapper inside Shark Bay, particularly by recreational fishers during the winter spawning season, were initially expressed as far back as the 1970s. By the mid 1990s, it was becoming more widely recognised that there had been a significant increase in the level and effectiveness of recreational fishing for pink snapper, particularly with fishers targeting spawning aggregations in the Eastern Gulf out of the popular tourist resort of Monkey Mia. Although limited information existed at the time, anecdotal evidence suggested that the Eastern Gulf breeding stock was severely depleted following excessive exploitation over a number of years. In addition, there has been a longstanding belief held by some in the local community that commercial trawling for prawns and scallops in Denham Sound has had a detrimental effect on juvenile pink snapper in that area.

In the absence of adequate information on the status of pink snapper breeding stocks in either gulf, researchers proposed that juvenile recruitment surveys could provide information on the reproductive success of local pink snapper populations. Trawl surveys using commercial twin flat prawn-type nets (45 mm mesh) were undertaken throughout gulf waters by the Department of Fisheries, initially in November 1996, and again in February and November 1997. Either zero or very low numbers of 0+ or 1+ pink snapper, i.e. fish in their first and second years, were caught in the deeper waters in the Eastern Gulf, in sharp contrast to large numbers caught in the Freycinet Estuary during the same surveys. These results were thought to reflect poor recruitment in the Eastern Gulf in 1996 and 1997, in comparison to strong recruitment in the Freycinet Estuary. This information, combined with results from pilot stock assessment surveys using the daily egg production method in 1997 (Jackson and Cheng 2001), and a preliminary recreational fishing survey conducted at the Monkey Mia boat ramp in 1996 (Sumner and Steckis 1999), resulted in the Eastern Gulf breeding stock being judged as severely depleted. Following consultation with various community groups, the Eastern Gulf pink snapper fishery was subsequently closed to all fishing in June 1998 (and remained closed until March 2003) to allow the spawning stock to rebuild (Jackson et al. 2005).

During discussions between the Department of Fisheries and various community groups in 1997-1998, aimed at developing future management strategies for rebuilding of gulf pink snapper stocks, there was some criticism of the research trawl survey results that had indicated low juvenile recruitment in Eastern Gulf in 1996/1997. Some expressed the view that juvenile pink snapper inside Shark Bay were not only to be found in the deeper (trawlable) waters but also in nearshore, shallower (untrawlable) habitats. Researchers accepted that the deeper basins where trawling had been carried out might have represented only a proportion of the total habitat used by 0+ and 1+ pink snapper. Further research was called for and Natural Heritage Trust funding (Fisheries Action Program) was awarded to address the issue. This report describes a series of research trap surveys carried out in the gulfs of Shark Bay between 1998 and 2000. The objectives of the study were:

- to evaluate the efficiency of fish traps in catching 0+ and 1+ pink snapper
- to investigate the distribution and abundance of juvenile pink snapper in both gulfs using trap surveys over a three year period
- to investigate the influence of environmental factors including habitat-type on the distribution of juvenile pink snapper
- to develop trap indices of 0+ relative abundance and assess their use for monitoring of juvenile pink snapper recruitment

Note: Since this research was completed, a comprehensive study investigating the effects of commercial prawn trawling on juvenile pink snapper in the Denham Sound area has been undertaken by the Department of Fisheries (Moran and Kangas 2003). Although no details of the survey methods used in that study are reproduced here, some reference is made to the results to assist interpretation of data obtained from the trap surveys here.

2.0 Methods

2.1 Trap design

Sampling of fish populations in areas characterised by complex and inaccessible habitat has the potential to produce biased results if the gear is unable to equally sample all habitat-types present within the area of interest. Fish traps have been used worldwide to sample in habitats that are inaccessible to other techniques because of depth (e.g. visual census) or habitat complexity (e.g. various netting methods) (Sheaves 1995). In Australia, Antillean-Z fish traps, originally developed for use in the Caribbean (Munro et al. 1971, Munro 1974), were successfully used by Sheaves (1992) to determine the distribution and abundance of fishes in a northern Queensland estuary which could not be sampled using more conventional techniques. Detailed information on trap design, optimum mesh size and soak times was therefore available, and this gear was selected for trial and evaluation in Shark Bay.

Trap design followed that described by Sheaves (1995) and comprised a welded galvanized angle-iron (25 x 25 x 3 mm) frame with two straight funnel entrances (Figure 2). The traps were initially covered with galvanized ‘chicken-wire’ (30 x 30 mm mesh). Results of a pilot study (see 2.2) indicated that this mesh size did not fully retain 0+ pink snapper and, prior to commencement of extensive trap surveys throughout the gulfs, the ‘chicken-wire’ was replaced with galvanized wire square mesh (12 x 12 mm) laced to the trap frames with 1.2 mm galvanized wire. Each entrance funnel was elliptical in shape with a 430 x 200 mm outer and 200 x 140 mm inner opening. A pair of short ropes was tied to the top of each trap to form two bridles and a longer rope (12 mm diameter) with a float at one end was tied to both bridles for hauling purposes. The length of rope varied according to operational water depth and state of tide.

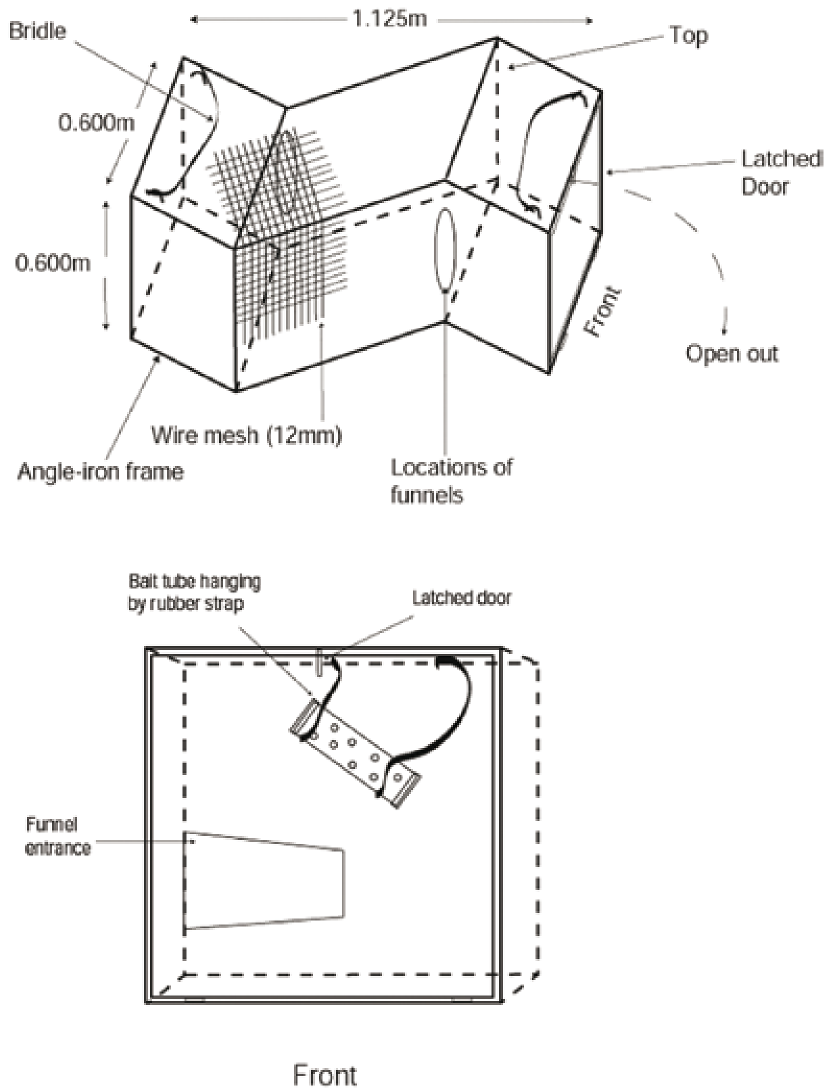

Figure 2. Design of Antillean-Z fish trap used in the gulfs of Shark Bay.

2.2 Preliminary evaluation of trap efficiency

In December 1997, a pilot study was undertaken to establish whether the Antillean-Z fish traps were effective in catching juvenile pink snapper in Shark Bay. Between three and six individual baited traps were set at approximately equal intervals along each of six research trawl transects in the Freycinet Estuary for soak times of approximately 2 hrs. These transects were then trawled later that same day by the *RV Flinders* using commercial prawn-type nets (45 mm mesh). Pink snapper caught in both gears were assigned to the 0+ and 1+ age groups based on modes in length frequency data obtained from a previous Freycinet Estuary trawl survey in November 1996 and the trawls undertaken in December 1997 as part of the current project. Pink snapper caught in the Freycinet Estuary in November or December of fork length 0-104 mm were taken to be 0+ and fish of fork length 105– 154 mm were taken to be 1+ (Figure 3).

Very few 0+ were caught by the traps (n = 4) compared with the trawls (n = 700+) which may have indicated that the 30 x 30 mm mesh had allowed most 0+ fish to escape. However, the traps caught adequate numbers of 1+ (n = 36) to allow some comparison with the numbers of 1+ caught by trawl (n = 129) at each sampling location. There was some similarity in the pattern of variation in 1+ abundance at each trawl site from the two sampling gears, however the relationship was not significant (linear regression $r^2 = 0.09$, df = 4, $P>0.05$, not presented) (Figure 4). Although it was clear that the 30 mm trap mesh needed to be reduced to fully retain 0+, results of the pilot study suggested that the traps successfully caught juvenile pink snapper.

Figure 3. A typical 0+ *P. auratus* (top) compared with 1+ fish (bottom).

