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Localised movement of snapper (*Pagrus auratus*, Sparidae) in a large subtropical marine embayment

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Abstract. Snapper were tagged with dart and anchor tags in order to determine movement and the contribution of juveniles inhabiting estuarine areas to the offshore adult population. Laboratory experiments showed that loss of anchor tags was greater than dart tags, although this was not reflected in the results of field trials. A total of 6572 individuals were tagged in field experiments, of which 509 (7.7%) were recaptured. Only four of over 2500 fish tagged and released in Moreton Bay were recaptured in waters outside the bay, suggesting the bay is not an important source of recruits to the offshore fishery. However, problems associated with tag loss and mortality meant that the actual contribution of juveniles to the offshore fisheries remained unclear. Most snapper movements were localised; only ∼1% of movements exceeded 100 km. Movements of snapper were mainly directed northward against the prevailing direction of the East Australian Current. Snapper were considered to be a suitable species for marine reserve protection owing to their relatively localised movement patterns.

Extra keywords: anchor tag, dart tag, dispersal, fish, tagging, tagging mortality.

Introduction

Tagging studies have been used to infer the degree of mixing of fish stocks (Ihssen *et al*. 1981) as well as provide information on mortality, growth, exploitation, recruitment and stock size (Stoddart 1989). In a carefully designed study, it is possible to infer the degree of mixing among stocks by observing the spatial and temporal pattern of tag returns and relating this to the areas and times when the fish were originally tagged and released. In addition, one of the traditional ways of determining the contribution of specific fisheries to total exploitation rate is by tagging and subsequently observing the pattern of tag returns. The success of such a programme will be dependent on both the patterns of fishing effort relative to the spatial and temporal distribution of the tagging effort and the success of the tag-reporting programme.

In recent years in Australia, recreational anglers and particularly members of the Australian National Sportfishers Association (ANSA) have been involved in tagging large numbers of important recreational fish species in collaborative studies with researchers (Begg 1996; McPhee *et al*. 1999). These studies have been useful because of the benefits that flow from the active involvement of the recreational community in tagging efforts. In many cases, the involvement of recreational anglers is the only way to tag large numbers of fish over a wide geographic area in a cost-effective manner (Saul and Holdsworth 1992). Matthews and Deguara (1992) also noted that collaborative tagging programmes increase conservation ethics among anglers by encouraging the release of captured fish. Despite these advantages, problems that arise include lack of accuracy in measurement and data recording, inconsistent tag application and handling procedures as well as uncertainty in species identification (Lenanton 1989; Saul and Holdsworth 1992; Van der Elst 1990). Ricker (1975) noted that the more useful applications of tagging, such as estimation of mortality, exploitation rate and population size are strongly influenced by tag shedding and mortality associated with the capture and tagging of fish. Many of these problems can be minimised if the programme is well supervised and anglers receive appropriate training. Finally, for important recreational species, such as pink snapper, it is important to encourage community involvement and obtain media coverage so that returns of tagged fish can be maximised. The involvement of the recreational community in the tagging process is one way of achieving this goal.

There have been several snapper-tagging programmes in New Zealand and temperate latitudes in southern Australia. Sanders (1973), Sanders and Powell (1979) and Francis and Winstanley (1989) used tagging methods to examine stock structure and growth rates of snapper in southern Australia. The resultant pattern of tag returns suggested the presence of an eastern and western stock and the possibility of different growth rates between inshore and offshore stocks. More

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recently, McGlennon and Partington (1997) studied tag loss and mortality when using dart and loop tags to tag snapper in South Australia. Tagging has been used in New Zealand to study movements and general methodology relating to tag shedding (Paul 1967; Tong 1978; Crossland 1982), as well as in conjunction with otolith marking for validating otolith ring counts (Francis *et al*. 1992). More recently, Willis *et al*. (2001) found considerable site fidelity in tagged snapper in a marine reserve in New Zealand using visible implant fluorescent elastomer (VIE) tags (Willis and Babcock 1998). Other recent studies have also increased our understanding of snapper movement patterns (Hartill *et al.* 2003; Moran *et al.* 2003).

