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Movements and stock structure of school mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) in Australian east-coast waters

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Abstract. Movements of school mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) in Australian east-coast waters were determined by tag and recapture methods and were used to investigate the stock structure of each species. In all, 4427 school mackerel and 2106 spotted mackerel were tagged and released between 1985 and 1995 in a collaborative tagging exercise with the Australian National Sportfishing Association. School and spotted mackerel were recaptured at rates of 2.1% and 1.8% respectively. School mackerel moved small distances from their release sites (26 ± 55 km, mean ± s.d.; maximum distance, 270 km), with these restricted movements indicating the possible existence of a number of stocks. In contrast, spotted mackerel moved large distances from their release sites (202 ± 290 km; maximum distance, 1100 km). Temporal and spatial movement patterns of spotted mackerel were characteristic of fish from a single stock undertaking a seasonal migration. Commercial harvest information in combination with tagging effort reflected the different movements of school and spotted mackerel and strengthened the suggested stock structure of each species.

Extra keywords: collaboration, fisheries, management.

Introduction

School mackerel (*Scomberomorus queenslandicus*) and spotted mackerel (*S. munroi*) are pelagic species that cohabit coastal waters of northern Australia and southern Papua New Guinea (Collette and Russo 1980). These species, together with grey mackerel (*S. semifasciatus*) and narrow-barred Spanish mackerel (*S. commerson*), form important commercial and recreational fisheries off Queensland, the Northern Territory, Western Australia and, to a lesser extent, northern New South Wales. Conflict between the fishing sectors over a perceived decline in catch rates and access to the school and spotted mackerel resources, and the need for biological information on these species, were responsible for this study.

Evidence of stock differentiation can be indirectly obtained from tagging studies (Brown *et al.* 1987; Sutter *et al.* 1991). Recoveries through time give point locations of organisms, and from their range and movements the degree of mixing between stocks can be inferred (Ihssen *et al.* 1981). Tag–recapture data, however, are generally limited by the proportion of the population that the tagged fish represent. Also, it is difficult to demonstrate from tagging that movement and behaviour patterns indicate gene flow. Recapture patterns may simply be measuring movement rather than genetic interchange (Ihssen *et al.* 1981). Presently, however, tag recovery patterns are the best indicator of seasonal movements throughout the life cycle of a species (Allen 1989).

Collaborative tagging programmes in which recreational anglers use tags and equipment supplied by government fisheries agencies are a cost-effective method for studying fish populations that would otherwise be difficult or very expensive to study by conventional means (Saul and Holdsworth 1992). They are particularly useful for species that undertake extensive migrations and are distributed throughout large geographical regions. Collaborative tagging studies provide valuable biological information for management (Fable 1990; Van Der Elst 1990) and indirect social benefits to the community (Lenanton 1989; Matthews and Deguara 1992), and are suitable in providing data on movement and stock discrimination of a species (Pepperell 1989). The infrastructure for a cooperative tagging programme existed in the Australian National Sportfishing Association (ANSA) Queensland Sportfish Tagging Program (Sawynok 1996). Subsequently, a collaborative tagging project with ANSA Queensland members targeting school and spotted mackerel was initiated because of the existing infrastructure, the economic and logistic constraints of

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undertaking research over a broad geographic area, and the enthusiasm and availability of experienced tagging anglers.

Although movements of highly mobile pelagic species such as billfish (Stroud 1989; Bayliff 1993), tuna (Laurs and Lynn 1977; Eckert and Majkowski 1987) and some mackerels (McPherson 1981; Fable *et al.* 1987; Sutter *et al.* 1991) are well documented, no information has been published on the movements of school and spotted mackerel. This study therefore aimed to determine spatial and temporal movement patterns of school and spotted mackerel in Australian east-coast waters by a collaborative tagging exercise. Movement patterns were used to discriminate stocks.

Materials and methods

Tagging

School and spotted mackerel were tagged in Queensland and northern New South Wales waters (16˚S to 30˚S) in a collaborative exercise involving scientific researchers and ANSA members between 1992 and 1995. A total of 796 school mackerel and 229 spotted mackerel had been tagged by ANSA members from 1985 to 1991. These data were incorporated into the present study. Tagging efforts were concentrated in Moreton Bay and Hervey Bay and in waters off Rockhampton, Mackay, Townsville and Cairns (see Figs 2 and 6). Mackerel were captured by anglers using rod and reel. Captured fish were usually subdued by placing a moist cloth over their head and the hooks removed. Fish were examined for any injuries that could affect their survival. Uninjured fish were measured (fork length), tagged, and released. Tagged fish were usually returned to the water within 20 s. Date and location of each released fish were recorded. One or two yellow, nylon-headed Hallprint dart tags (102 mm long, 2 mm in diameter) were inserted at an angle of approximately 45˚ into either side of the musculature just below the second dorsal fin. Tags were usually locked behind the vertebral or basal fin spines. Individual tags were uniquely numbered and labelled with a 24-h toll-free telephone number, the details to be recorded by the finder of the tag, and the word ‘Reward’ to encourage the reporting of recapture information. The tagging programme was publicized through posters, newspaper and magazine advertisements, television and radio, and oral communications with fishers and processors. Rewards included certificates, hats and drink holders.

Data analysis

Tagging patterns were determined by log-linear models in which seasonal and areal effects were analysed to examine their dependence on tagging effort. Lengths at tagging of fish that were subsequently recaptured were compared with lengths at tagging of all fish, and unpaired *t*-tests determined if recaptured fish were representative of the total tagged population. Spatial variations in the lengths of tagged fish were compared for each species by one-way fixed-effects analysis of variance (ANOVA). Tukey’s Studentized range (HSD) test was used for *a posteriori* comparisons.