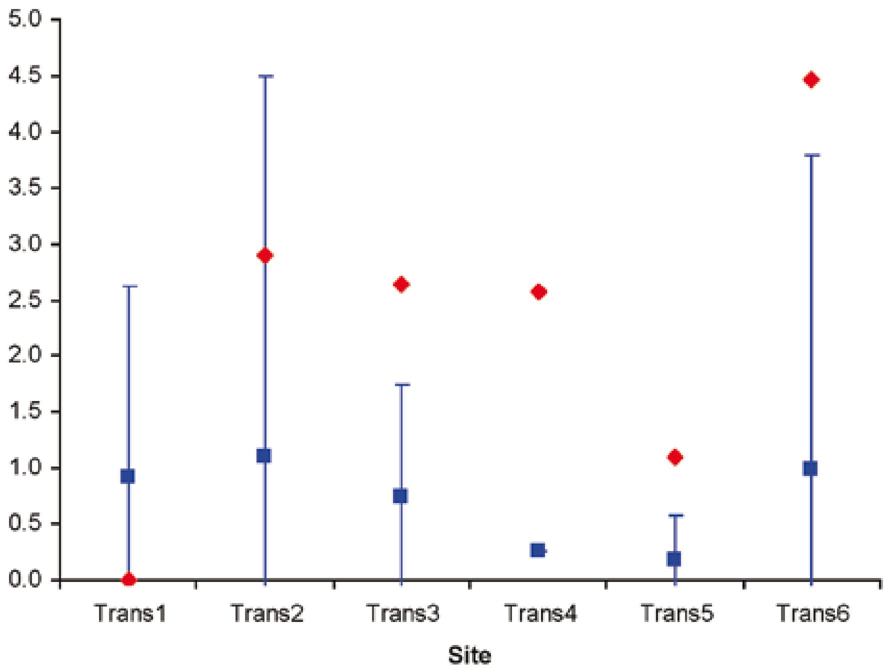

Figure 4. Comparison of catches of 1+ pink snapper taken by trap (blue squares) compared with trawl (red diamonds) at the same six transect sites in the Freycinet Estuary in December 1997. Trap catches are log mean values +1 (error bars are 1 s.d.) while trawl catches are log total number caught per trawl shot +1.

2.3 Field surveys

2.3.1 Study area and survey design

In 1998, due to the large area of the gulfs to be surveyed (approximately 5000 km^2), and the initial availability of only a small research vessel (*RV Snipe*, overall length 7.1 m), sampling design was based on a 2 x 4 nautical mile grid pattern of trap survey locations. In 1999 and 2000, following preliminary analysis of the 1998 trap survey results, and the addition of a second, larger research vessel (*RV Flinders*, overall length 22 m) to the project, more intensive trapping was possible, and a 2 x 2 nautical mile grid pattern was used.

The gulf waters were divided into three sampling areas; the Eastern Gulf including the northern part of Hamelin Pool, Denham Sound and the Freycinet Estuary (Figure 1). Pink snapper in the Eastern Gulf and in Denham Sound mostly spawn May-July while fish in the Freycinet Estuary mostly spawn slightly later around July-September. Trap surveys were planned to take place during the autumn-winter period when young-of-the-year pink snapper (0+) would be approximately 10-12 months old.

The first trap survey was conducted in the Freycinet Estuary in May-June as previous trawl surveys had found juveniles to be most abundant there compared with the other two areas. Following relatively large catches of 0+ and 1+ pink snapper there, trapping was subsequently carried out in Denham Sound and the Eastern Gulf in June–August. In 1999 and 2000, trapping was undertaken during the period March-June, firstly in Denham Sound followed by the Eastern Gulf and lastly in the Freycinet Estuary.

2.3.2 Trap deployment

Trapping from the *RV Snipe* involved a crew of two or three. Traps were baited by squashing whiting heads (*Sillago* spp.) and whole pilchards (*Sardinops* and *Sardinella*) into a single PVC bait tube (30 cm length, 8 cm diameter) which was suspended centrally from the inside top of each trap (Figure 2). Approximately 20, 1 cm holes were drilled into the sides of each bait tube. In addition, a handful of loose bait was placed in the bottom of each trap to encourage fish to feed and remain in the trap for the duration of the soak period. On arrival at each location, a baited trap was deployed from the gunwale with the bridles uppermost. During the trap's descent, tension was maintained on the hauling rope to ensure the trap remained upright. Ballast, in the form of steel bars, was fixed to the bottom of the traps, to ensure they remained upright on the seabed.

Because of the limited deck area, a maximum of only eight traps could be carried aboard the *RV Snipe* at any one time. Traps were deployed sequentially with a single trap only set at each location. When the vessel had set the last trap in a sequence of eight, it returned to the first location. The traps were then retrieved in the same order in which they had been deployed. This resulted in each trap being set for between 1-2 hours, the optimum soak time determined by Sheaves (1995). All fish caught were identified (to species level where possible), counted and returned alive. All pink snapper were measured to the nearest mm (fork length, FL).

A trap-set was recorded as 'invalid' if (i) the mesh was found to have been damaged sufficiently to allow 0+ pink snapper to escape, (ii) the door had opened, or (iii) there was evidence to suggest the trap had not remained in the upright position on the seabed. At each location, site number, GPS latitude and longitude, date, set time, retrieval time, depth and sea surface temperature (SST) were recorded on waterproof data sheets (Appendix 1). Numbers of all species were recorded together with fork lengths of all pink snapper.

2.3.3 Habitat video assessment

In 2000, underwater camera systems were used to film the seabed habitat at each trap site. A white board inscribed with details of the location, date and site number was placed in front of the camera, prior to filming, at each site. The camera was then lowered to the seabed while the vessel was stationary and film recorded for approximately one minute. At shallow sites, a visual assessment of habitat was made where possible. Filming from the *RV Snipe* used either a Panasonic Digital Video (DV) camera mounted in a stainless steel cylindrical housing or a Sony DV camera mounted in a PVC housing fixed to an aluminium frame. On the *RV Flinders* filming was done with a Mako 'live-feed' 240v system consisting of a Sony digital processing unit and camera enclosed in an aluminium housing.

2.4 Data analysis

2.4.1 Pink snapper size composition

Data from trap-sets that were determined to be 'invalid' (see 2.3.2) were excluded from the analyses. Length frequency data for pink snapper catches in each area, in each year, were plotted as frequency histograms. Pink snapper were assigned to the 0+, 1+, and older age groups based on modes in length frequency distributions (see Results).

2.4.2 Pink snapper catch rates

Catches of pink snapper for each of the three age groups were standardized to catch rates (number of fish per trap hour) and then transformed using $\log(x + 1)$, where x = standardised catch rate. Standardised catch rates were used as the measure of abundance in all analyses.

2.4.3 Indices of 0+ abundance

The mean 0+ pink snapper catch rate (± 1 s.e.) was calculated for each survey area and year.

2.4.4 Habitat classification based on video film

Video footage was converted to DV format using a Macintosh computer and iMovie software. Film recorded at each site was viewed at least three times. A habitat classification system modified from that used by the Department of Conservation and Land Management (CALM) was used to categorise habitat-type at each trap location into one of 14 possible categories (Appendix 2). Seagrass was identified to the genus level where possible but more usually could only be categorised as either 'branched' or 'ribbon'. Visual estimates of seagrass density at each location were made based on stand height relative to camera height.

2.4.5 Distribution and abundance of juvenile pink snapper in relation to environmental variables

Because pink snapper trap catch rates were highly skewed, i.e. not normally distributed, we could not use conventional parametric methods (e.g. ANCOVA) to test for possible relationships between the distribution of juvenile pink snapper and the environmental variables measured.

Instead we used classification and regression tree analysis to investigate the influence of year, depth, latitude, sea surface temperature and habitat-type on the distribution of the 0+, 1+ and older age groups of pink snapper. Classification and regression tree analysis are techniques used to predict or explain the responses of a categorical or continuous dependent variable (e.g. fish counts) based on one or more predictor variables (e.g. environmental factors) (De'ath and Fabricus 2000). Regression trees here were calculated using pink snapper catch rates (i.e. continuous) to determine which combination of environmental variables coincided with the highest catches in each survey year while classification trees were calculated using catch rates converted to presence/absence data (i.e. categorical). Further details on the theory and application of classification and regression trees are given by Breiman et al. (1994) and examples of their use in fish habitat modelling by Bell (1999).

3.0 Results

3.1 Trap catches

A total of 1,020 trap-sets were made during the study (Table 1). Sampling effort increased progressively over the three years from 215 trap-sets in 1998 to 438 trap-sets in 2000. Overall, 24,248 individual fish representing more than 34 species were caught (Table 2). Trap catches were numerically dominated by striped trumpeters (*Pelates* and *Terapon* spp. were combined due to inconsistencies in species identification) and western butterfish (*Pentapodus vitta*) which comprised 51% and 25% of the total catch, respectively. Pink snapper (*Pagrus auratus*) were ranked 5th numerically with a total of 782 caught.

3.2 Pink snapper size composition

We were able to assign pink snapper caught in the traps in the Eastern Gulf and the Freycinet Estuary to the three age* groups based on clear modes observed in the length frequency distributions from the trapping carried out in 1998 (Figure 5). This approach was not possible for trap-caught pink snapper in Denham Sound however, because the length frequency distributions in each year were much less clear (Figure 5, 6, 7). To assign pink snapper from Denham Sound to the three age groups, we used knowledge of the pink snapper spawning season (and therefore birth date, Jackson et al. in prep.) in conjunction with length frequency data obtained from trawl surveys conducted in Denham Sound between 2000-2001, to determine the most appropriate separation point between the 0+ and 1+ age-classes for the time of year when the trap surveys were conducted (Figure 8). For the purposes of this trap study, pink snapper were assigned to the three age groups based on fork length as follows:

Eastern Gulf: 0+, 0-160 mm; 1+, 161–230 mm; older, >230 mm

Denham Sound: 0+, 0-154 mm; 1+, 155–214 mm; older, >214 mm

Freycinet Estuary: 0+, 0-150 mm; 1+; 151-230 mm; older, >230 mm

*Note, since this study was completed, age validation based on sectioned otoliths has been undertaken for *P. auratus* from inner Shark Bay (Jackson et al. in prep.).