Earlier studies by Crossland (1976) showed that anchor tags and small dart tags were inferior to larger dart and loop tags in terms of tag shedding. However, many of the dart- and anchor-tagged fish were released in areas where fishing effort may not have been as high as in the areas where the loop-tagged fish were released. Since anchor tags have been commonly used by members of the Australian National Sportfishers Association to tag small snapper in particular, this study aimed to estimate shedding and mortality rates for these tags in both field and laboratory trials.

Many of the areas that support commercial and recreational fisheries for snapper are in large embayments. These include Port Phillip Bay in Victoria (Francis and Winstanley 1989), large gulfs such as Spencers Gulf and Gulf St Vincent in South Australia (McGlennon and Partington 1997), Shark Bay in Western Australia and Hauraki Gulf in New Zealand. By contrast, the fishery on the east coast of Australia is mainly in more exposed offshore waters, along the inner edge of the continental shelf. Despite this, juveniles (and adults) are known to be abundant in the more sheltered bays in this region. The present study involved tagging juveniles in sheltered bays (Moreton and Hervey Bays) and observing the spatial and temporal pattern of returns to determine the contribution that juveniles make to the offshore fisheries in southern Queensland.

Materials and methods

Laboratory experiments

Snapper (300 to 460 mm total length (TL)) were caught by line from RV *Warrego* during 1994 and 1995 in offshore waters (depth 60 to 90 m) of southern Queensland (28°S) to assess short-term tagging mortality. Healthy individuals were returned to the laboratory in 200-L holding tanks within 24 h of capture. There they were kept in 4000 L tanks and allowed to acclimatise for 7 days before tagging with either anchor or dart tags (of the same type as those used in field tagging). Tanks had flow-through seawater and snapper were fed daily to excess on fish (usually *Sillago maculata*). A proportion (usually 20%) of individuals in each holding tank were not tagged and these served as controls. Fish were observed daily to determine tag-induced mortality and tag shedding. Three separate trials were conducted over the two-year period, with a total of 68 fish tagged (36 with dart tags and 32 with anchor tags).

Field-tagging experiments

Between 1992 and 1996, snapper (*Pagrus auratus*) were tagged in Queensland waters in a collaborative exercise involving scientific researchers and members of the Australian National Sportsfishers Association (ANSA). Fish were sampled throughout the species distributional range in Queensland waters (20°S to 28°S), although tagging intensity was concentrated mostly in Moreton Bay and Hervey Bay in order to determine the contribution of juvenile inshore fish to the offshore population.

All fish were caught by hook and line; they were handled using a moist cloth to minimise injury during hook removal and tagging. Fish were measured (±10 mm), tagged and released, usually within 30 s of capture. Where fork length was measured, this was later converted to total length. The release location (usually recorded from GPS coordinates) and date were recorded and the condition of fish on release was assigned a subjective rating scheme from 1 to 4. Fish that were hooked in the lip, suffered no detectable damage and swam away strongly were classified as category 1. Category 2 fish were those that were apparently uninjured but swam away weakly. Snapper that had distended swim bladders were recorded as category 3. The last category (4) was used for fish that suffered some type of damage (other than lip hooking) and swam away in a sluggish manner. Anchor tags (Hallprint 75 mm long, 2 mm diameter; http://www.hallprint.com) and dart tags (Hallprint 91 mm long, 2 mm diameter) were the main tags used, although selections of other tags including loop and streamer tags were also trialed. Anchor and dart tags were placed in the dorsal musculature and locked between the pterygiophores below the dorsal fin rays. Loop tags were placed just anterior to the first dorsal spine (Crossland 1976). Australian National Sportsfishers Association members applied 91% of tags; researchers applied the remaining 9%. Tags were each individually numbered and labelled with a 24-h toll free telephone number. The words 'record size date sex and location' as well as the word 'REWARD' were also written on the tag to encourage the reporting of recaptured fish. Twenty-five per cent of fish were injected intramuscularly with oxytetracycline (OTC) (40 to 50 mg kg^{-1}) to assist with age-validation studies. To determine reporting rates by commercial fishers, tagged fish were also seeded in catches of commercial fishers and in catches sent to fish processing plants by placing fish in catches during observer trips.

Data analysis

Distances moved by individual fish were measured by direct route between release point and recapture location (usually specified as GPS coordinates) and the relationship between distance moved and time at liberty were analysed using the Spearman rank correlation coefficient to investigate the relationship between the variables.