Table 1. Catches of pink snapper from trap surveys in inner Shark Bay 1998-2000.

Survey Year	Eastern Gulf	Denham Sound	Freycinet	Areas combined
1998				
Total number 0+	38	10	199	**247**
Mean number 0+/hour (s.e.)	0.25 (0.78)	0.15 (0.33)	1.57 (2.29)	
Total number 1+	9	9	30	**48**
Mean number 1+/hour (s.e.)	0.06 (0.19)	0.14 (0.45)	0.24 (0.91)	
Total number 'older'	4	0	10	**14**
Total number trap-sets	94	45	76	**215**
Trap-sets with pink snapper	4	4	24	**32**
Total number pink snapper	51	19	239	**309**
1999				
Total number 0+	21	39	9	**69**
Mean number 0+/hour (s.e.)	0.12 (0.36)	0.17 (0.22)	0.08 (0.25)	
Total number 1+	1	57	34	**92**
Mean number 1+/hour (s.e.)	0.01 (0.03)	0.25 (0.45)	0.32 (1.12)	
Total number 'older'	3	5	25	**33**
Total number trap-sets	118	150	99	**367**
Trap-sets with pink snapper	9	23	7	**39**
Total number pink snapper	25	101	68	**194**
2000				
Total number 0+	46	57	57	**160**
Mean number 0+/hour (s.e.)	0.21 (0.30)	0.19 (0.27)	0.32 (0.45)	
Total number 1+	12	17	46	**75**
Mean number 1+/hour (s.e.)	0.06 (0.10)	0.06 (0.11)	0.26 (0.65)	
Total number 'older'	1	41	2	**44**
Total number trap-sets	133	189	116	**438**
Trap-sets with pink snapper	21	25	17	**63**
Total number pink snapper	59	115	105	**279**
Overall total number trap-sets				**1020**
Overall total number pink snapper				**782**
Overall mean number 0+/hour (s.e.)				**0.34 (0.58)**
Overall mean number 1+/hour (s.e.)				**0.15 (0.44)**

Table 2. Species caught during trap surveys in inner Shark Bay 1998-2000, ranked numerically (var. = various).

Common name	Taxonomic name	Total	% by number	Ranked
Striped trumpeters	*Pelates spp., Terapon* spp.	12,471	51.4	1
Western butterfish	*Pentapodus vitta*	6,084	25.1	2
Leatherjackets	var. Monacanthidae	1,574	6.5	3
Gobbleguts	*Apogon rueppelli*	794	3.3	4
Pink snapper	*Pagrus auratus*	782	3.2	5
Grass snapper	*Lethrinus choerynch*	456	1.9	6
Threadfin emperor	*Lethrinus genivittatus*	379	1.6	7
Black snapper	*Lethrinus laticaudis*	326	1.3	8
Western yellowfin bream	*Acanthopagrus latus*	295	1.2	9
Red-barred grubfish	*Parapercis nebulosa*	273	1.1	10
Yellowtail trumpeter	*Amniataba caudovittatus*	147	0.6	11
Wrasses	var. Labridae	123	0.5	12
Puffers, porcupinefishes	var. Tetraodontidae	117	0.5	13
Lined dottyback	*Labracinus lineatus*	92	0.4	14
Sand bass	*Psammoperca waigiensis*	77	0.3	15
Tarwhine	*Rhabdosargus sarba*	69	0.3	16
Trevallies	var. Carangidae	56	0.2	17
Whiptails	var. Nemipteridae	30	0.1	18
Gobies	var. Gobiidae	22	0.1	19
Sharks	var.	18	0.1	20
Goatfishes	var. Mullidae	17	0.1	21
Tuskfishes	var. Labridae	15	0.1	22
Flatheads	*Platycephalus* spp.	7	0.0	23
Sweetlip emperor	*Lethrinus miniatus*	6	0.0	24
Parrotfishes	var. Scaridae	4	0.0	25
Grinners	*Saurida* spp.	4	0.0	26
Mangrove Jack	*Lutjanus argentimaculatus*	2	0.0	27
Damselfish	*Pomacentrid* spp.	2	0.0	28
Whiting	*Sillago* spp.	2	0.0	29
Rockcod	*Epinephelus* sp.	1	0.0	30
Scorpionfish	*Centrogenys vaigiensis*	1	0.0	31
Slender suckerfish	*Echeneis naucrates*	1	0.0	32
Spanish flag	*Lutjanus vitta*	1	0.0	33
	Total fish caught	**24,248**		

Of the total 1,020 trap-sets made over the three study, only 134 (13%) caught pink snapper. The number of pink snapper caught per trap varied between 1 and 62. The traps caught pink snapper between 50 mm and more than 500 mm in length (Figures 5,6,7). More pink snapper were caught (n = 309) in 1998 compared with other survey years even though the number of sites sampled was greater in 1999 and 2000.

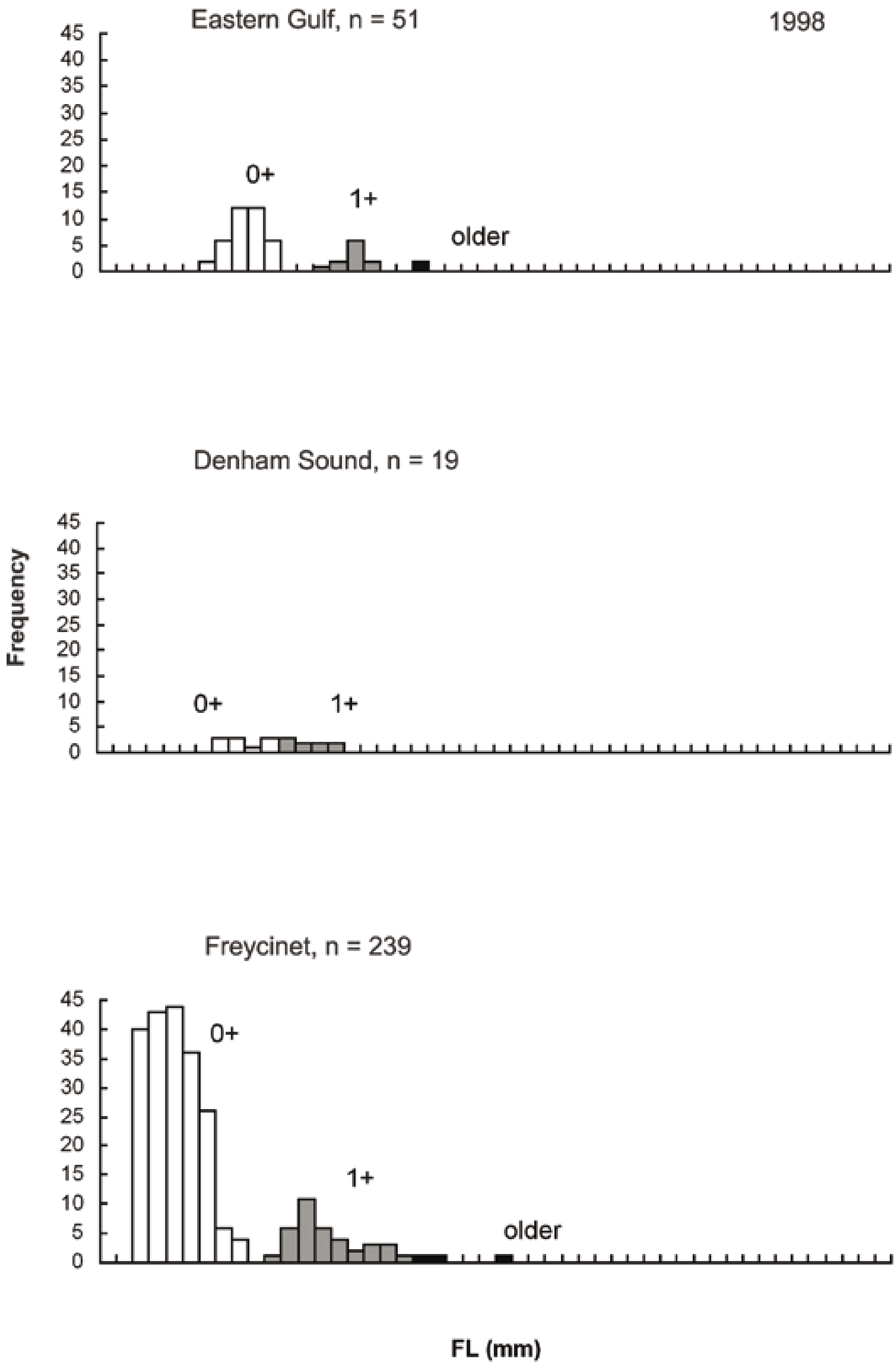

Figure 5. Length frequencies of pink snapper caught in traps in 1998. Numbers of fish caught in each area as indicated.

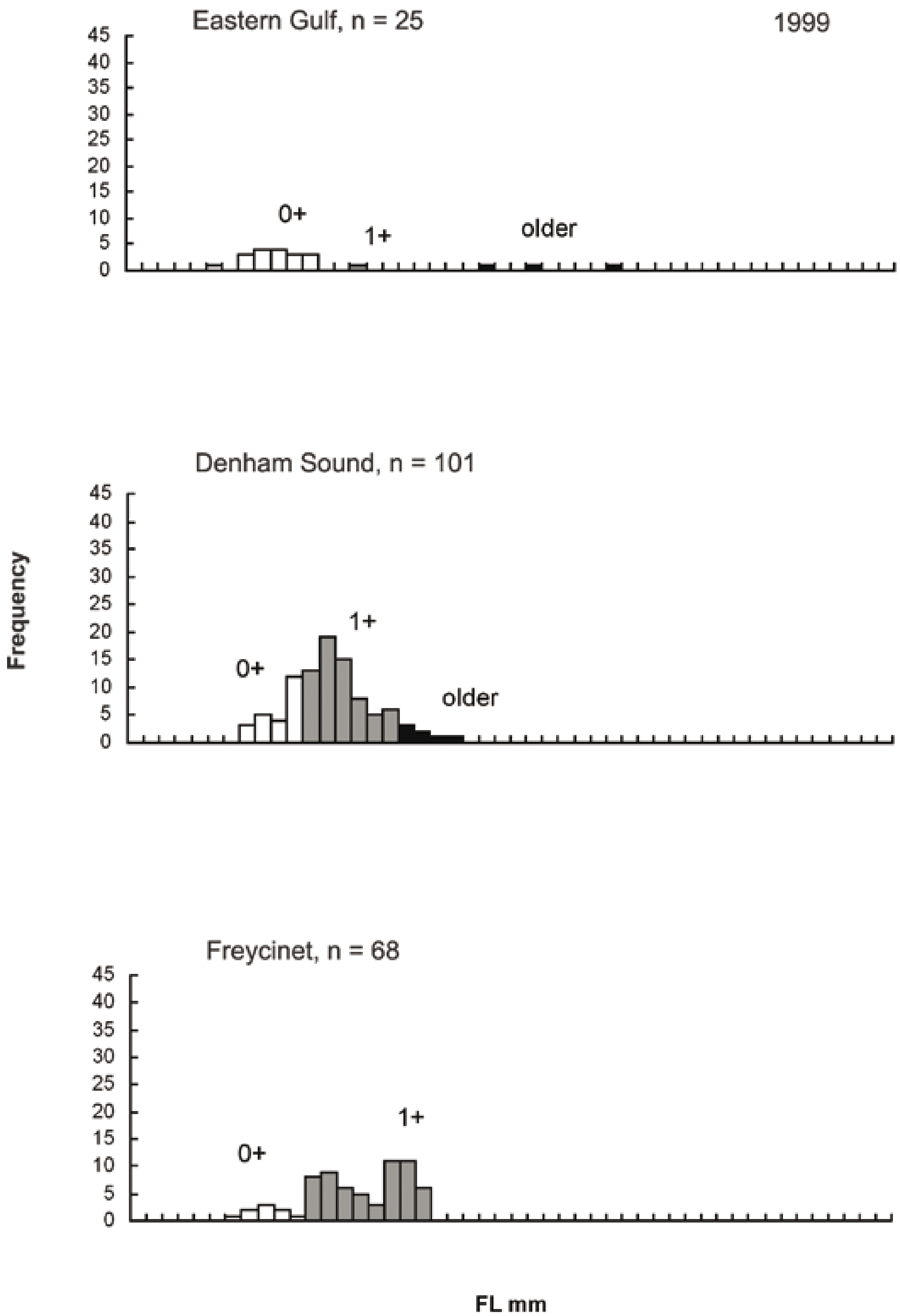

Figure 6. Length frequencies of pink snapper caught in traps in 1999. Numbers of fish caught in each area as indicated.

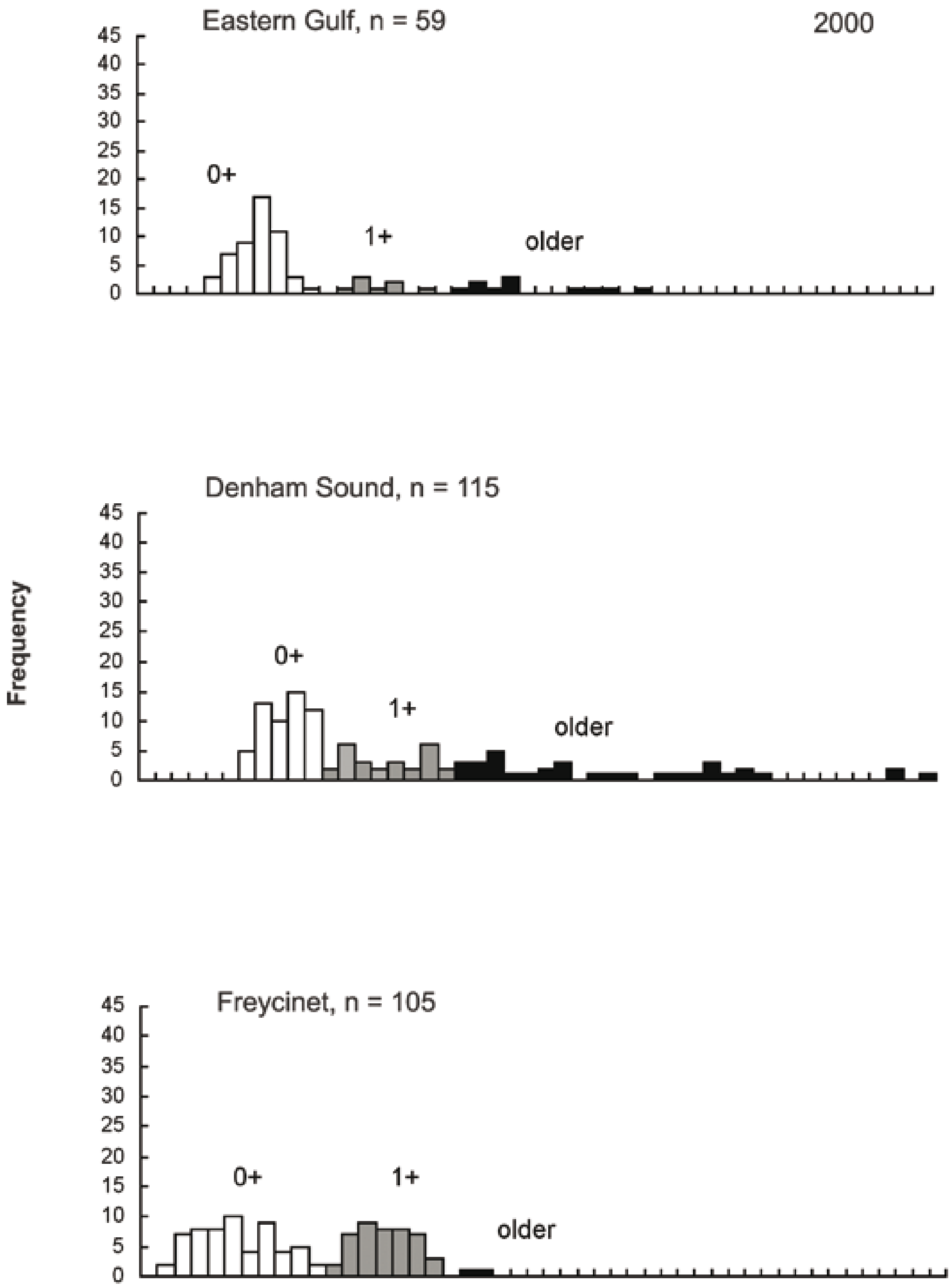

Figure 7. Length frequencies of pink snapper caught in traps in 2000. Numbers of fish caught in each area as indicated.

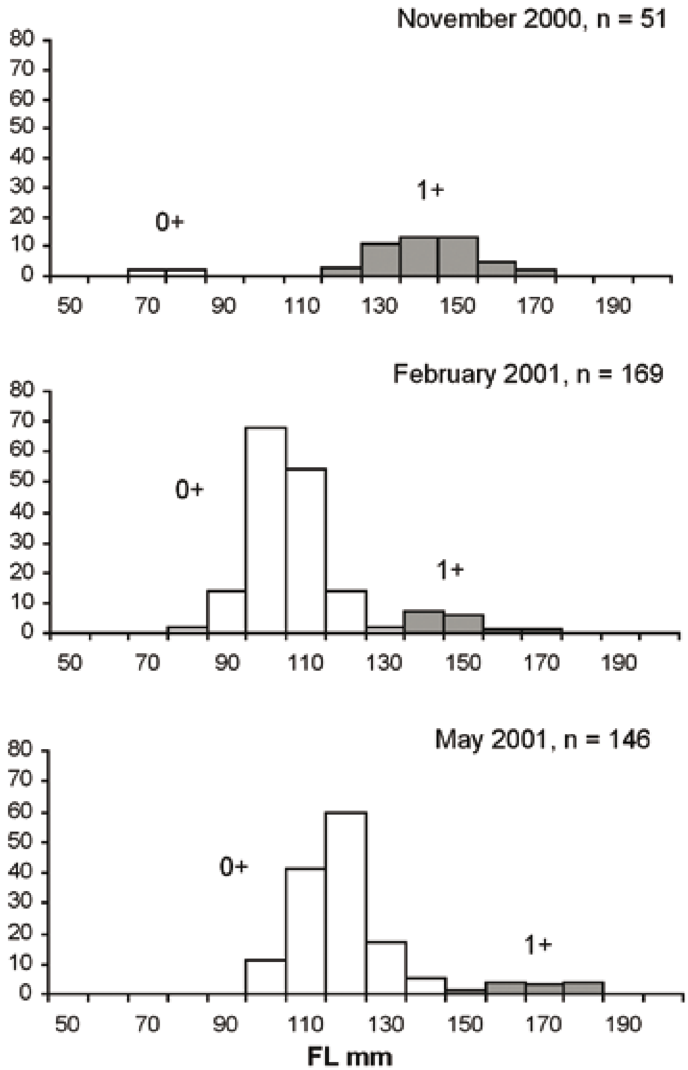

Figure 8. Length frequencies of pink snapper caught in trawls in Denham Sound between November 2000 and May 2001, showing size progression of 0+ and 1+ age classes. Numbers of pink snapper caught in each month as indicated. These data were used to separate 0+ and 1+ fish caught in Denham Sound during the trap surveys 1998-2000.