Results

Laboratory experiments

In two of the three sets of tank trials, disease caused mortality of fish within 3 months, causing the early termination of experiments. The tag-shedding rates for both tags totalled for all trials are shown in Fig. 1. During one of the trials, 20% of anchor tags were shed within the first month. Overall, the shedding varied between trials. In all cases where tags were shed, the entire tag was dislodged from the body of the fish and none were broken or chewed off by other fish.

There were no mortalities within the first 7 days after tagging and none of the subsequent mortalities could be directly attributable to the tag or handling practices because there were

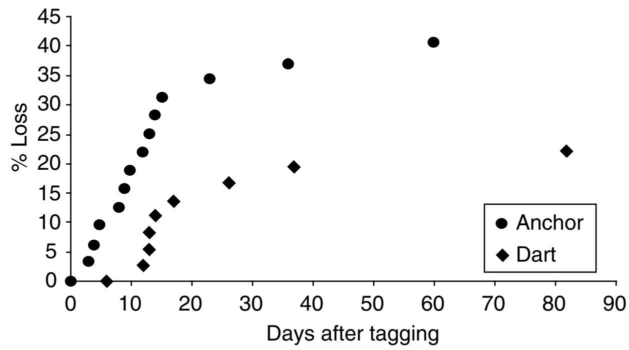

Fig. 1. Loss of dart ($n = 32$) and anchor ($n = 36$) tags by snapper held in laboratory tanks. (Data pooled from all trials.)

Table 1. Tagged snapper release and recapture information
Percentages are shown in parentheses

	Number tagged	Number recaptured
Total fish numbers	6572	509 (7.7%)
Double tagged	226	3 (1.3%)
Oxytetracycline injected	1459	46 (3.1%)
Commercial fishers		26 (5.1% of total recaptures)
Recreational fishers		481 (94.5% of total recaptures)

no significant differences between the mortality of controls and tagged fish ($\chi^2 = 2.34$, d.f. $= 36$, $P > 0.05$). The overall loss of anchor tags was double that of dart tags, with over 40% anchor tag loss within 2 months of tagging.

Field experiments

There were 6572 snapper tagged over the five years of the study, of which 7.7% were recaptured (Table 1). Most of the recaptures (94.5%) were reported by the recreational sector, despite extensive publicity among commercial fishers, many of who were individually contacted by members of the tagging team. Fish-processing companies reported all six tagged fish that were ‘seeded’ in commercial catches. Of the 226 snapper that were double tagged in field trials, only three (1.3%) were recaptured, all with both tags intact. Recapture of fish injected with OTC was significantly less ($\chi^2 = 6.4$, d.f. $= 1$, $P < 0.05$) than that for those that had not been injected. Recapture rates of dart and anchor tags did not differ significantly ($\chi^2 = 0.554$, d.f. $= 1$, $P > 0.05$), with 8% of dart-tagged fish recaptured compared to 7.8% of anchor-tagged fish. To determine the influence of tagger on recapture rates, the recapture rate of fish tagged by the five anglers who tagged the most fish was compared and no significant difference ($\chi^2 = 0.14$, d.f. $= 4$, $P > 0.05$) was found.

As expected, the average size of recaptured snapper was significantly larger ($t = 2.43$, d.f. $= 6690$, $P < 0.05$) than that of released fish (Fig. 2). The length-frequency distribution

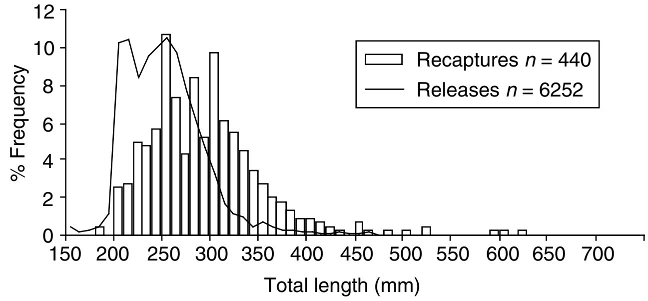

Fig. 2. Length–frequency of released and recaptured snapper from all areas combined.

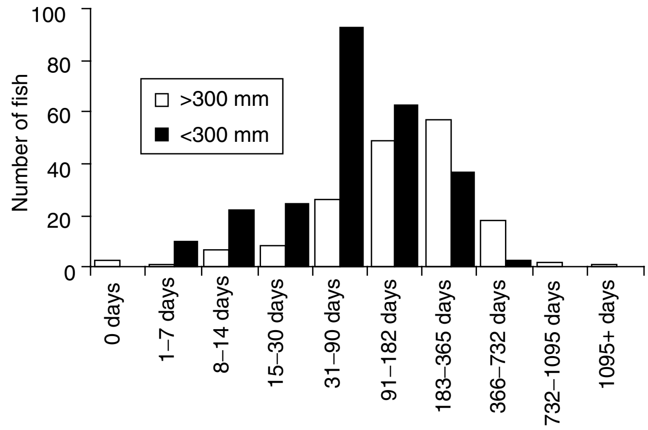

Fig. 3. Number of days at large for snapper less than the minimum legal size (MLS) of 300 mm total length (TL) and fish exceeding the MLS on release.

of recaptures was not simply displaced to the right and it was possible that differential mortality of smaller fish, low reporting rates or some other factor caused a different pattern of recaptures for fish less than 250 mm TL on recapture.

The slopes of both length–frequency distributions to the right of the median were not significantly different (ANCOVA $F = 3.11$, d.f. $= 1{,}54$, $P > 0.05$), indicating that the probability of recapture was the same for all recruited size classes. The greatest proportion of undersized fish was returned within 3 months of release, whereas recaptures of fish greater than the minimum legal size (300 mm) occurred between 6 and 12 months after release (Fig. 3).

Movements of tagged snapper were localised, with over 85% of recaptures occurring within 1 km of their release location (Table 2). Despite this, a few extensive movements were recorded. One fish moved 290 km from Green Island (Moreton Bay) to Platypus Bay (Fraser Island) over a period of six months (Fig. 4). Another travelled from the Qld/NSW border 150 km north to Mooloolaba (Sunshine Coast). Of the 2700 fish that were tagged in Moreton Bay, only four were recaptured in offshore waters outside the bay (Fig. 4). Three of these movements were northward (two to the Sunshine Coast

Table 2. Distance moved between release and recapture for snapper greater than and less than the minimum legal size (300 mm total length) on release

Total length (mm)	Distance moved (km)								
	0	1–9	10–19	20–29	30–39	40–59	50–99	100–149	150+
>300	142	16	5	4	1	0	1	1	1
<300	227	16	6	0	1	0	3	0	0

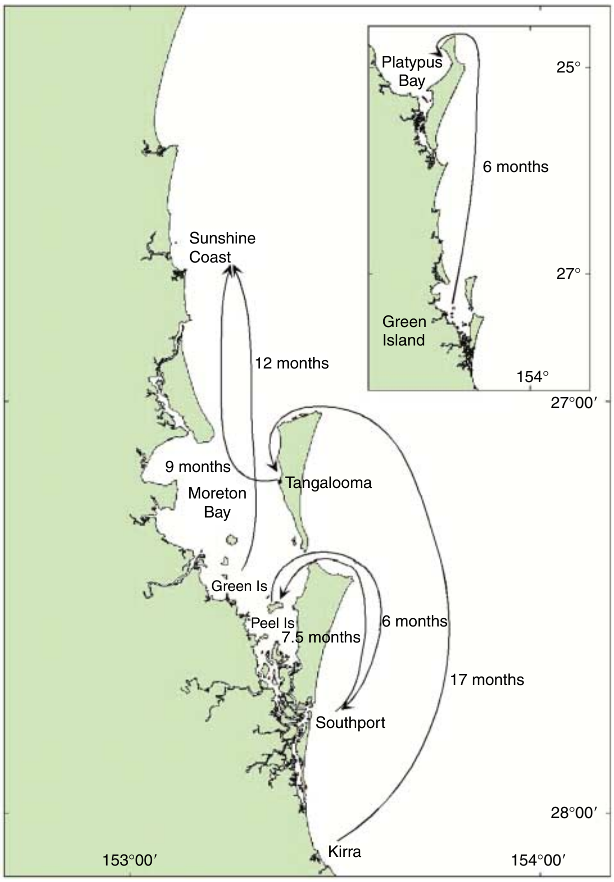

Fig. 4. Movements of snapper that moved out of, or into, Moreton Bay. Note: arrows showing entrance and exit routes into Moreton Bay are speculative because fish may have entered and exited either through the northern, central or southern entrances.