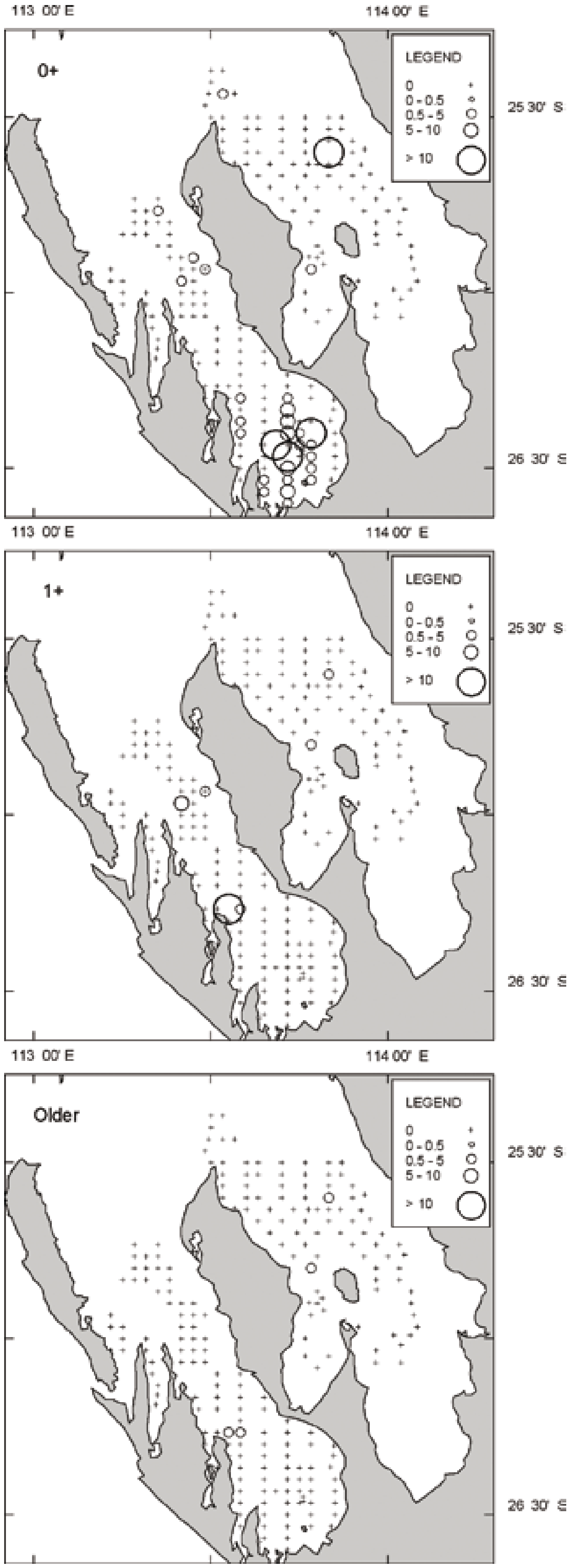

Figure 9. Distribution of 0+, 1+ and older pink snapper from trap surveys in 1998. Units are numbers of fish per trap hour.

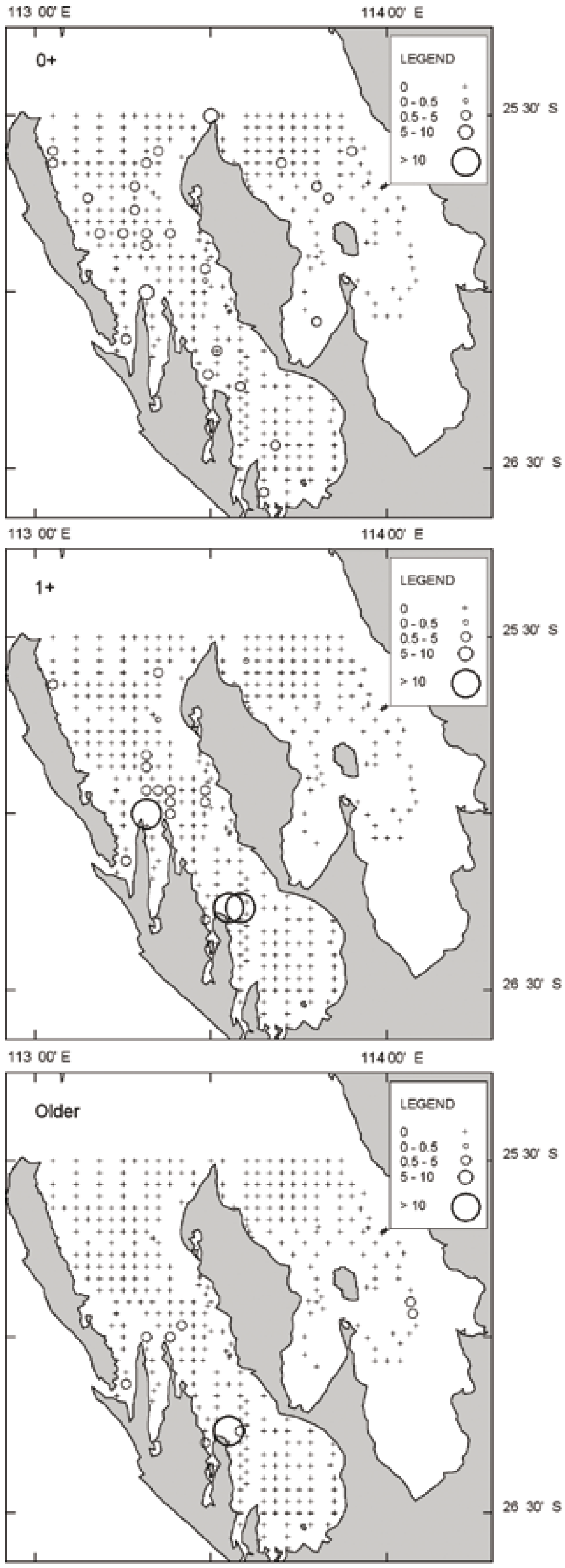

Figure 10. Distribution of 0+, 1+ and older pink snapper from trap surveys in 1999. Units are numbers of fish per trap hour. Note increased sampling compared with 1998 surveys.

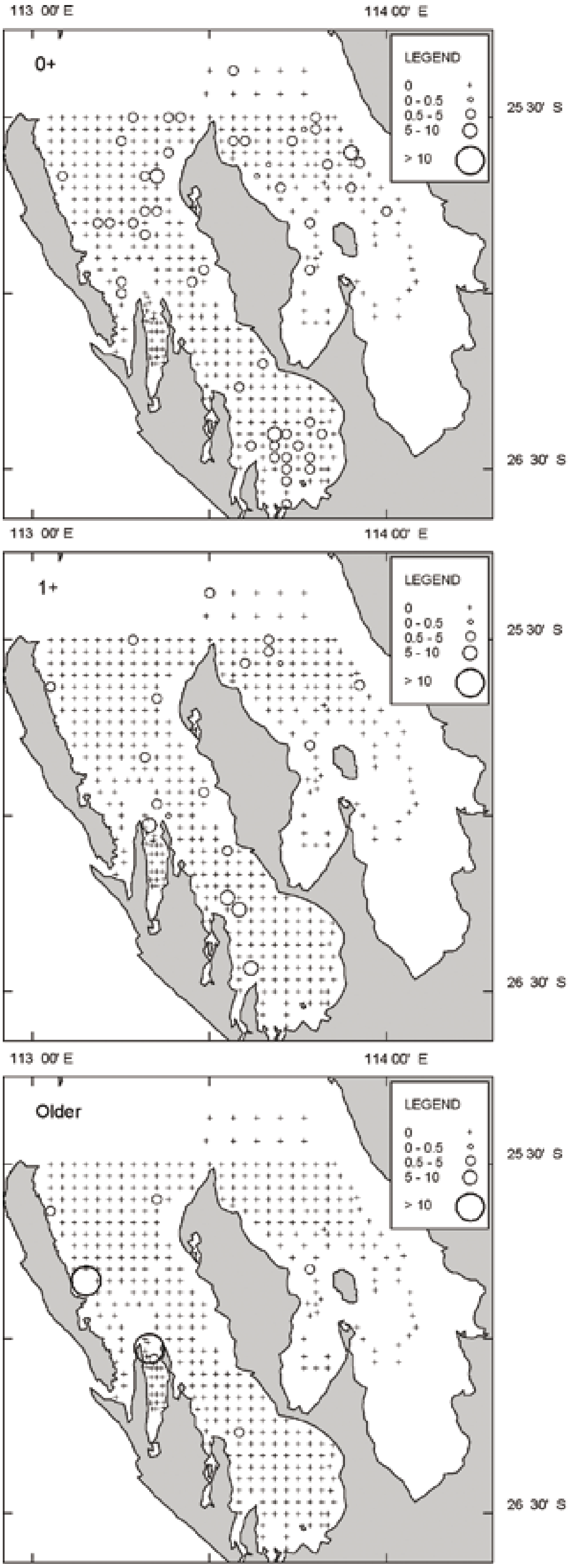

Figure 11. Distribution of 0+, 1+ and older pink snapper from trap surveys in 2000. Units are numbers of fish per trap hour. Note increased sampling compared with 1998 surveys.

In 1998 (Figure 9), very few 0+ or 1+ pink snapper were caught either in the Eastern Gulf or Denham Sound. In contrast, high numbers of 0+ were recorded at sites in the central and southern waters of the Freycinet Estuary. In 1999 (Figure 10), in the Eastern Gulf, 0+ pink snapper were caught at a small number of sites while no 1+ fish were recorded. Higher numbers of 0+ were caught in Denham Sound, mainly at the eastern margin of the deeper waters and across the shallower areas to the south. In contrast to 1998, very few juvenile pink snapper were found in the Freycinet Estuary in 1999. In 2000 (Figure 11), 0+ pink snapper were recorded at more sites in all three survey areas compared with both previous years. In Denham Sound and the Freycinet Estuary, 0+ fish were caught in similar areas to those at which they were found in both 1998 and 1999. Both 0+ and 1+ pink snapper were recorded at more sites throughout the Eastern Gulf in 2000 compared with any other year.

3.3 Pink snapper catch rates

Catch rates for all age groups were dominated by zero catch. The highest 0+ catch rates were in the Freycinet Estuary in 1998 (1.57 fish per trap hour) and lowest in same area in the following year (1999, 0.08 fish per trap hour). The highest 1+ catch rates were in the Freycinet Estuary in 1999 (0.32 fish per trap hour) and lowest in Denham Sound in the same year (0.01 fish per trap hour) (Table 1).

3.4 Indices of 0+ abundance

Mean catch rates of 0+ in each year were low (Table 1). From these data, recruitment in the Eastern Gulf and Denham Sound appeared to be at a relatively low and constant level between 1998 and 2000. In contrast, recruitment in the Freycinet Estuary appeared to be more variable, at a much higher level in 1998 than all other areas, declining in 1999, and then recovering moderately in 2000.

3.5 Habitat classification

Based on analysis of video film obtained in 2000 for 438 trap sites, habitat-types were identified as 45% seagrass, 37% sand, 6% sand + rock, and 12% unknown (i.e. not able to be determined). Although seagrass habitats represented the majority of sites in each area, more detailed classification identified some marked differences between the Eastern Gulf, Denham Sound and Freycinet (Figure 12). Denham Sound had a greater proportion of sites classified as sand than either the Eastern Gulf or the Freycinet Estuary. A larger number of sites were classified as unknown in the Eastern Gulf, mainly in northern portion of survey area, a consequence of the survey commencing immediately following the passage of Cyclone Lucy in March 2000, which resulted in a period of highly turbid conditions and poor underwater visibility. We were able to identify seagrass to genus level only with branched forms (*Amphibolis*, possibly *Halophila*), and ribbon forms (*Posidonia*, possibly *Halodule*) represented. Walker (1990) found 12 species of seagrass throughout Shark Bay; *Amphibolis antarctica* was the most abundant, followed by *Posidonia australis*, with some species, e.g. *Halodule uninervis*, highly localised.

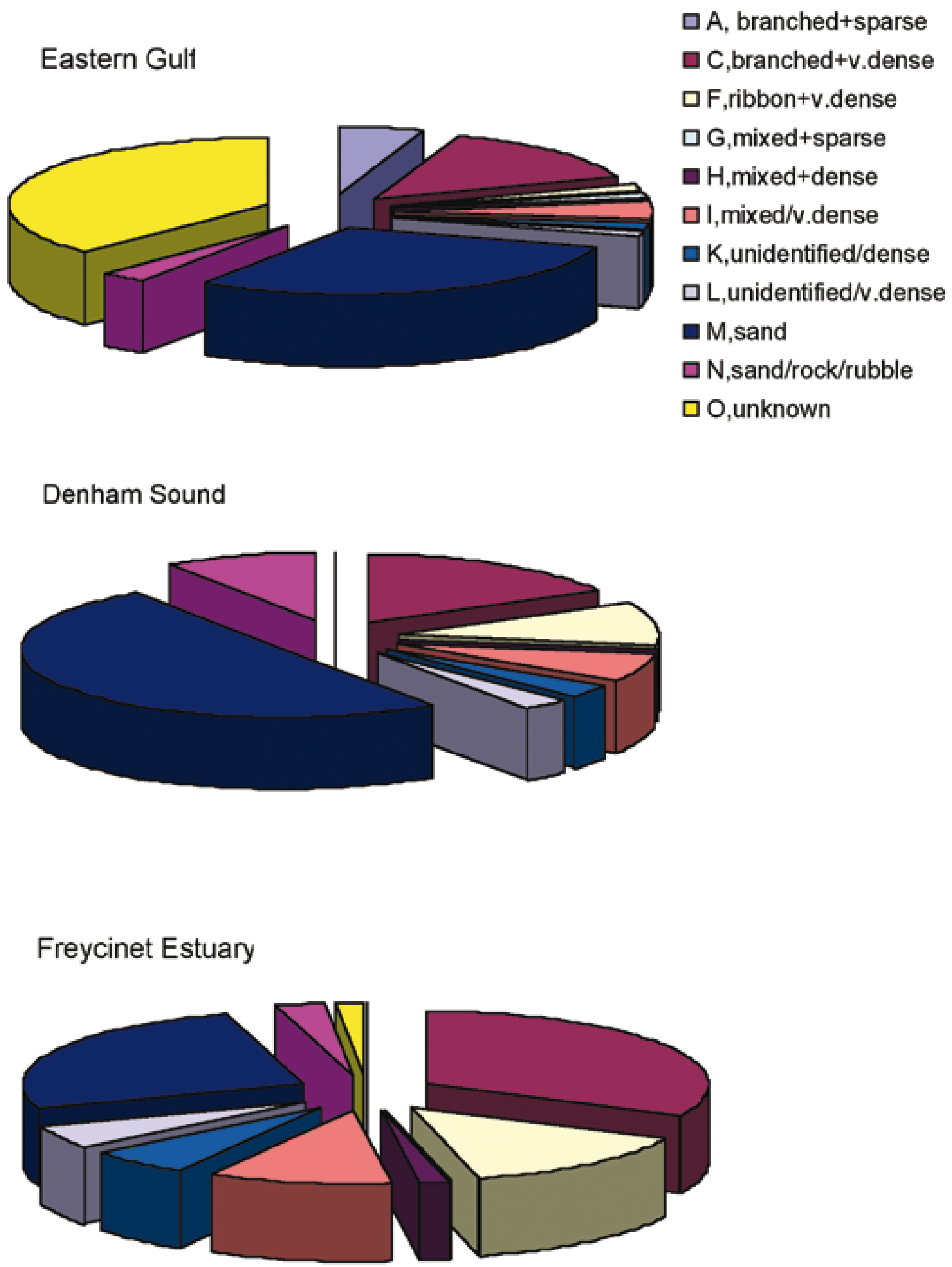

Figure 12. Habitat-types at trap sites identified by video film taken during survey in 2000 (see Appendix 2 for details of habitat classification).

3.6 Distribution and abundance of juvenile pink snapper in relation to environmental variables

Trap sites ranged in depth from 0.9 m to 22 m (mean 9.6 m). Of the total 1,020 trap-sets, 19% were at depths between 0 and 5 m, 37% at 5–10 m, 31% at 10–15 m, 10% at 15–20 m, and only 2% at 20–25 m.

Sea surface temperatures (SST) recorded at the trap sites ranged from 13.3 to 29.7°C (mean

22.9°C). There were marked differences in SST recorded during the surveys between years mostly due to differences in the timing of the surveys (Table 3).

Table 3. Mean sea surface temperatures (+s.e.) recorded during trap surveys in inner Shark Bay 1998-2000.

Year	Survey area	Months surveyed	Mean SST degC (s.e.)
1998	Eastern Gulf	June, August	20.3 (0.15)
	Denham Sound	August	17.6 (0.18)
	Freycinet	May, June	21.2 (0.06)
1999	Eastern Gulf	April, May	23.1 (0.12)
	Denham Sound	March, April, May	25.3 (0.08)
	Freycinet	May, June	19.5 (0.18)
2000	Eastern Gulf	March, April, May	25.8 (0.17)
	Denham Sound	March, April, May	24.1 (0.19)
	Freycinet	March, May, June	21.9 (0.31)

There was a weak positive relationship between catches of 0+ pink snapper and SST in each year (Figure 13) but a stronger relationship with depth (Figure 14). Most 0+ were caught between 5 and 15 m depth. There was no clear relationship found between 0+ pink snapper abundance and habitat-type (not presented).

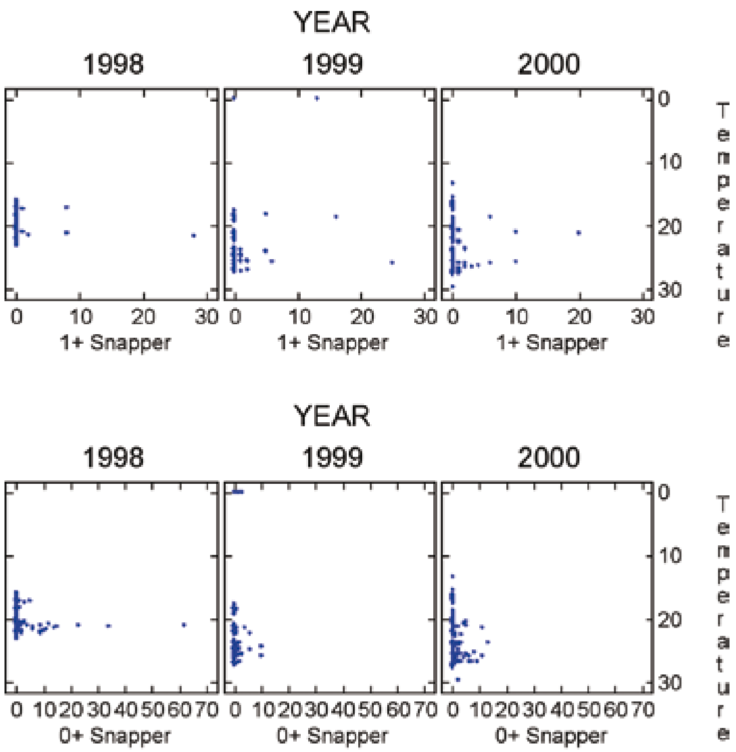

Figure 13. Catches of 0+ and 1+ pink snapper in relation to sea surface temperature in each survey year (areas pooled).