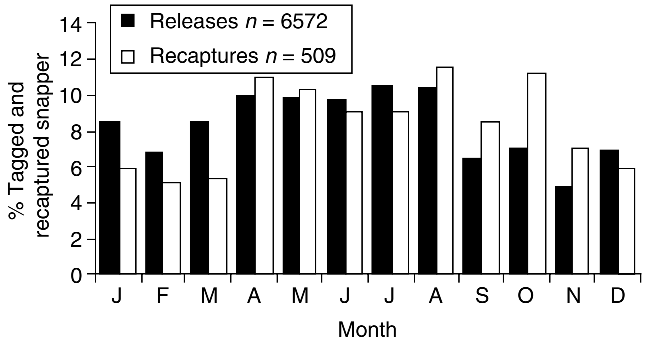

Fig. 5. The percentage of snapper that were tagged and recaptured during various months.

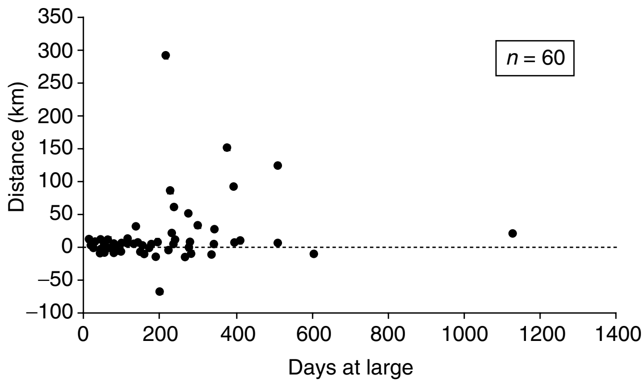

Fig. 6. Directional movement of snapper relative to time at large. Negative distances refer to movement south of the release point and positive values are northerly movement.

and the third to Hervey Bay), whereas one was captured 4 km offshore of Southport on the Gold Coast.

The temporal pattern of tagging effort was significantly different from that of returns (Mann–Whitney U test, $P >$ 0.05). Tagging effort was greatest from April to August, with disproportionately high recaptures from August to November (Fig. 5).

As expected, the distance moved by individual fish was weakly correlated ($R^2 = 0.046$) with their time at liberty (Fig. 6). Overall, there were no consistent directional trends in movement regardless of the area of release, but distances travelled were significantly greater ($\chi^2 = 28.6$, d.f. $= 1$, $P < 0.001$) in a northerly than southerly direction. There was also a weak relationship between fish size and distance moved (Fig. 7), although this trend was not strong ($R^2 = 0.083$) and was influenced by the large movement of two fish that had moved more than 100 km.

Discussion

Tag-induced mortality and tag shedding

Tag-induced mortality is often a major problem in any tagging study, particularly when inferences are to be drawn regarding interactions between fishing sectors, fishing mortality or other population parameters (Hampton and Kirkwood, 1990). In this study, an assessment of tag-induced mortality was

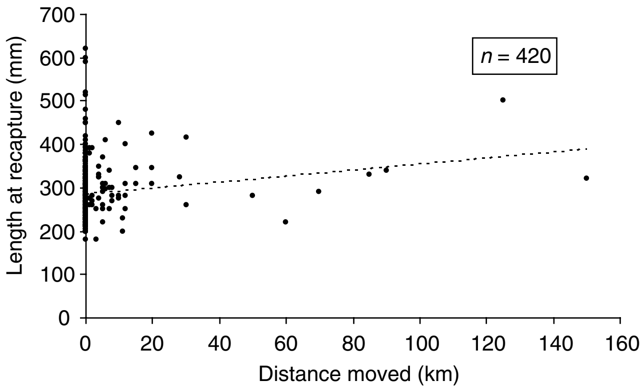

Fig. 7. Fish length (mm total length (TL)) at recapture related to distance moved (km) from release site.

undertaken by observing tagged fish in laboratory conditions. This was a highly artificial situation given that the fish had time to recover from the initial trauma of capture before they were subsequently tagged and released. Nevertheless, the mortality of control fish was not significantly different from either of the tagging treatments. In fact, none of the mortalities could be directly attributable to the tag or tagging process because there were no infections observed at tag-wound sites. In all three experiments, disease (apparently unrelated to the tagging) and water-quality problems caused deaths and the termination of all trials. Capture depth and possible effects of barotrauma has been directly linked to snapper mortality in other tagging trials (see Willis and Babcock 1998). Increased predation of tagged snapper by sharks and other predators may have also been an important source of mortality in the field, but this was unable to be tested.