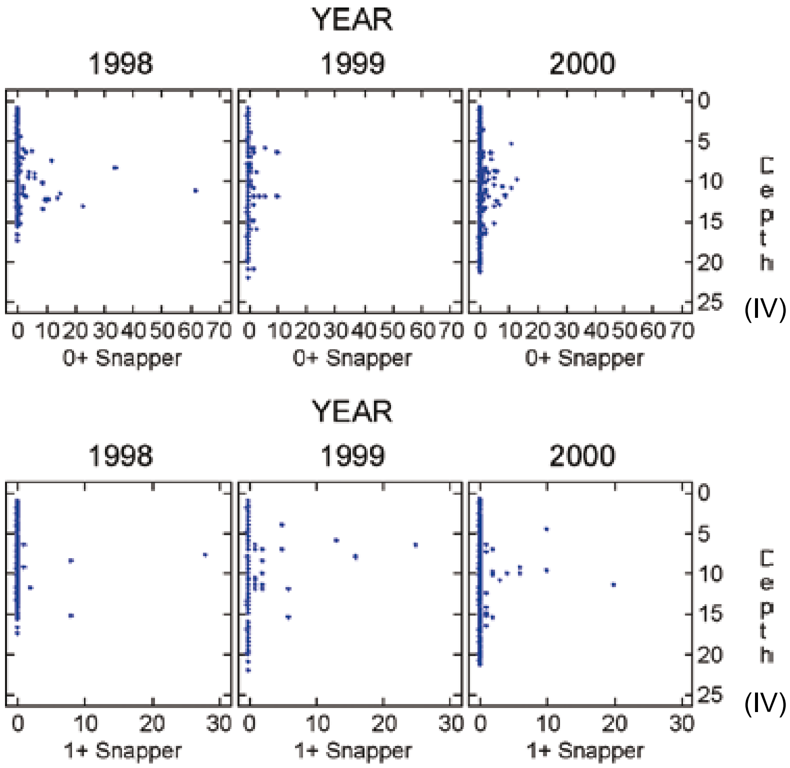

Figure 14. Catches of 0+ and 1+ pink snapper in relation to depth in each survey year (areas pooled).

Classification and regression tree analysis, to investigate the influence of year, depth, latitude, SST and habitat-type on abundance of juvenile pink snapper was only possible for the 0+ age group because data for 1+ were inadequate due to the very low numbers caught.

Classification tree analysis was more successful in predicting the presence of 0+ pink snapper with 61% of the total variance explained compared with regression tree analysis where only 25% of the total variance was explained (Table 4). From the regression tree, 0+ catch rates were mostly correlated with depth, and to a lesser extent, year and latitude (Table 4). From the classification tree, presence of 0+ pink snapper was highly correlated with depth, location and to a lesser extent, sea surface temperature. 0+ pink snapper were mostly caught where SST was > 19.6 and water depth was > 8.4 m.

Table 4. Relationship between distribution of 0+ pink snapper and key environmental variables in the gulfs of Shark Bay from classification and regression tree analysis.

Regression tree analysis of 0+ catch rate data.

Variable	% of total variance
Depth	11.4
Year	7.1
Latitude	6.8
SST	-
Habitat-type	-
Total % explained variance	**25.3**

Table 4 (cont). Classification tree analysis of 0+ presence/absence data.

Variable	% of total variance
Depth	43
Latitude	13
SST	5
Year	-
Habitat-type	-
Total % explained variance	**61**

4.0 Discussion

Efficiency of traps in catching juvenile pink snapper in Shark Bay

The traps are clearly capable of catching both 0+ and 1+ *P. auratus* in the gulfs of Shark Bay. Pink snapper was the 5th most numerically abundant species caught during this study with the 0+ and 1+ age groups representing 61% and 27% of all pink snapper caught, respectively. Pink snapper (mostly 1+), ranked 3rd overall in a similar study that sampled fish communities in seagrass habitats adjacent to Monkey Mia using the same Antillean-Z style traps (Heithaus 2004). In contrast, pink snapper were either not caught or were very much less abundant in catches taken using otter trawl and beach seine gears during other studies of nearshore fish faunas inside Shark Bay (Lenanton 1977, Black et al. 1990, Pember 1999, Travers and Potter 2002).

Although we were unable to quantify the relationship between catchability of the different size/age groups and the traps there is a suggestion that the gear catches 1+ pink snapper more readily than 0+. In the direct comparison we were able to make between the traps and trawls from the preliminary evaluation of trap efficiency (see 2.2 Preliminary evaluation of trap efficiency), the traps with the larger mesh (30 x 30 mm) as used initially caught approximately 1/4 of the number of 1+ as 20-minute trawls in the same area. Moran and Kangas (2003) calculated that traps caught approximately 1/30 of the number of 0+ caught in a 20-minute trawl. The 0+ to 1+ ratio pooled for all areas and all years is 2.27:1 (0.34 per trap hour to 0.15 per trap hour). Natural mortality of 0+ to 1+ pink snapper was estimated to range between 86% and 95% per year (Moran and Kangas 2003) thus the ratio of 0+ to 1+ would be expected to be approximately 9:1. This indicates that 1+ pink snapper are around four times more catchable by trap than 0+ fish.

Although many factors affect the effectiveness of fish traps, e.g. fish behaviour, soak time, mesh size, internal trap volume, type of bait, and trap placement (Kneib and Craig 2001), there is evidence that more mobile fish have a higher probability of encountering the traps. These fish are correspondingly more likely to enter the traps and therefore have a higher catchability (Robichaud et al. 2000). Species such as pink snapper that are gregarious and form schools in their early years tend to have higher catchability than more solitary species (Robichaud et al. 2000). The higher catchability of 1+ pink snapper compared with 0+ fish may be a function of the greater distance that larger fish will swim to approach a trap, simply as a function of body size and, hence, swimming ability. There may also be behavioural differences between the 0+ and 1+ age groups related to ontogenetic changes in foraging patterns. Studies elsewhere have shown that the presence of fish already within a trap can affect other fish entering the same trap due to either attraction or repulsion between species (Kneib and Craig 2001).

Distribution and abundance of juvenile pink snapper

The trap surveys show that 0+ and 1+ pink snapper are not evenly distributed across the gulfs of Shark Bay. Numbers of juveniles caught overall were low in comparison to the numbers caught during research trawl surveys in the Freycinet Estuary (Moran and Kangas 2003). The relatively low trap catch rates are partly a function of the extreme patchiness of juvenile pink snapper distribution in relation to the spatial scale of sampling we used, i.e. 2 x 2 and 2 x 4 nm grids, and the low efficiency of traps compared with trawls (see 'Trap indices of 0+ abundance and monitoring of juvenile pink snapper recruitment in future').

Trawl surveys elsewhere in Australia and New Zealand have also shown 0+ and 1+ *P. auratus* to be extremely patchily distributed. In Haruaki Gulf, New Zealand, the degree of patchiness varied with survey area and habitat-type with large variation in catch rates at spatial scales of between 1 km and less than a few hundred metres (Francis 1998). In northern Spencer Gulf, South Australia, the distribution of 0+ snapper was found to be highly clumped from the results of trawl surveys (otter trawl, 12 mm mesh) using transects approximately 2.5 nautical miles apart (Fowler and Jennings 2003).

The benefits of being able to sample across all habitat-types and depths in this study were particularly evident in Denham Sound, where the trawlable habitat, i.e. waters of more than 6 m depth with sand or mud bottom, is located to the north-west with shallow banks to the east and channels with rough bottom to the south. Most of the 0+ pink snapper in this area were found outside the trawlable habitat and the 1+ pink snapper even more so. This was not the case in Freycinet Estuary, where most of the 0+ pink snapper were caught by traps in the trawlable areas while 1+ were mostly caught outside of the trawlable habitat. The pattern in the Eastern Gulf was intermediate between that observed in Denham Sound and the Freycinet Estuary with a minority of the juvenile pink snapper caught in the southern channel habitat and the edges of the eastern shallow banks.

Sampling over the three years proved to be very beneficial given the inter-annual variability and the overall low catch rates. Although annual differences in the distribution of 0+ and 1+ pink snapper were not able to be tested statistically in our analysis, some variation between years was apparent. The combined data for the three years gives a credible picture of the distribution and abundance of at least 0+ pink snapper and strongly supports the view that trawling alone does not give a full picture of juvenile pink snapper distribution and abundance.

Environmental factors influencing distribution of juvenile pink snapper

Our results show that 0+ pink snapper in the gulf waters of Shark Bay are mostly found in depths of 8–12 m. This goes some way to answer earlier questions raised by some in the community about where juvenile pink snapper are to be found inside Shark Bay, and therefore the validity of trawl surveys results used in the past. Researchers use the term 'juvenile' specifically in relation to the 0+ and 1+ age classes whereas recreational fishers, who are unlikely to regularly catch pink snapper this small, are possibly referring to pink snapper just below the minimum legal size (500 mm total length). Such pink snapper are more likely to be 2+, 3+ or 4+ fish, which inhabit quite different waters in terms of depth and habitat-type. In his study using the Antillean-Z traps in waters adjacent to Monkey Mia in the Eastern Gulf, Heithaus (2004) only found juvenile pink snapper (mostly 1+) in what the author described as 'deep' habitats. However the range of depths sampled was only 0.8–10 m (mean 5 m), i.e. significantly less than waters surveyed in our study.

Research trawl surveys in northern Spencer Gulf, South Australia found that most 0+ pink snapper were distributed in the deeper waters, at depths of 17–24 m (Fowler 2000). In contrast, Sumpton and Jackson (2005) found 0+ pink snapper in Moreton Bay, Queensland, were more abundant in areas shallower than 7 m based on trawl (38 mm mesh) and trap (20 mm mesh) surveys. Francis (1998) found no consistent depth-related trends in the abundance of juvenile pink snapper in Hauraki Gulf, New Zealand although the waters surveyed were mainly 10–30 m, i.e. generally deeper than much of Shark Bay surveyed in our trap study. Francis (1998) also found the abundance of 0+ and 1+ pink snapper to be positively correlated, suggesting that both age-classes require similar habitat/environmental conditions in Hauraki Gulf.

From analysis of habitat video footage taken in Shark Bay in 2000, we were unable to identify any clear relationships between habitat-type and the distribution of juvenile pink snapper. Most of the gulf waters can be broadly classified as either seagrass meadow or sand, these habitat-types accounting for over 80% (approximately 40% each) of the sites surveyed. Our inability to demonstrate any significant relationship between habitat-type and the distribution and abundance of juvenile pink snapper was due to the relatively coarse spatial scale of sampling used and the corresponding under-representation of habitats other than sand and dense seagrass in the sites surveyed.

There is evidence that juvenile pink snapper are closely associated with particular habitat-types from studies elsewhere. In the Kawau Bay region of Hauraki Gulf, New Zealand, Francis (1995) found the highest abundances of 0+ and 1+ over areas of relatively flat, muddy bottom. Sampling at a finer scale in the same area using ‘opera-house’ traps, Thrush et al. (2002), found 1+ and 2+ fish to be closely associated with small-scale habitat structure within muddy substrates e.g. depressions made by feeding rays, burrows, shells, and sand-waves. In northern Spencer Gulf, South Australia, 0+ fish were consistently caught in areas that were characterised by muddy substrata rather than sand or gravel (Fowler and Jennings 2003).

Trap indices of 0+ abundance and monitoring of juvenile pink snapper recruitment in future

Standardised mean 0+ trap catch rates from our study, i.e. 0.08–1.57 fish per hour, are higher than the 0.18-0.31 fish per hour found by Heithaus (2004) but low in comparison with 0+ trawl catch rates (e.g. 135–443 fish per hour, Freycinet Estuary survey data, 1996–1998, assuming a 20-minute tow), and reflect the significant differences in fishing efficiency between the gear types. Traps are passive and do not retain all fish which are able to swim out of the entrance funnel. Miller and Hunte (1987) estimated that the effective area fished by Antillean-Z fish traps ranged from 135-345 m^2 for various species of Caribbean reef fish. Trawls in contrast, actively herd and run-down fish, with the total catch integrated over the entire swept area that could include a number of patches of high abundance. Given the World Heritage status of Shark Bay, it should be acknowledged that the trawl gear may cause significantly more damage than the traps in some habitat types (e.g. seagrass areas).

The large proportion of zero catches makes the catch data difficult to analyse statistically. Because the distribution of juvenile pink snapper is extremely patchy, we propose that better precision could be achieved by using a method that covered a larger area and hence had a probability of covering more patches of higher snapper abundance. The 20-minute trawl shots do this and, in Freycinet Estuary in November-December, zero trawl catches are generally rare. The trawls have the disadvantage of not being able to sample areas that are shallow or have a rocky bottom. In any future study we would not use the large Antillean Z-traps but the smaller more-easily deployed ‘opera-house’ traps found to be effective for catching juvenile pink snapper by Ferrell and Sumpton (1998). We would deploy them in lines of 10 or more, with a spacing of approximately 30-50 m between adjacent traps on a line. The line of traps rather than the individual traps, would be the sampling unit, and would enable sampling of all kinds of habitat and provide more statistically useful data.

The purpose of having an index of abundance of 0+ pink snapper is to have a number which accurately reflects relative abundance in one year in comparison to other years. Such indices may be used to determine environmental effects on recruitment, predict future abundance of adults and test for the existence of a relationship between spawning stock size and subsequent recruitment. Clearly, one of the desirable attributes of an index of abundance is a small coefficient of variation. Without this, such indices are of limited value. The standard error of snapper catch rate for a region in a year in this study ranges from 1.5 to 4 times the mean. With the number of traps per area per year being around 100, the coefficients of variation are approximately 15 to 40, much too high for a useful index of 0+ abundance. One source of the variation is likely due to habitat type but another is the scale of sampling relative to the patchy distribution of the target species. The scale of trawl sampling integrates over a number of snapper patches and hence has a much lower variance and a more normal frequency distribution. The trawl sampling with 20-minute, approximately 1 nautical mile (=1.85 km) shots, enables three samples to be collected in a two-hour period. We believe that if trapping could operate more at this scale, it would provide a more useful index of abundance.

A 500 m line of 10 traps is probably a large enough sampling unit to avoid the problem of too many zero catches. Around eight lines could be deployed and retrieved in a two-hour period, allowing for approximately one-hour soak times. Moran and Kangas (2003) inferred the following age-related movement patterns for juvenile pink snapper in the gulfs of Shark Bay based mainly on trawl survey results but also taking account of the trap survey results presented in this report. They concluded that in the Freycinet Estuary, 0+ fish reside in the trawlable habitats from the time of settlement at around 3 weeks of age until well after their first birthday. In contrast, in Denham Sound, 0+ fish only move into the trawlable habitats in their first summer at around six months of age and then remain there until their second summer at around 18 months of age. There is less data available to determine whether the pattern in the Eastern Gulf is more like the Freycinet Estuary or Denham Sound, however, a trawl survey in February 1997 caught many more pink snapper than one in November 1996 (M. Moran and G. Jackson, unpublished data) which suggests fish in the Eastern Gulf follow more the Denham Sound pattern. Based on this, November trawl surveys as currently undertaken do not provide a good index of recruitment for Denham Sound or the Eastern Gulf. Trawl surveys conducted in February-April would provide a better indication of pink snapper abundance on the trawl grounds in all three areas. Since the natural mortality rate is high and catchability in traps may be a function of water temperature, it would be better to conduct trap surveys in February-March while the water is warmer and the numbers of pink snapper have not declined due to natural mortality as low as they would have by May-August. A factor for consideration if a small vessel is used is that conditions in Shark Bay in February are usually windier than in March.

5.0 Conclusions

The trap surveys should be considered a success given the geographic scale at which the research was undertaken, and, in the context that similar studies involving key demersal finfish species are comparatively rare worldwide. This study provides baseline information in relation to the distribution and abundance of juvenile pink snapper in the gulfs of Shark Bay. In addition the research has increased our knowledge of habitat-type in some areas of the gulfs previously unsurveyed. The study has evaluated the usefulness of trap surveys to estimate annual variation in relative abundance of 0+ pink snapper compared with trawl surveys. Our conclusion is that trap surveys of the kind reported here are not suitable for ongoing monitoring of juvenile pink snapper abundance inside Shark Bay. A trawl survey undertaken either in November-December or February-March is the preferred method of estimating relative abundance of 0+ in the Freycinet Estuary where most of the 0+ pink snapper inhabit the deeper, trawlable grounds. In Denham Sound and the Eastern Gulf, lines of traps in combination with trawling in February-March is suggested, to allow sampling of a wider range of habitats where 0+ pink snapper are found.

6.0 Acknowledgements

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8.0 Appendices

Appendix 1

Pink Snapper Trap Survey Data Sheet.

Date: / /	**Personnel:**	**Vessel:**	**Area:**
Weather Conditions:			
Drop No:________ Site Id:	Drop No:________ Site Id:	Drop No:________ Site Id:	Drop No:________ Site Id:
Latitude:	Latitude:	Latitude:	Latitude:
Longitude:	Longitude:	Longitude:	Longitude:
Habitat Type:	Habitat Type:	Habitat Type:	Habitat Type:
Time in:	Time in:	Time in:	Time in:
Time out:	Time out:	Time out:	Time out:
Depth in: out: Temp° in: out:	Depth in: out: Temp° in: out:	Depth in: out: Temp° in: out:	Depth in: out: Temp° in: out:
Video: yes / no Tape No: Frame Nos:	Video: yes / no Tape No: Frame Nos:	Video: yes / no Tape No: Frame Nos:	Video: yes / no Tape No: Frame Nos:
Species and Length Frequency	Species and Length Frequency	Species and Length Frequency	Species and Length Frequency
Drop No:________ Site Id:	Drop No:________ Site Id:	Drop No:________ Site Id:	Drop No:________ Site Id:
Latitude:	Latitude:	Latitude:	Latitude:
Longitude:	Longitude:	Longitude:	Longitude:
Habitat Type:	Habitat Type:	Habitat Type:	Habitat Type:
Time in:	Time in:	Time in:	Time in:
Time out:	Time out:	Time out:	Time out:
Depth in: out: Temp° in: out:	Depth in: out: Temp° in: out:	Depth in: out: Temp° in: out:	Depth in: out: Temp° in: out:
Video: yes / no Tape No: Frame Nos:	Video: yes / no Tape No: Frame Nos:	Video: yes / no Tape No: Frame Nos:	Video: yes / no Tape No: Frame Nos:
Species and Length Frequency	Species and Length Frequency	Species and Length Frequency	Species and Length Frequency

Appendix 2

Habitat classification system used for underwater video footage taken during trap surveys in Shark Bay in 2000 (modified from classification system used by WA Department of Conservation and Land Management).

Habitat Type	Density of cover	Classified Habitat	Sub categories	Size or Form	Description	Comments
Seagrass meadows	sparse cover <20% dense cover >20% very dense cover >50% cant distinguish	A B C	A. Branched	1 tall 2 short 3 undetermined	Generally stands higher than camera Generally stands lower than camera Difficult to determine size or species	Perenial: Amphibolis; has a cluster habit of leaves; Possible Halodule and Halophila and other species.
	sparse cover <20% dense cover >20% very dense cover >50% cant distinguish	D E F	B. Ribbon	1 tall 2 short 3 undetermined	Generally stands higher than camera Generally stands lower than camera Difficult to determine size or species	Perenial: Posidonia; has long straight single leaves; Possible Halodule and Halophila and other species.
	sparse cover <20% dense cover >20% very dense cover >50% cant distinguish	G H I	C. Mixed	1 tall 2 short 3 undetermined	Generally stands higher than camera Generally stands lower than camera Difficult to determine size or species	Perenial: Posidonia and Amphibolis; Possible Halodule and Halophila and other species.
	sparse cover <20% dense cover >20% very dense cover >50% cant distinguish	J K L	D.Unidentified	1 tall 2 short 3 undetermined	Generally stands higher than camera Generally stands lower than camera Difficult to determine size or species	Possible Posidonia, Amphibolis Possible Halodule and Halophila and other species
Sand		M	E. No seagrass	4 Bare	Bare sand; no seagrass	Clear sand, fine or coarse.
Sand and rock, rubble, coral or sponges		N	F. No seagrass	5 undulating	Sand and rock, coral, sponge or rubble	Mainly sand with proportions of coral, sponge, rocks or rubble
Unknown		O	G. Can't distinguish	6 unknown	Very green and silty water	

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Not all have been listed here, a complete list is available online at http://www.fish.wa.gov.au

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