The use of recreational anglers in a collaborative-tagging exercise, such as this, potentially compromises the use of data for more quantitative fishery assessments owing to non-uniform handling, tagging and release standards. This is because the involvement of many anglers compromises the maintenance of uniform handling, tagging and release standards. This problem was minimised in the present study by only analysing those data from experienced taggers. Over 50% of all fish tagged in Moreton Bay were tagged by a single experienced tagger (N.C.). Analysis of the tagging data of the top five anglers also failed to show any difference in recapture rates, confirming the lack of variation in handling standards.

Studies looking at tag shedding and tagging-induced mortality have often shown considerable variation in these parameters. McGlennon and Partington, (1997) investigated tag-induced mortality and loss of dart and loop tags by snapper and found that loop tags had better retention properties than dart tags. In the present study, tag loss was estimated both via double tagging and by laboratory observation of tagged fish. The relatively low proportion of fish that were double tagged, coupled with low recapture rates, prevented conclusions being drawn about tag loss from field experiments. The laboratory studies clearly indicated that anchor tags were prone to loss and dart tags were retained for significantly longer periods. Field results, however, showed that recapture rates did not differ between the two types of tags. As a precautionary measure, ANSA members have been advised against the use of anchor tags for tagging juvenile snapper and it appears that these tags should be avoided in any long-term study involving this species.

Use of recreational anglers as taggers

The increased involvement of recreational fishers in experimental tagging programmes (Begg 1996; Van der Elst 1990) has raised concerns about variations in tag shedding and tag-induced mortality resulting from the participation of many anglers in the tagging programme. As mentioned earlier, this was minimised in the present study by having only a few people involved in the tagging process. This study has also shown that tagger was not a significant factor influencing recapture rates. McGlennon and Partington (1997) used commercial and recreational fishers as well as research staff during field tagging of snapper in South Australia and found that the recapture rate of fish tagged by recreational anglers was higher than for those tagged by either commercial fishers or research staff. The spatial distribution of tagging effort and subsequent recapture effort clearly influences any comparison of recapture rates and it is still possible for differential recapture rates in certain areas to mask the effects of tagger on recapture rates.

The proportion of recaptured snapper reported by the recreational sector was 18 times that of the commercial sector. The fact that recreational anglers returned most of the tags does not necessarily mean that a multiplier of 18 can be linked to the commercial catch of ~100 tonnes to infer the recreational catch (CFISH commercial catch and effort database, http://chrisweb.dpi.qld.gov.au/chris/). However, it does provide additional evidence of the relative magnitude of the recreational catch documented during recreational diary surveys (Higgs 1998). The survey by Higgs (1998) indicated that the recreational snapper catch was ~6 times the size of the commercial catch. This large recreational catch is one of the reasons why it was not possible to quantify total recapture fishing effort in the present study and link this with tag release and recapture information to provide a clearer picture of movement patterns. Anecdotally, both recreational and commercial fishers have commented on the high intensity of fishing effort in all fishing areas in southern Queensland. The main pattern is the general displacement of commercial effort with recreational effort towards the larger population centres in the south of the state, and particularly inside Moreton Bay, where most of the fishing effort for snapper is applied by recreational anglers.

Although biennial recreational surveys (Higgs 1998) have provided estimates of the recreational catch, effort data is recorded only on very broad spatial scales and cannot be resolved into effort targeting demersal species, such as snapper, compared with pelagic species. By comparison, commercial effort is recorded with relatively high precision and, in some cases, can be resolved into 6-nautical-miles-square grids. Despite all this, the fact that the commercial and recreational fisheries for snapper are line fisheries, which have virtually the same regulations, results in effort generally being distributed in proportion to the catch (Sumpton 2002), so there are no areas where total effort is considerably greater than anywhere else in the southern part of the state.

There was no evidence to support the non-reporting of recaptured snapper by either sector in this study and yet reported recaptures by the commercial sector were relatively limited. There are several possible explanations for this result. First, most tagging effort was directed towards the inshore waters of Moreton Bay, an area that is not heavily fished commercially for snapper, apart from the incidental bycatch of juvenile snapper by prawn otter trawlers (Sumpton 2002). In addition, commercial fishers may be reluctant to report recaptures because they feel they have more to gain by appearing to land significantly less fish than the recreational sector. The manipulation of catch and effort data to impact on management decisions, particularly in quota-managed fisheries, is a well recognised phenomenon in many fisheries around the world (Hilborn and Walters 1992). However, the relative level of recaptures by the two sectors appears to be related to the broad patterns of effort and a generally significantly greater catch by the recreational sector.

Movement patterns

Crossland (1982) concluded that most snapper in Hauraki Gulf, New Zealand were resident and made only localised movements associated with feeding and spawning. He also noted that a small proportion of fish undertook extensive migrations that served to maintain a continuous genetic stock. More recently, Gilbert and McKenzie (1999) have suggested that New Zealand snapper had consistent home ranges of 10–20 km diameter. By comparison, during a study where hatchery reared snapper were marked and released in Japan, Smith and Hataya (1982) found that although 0+ year old snapper could move up to 15 km, most remained within 2 km of their release site. The pattern of movement exhibited by snapper in Queensland was generally a localised pattern where the majority of tagged fish remained within 100 km of their release site. Indeed, most were caught within 2 km of where they were released, a result consistent with the documented behaviour of the species from more temperate areas of its range.

In an earlier study, Sanders (1973) reported on the movement of 210 snapper recaptured from 4155 that had been released in southern Australian waters. He hypothesised the existence of two separate stocks based on the relationship between release and recapture sites. One group of fish moved north along the southern coast of New South Wales, whereas the other stock moved west along Victoria and into South Australia. This study has shown that most movements for snapper in Queensland were northward against the prevailing direction of the East Australian Current. This behaviour is expected given that the projected pattern of movement of spawned eggs and larvae would be southward via that current system.

Despite the extensive tagging of juveniles inside Moreton Bay, there were only four tagged fish recaptured outside Moreton Bay. Given the relatively high commercial and recreational fishing effort in offshore waters adjacent to Moreton Bay, this result is somewhat surprising and indicates most fish remain inside the bay and contribute little to the offshore fisheries. However, high tag-shedding rates of anchor tags by snapper may have also contributed to the lack of detectable offshore movements.

Management implications

The apparently low migration rate of snapper (at least for the size of fish tagged) and lack of any size-related movement pattern suggests that snapper inside Moreton Bay could be managed separately to the offshore stocks. This is relevant given the differences in the recreational fishery in the bay compared to the offshore fishery. It also suggests that trawling in Moreton Bay may have a more localised effect and not necessarily impact to any large extent on the offshore snapper fishery. However, since snapper under 20 cm were not tagged extensively, little is known about their movement patterns and this is the size impacted predominantly by trawlers.

Marine reserves have proven popular in recent years as a means of conserving fish stocks, even when fishing pressure is high in the immediate vicinity of the reserve (Roberts and Polunin 1991; Attwood and Bennett 1994). Small reserves are unlikely to contain highly mobile populations, whereas a large reserve will not allow resident species to stray into adjacent exploited areas (Attwood and Bennett 1994; Kramer and Chapman 1999). Where a species has a relatively small home range, marine reserves have been commonly recommended as a conservation and fisheries management tool. Holland *et al.* (1996), for example, noted that *Caranx melampygus* were a suitable candidate for marine reserve protection because 75% of tagged individuals were captured within 0.5 km of their release point. In South Africa, no-fishing zones have proven effective in conserving resident reef-associated sparids, such as *Diplodus sargus capensis*, *Diplodus cervinus hottentotus* and *Pachymetopon grande* (Buxton and Allen 1989; Cowley 2002). Marine refugia are also commonly used fisheries management tools in the USA (Dugan and Davis 1993) and have been proposed as a conservation measure for *Pagrus auratus* in Queensland (Anon 1998), although none currently exist here specifically for snapper management. Results of tagging suggest that snapper in Queensland may be a good candidate for protection by means of a marine reserve since most of the population is locally resident (within the scale of a couple of kilometres), whereas a small proportion of fish undergo more extensive movement. The results suggest that a reserve of only a few square kilometres would protect a large proportion of the residents and perhaps assist in increasing the spawning biomass. At the same time, the moderate migrations undertaken by a small proportion of the population could enhance surrounding fisheries.

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