Distances moved by individual tagged fish were measured by the direct route between the release and recapture localities. Movement patterns were examined by plotting the distance and direction that recaptured fish moved in conjunction with dates of release and recapture. Distances moved and times at liberty were $\log_e$-transformed to correct for unequal variances and were compared between species by unpaired *t*-tests. Distances moved and times at liberty of recaptured fish for each species were examined by using Spearman rank correlation coefficients (r_s) to investigate relationships between the variables. Linear regressions were then used to examine any significant correlation. Relationships were compared between species by analysis of covariance (ANCOVA), with length as the covariate. The relationship between lengths of recaptured fish when they were initially tagged and their time at liberty was examined for each species with the aid of Spearman rank correlation coefficients.

Commercial harvest

Commercial harvest information up to 1995 was obtained from the Queensland commercial logbook database that was established in 1988. Commercial harvests were averaged monthly for this period. Temporal and spatial patterns of commercial harvest were examined in relation to tagging effort and movements.

Results

In all, 4427 school mackerel and 2106 spotted mackerel were tagged in Queensland east-coast waters and New South Wales north-coast waters between 1985 and 1995. Overall, school and spotted mackerel were recaptured at rates of 2.1% and 1.8% respectively. Altogether, 224 school mackerel and 338 spotted mackerel were double-tagged. Two of the nine recaptured school mackerel retained both tags. These fish had been at liberty for 22 and 203 days. Two of the three recaptured spotted mackerel possessed both tags, although the fish had been at liberty for only 2 and 39 days.

School mackerel

Tagging of school mackerel was unevenly distributed among seasons and among areas (χ^2 = 1009.61, d.f. = 15, $P < 0.0001$). School mackerel were predominantly tagged from late autumn to early spring in Moreton Bay and off Rockhampton and Mackay. Similarly, most of the commercial harvest of school mackerel was taken between Rockhampton and Moreton Bay throughout autumn to spring (Fig. 1). Recaptured school mackerel were larger when they were initially tagged than were tagged fish not recaptured (t = 5.189, d.f. = 4526, $P < 0.0001$), with the length of tagged school mackerel varying significantly between areas (one-way ANOVA, F = 72.6, d.f. = 5,4421, $P < 0.0001$). School mackerel tagged in Moreton Bay were larger than those tagged off Townsville and Rockhampton (HSD, d.f. = 4421, $P < 0.05$). Fish tagged off Townsville were significantly larger than those tagged off Rockhampton. School mackerel released in these localities were also significantly larger than those from Mackay and Hervey Bay (Table 1).

Movements of tagged school mackerel were limited, with 85% of recaptures being less than 50 km from the respective release sites. The largest movement observed for a recaptured school mackerel was 270 km. The fish had moved north from Moreton Bay to Hervey Bay and was at liberty for 199 days. The fish was tagged in March and recaptured in September. Only seven (7%) recaptured school mackerel had moved to a different embayment involving a movement of over 100 km. One recaptured fish moved 150 km north from Rockhampton. The other six fish tagged in Moreton Bay and Rockhampton were recaptured in Hervey Bay between August and January (Fig. 2). Recaptured school mackerel displayed no apparent directional movement pattern throughout the year, being caught in close proximity to their release sites (Fig. 3). The distances that recaptured school mackerel moved were correlated with their times at liberty (r_s = 0.456, d.f. = 100, P < 0.0001). A weak positive relationship (d = 15.33 + 0.12 t, r^2 = 0.06) was observed between distance (d) and days at liberty (t) (F = 6.387, d.f. = 1,100, P < 0.013) (Fig. 4). There was no relationship between the initial tagged lengths of recaptured school mackerel and the times they were at liberty (r_s = 0.167, d.f. = 92, not significant).

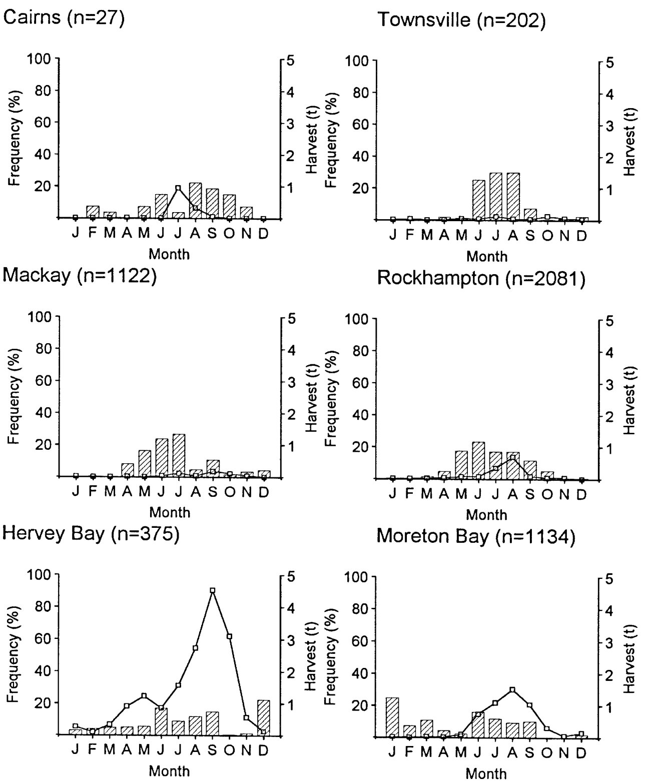

Fig. 1. Monthly distribution of (hatched bars) numbers tagged and (open squares) mean commercial harvest of school mackerel by area.

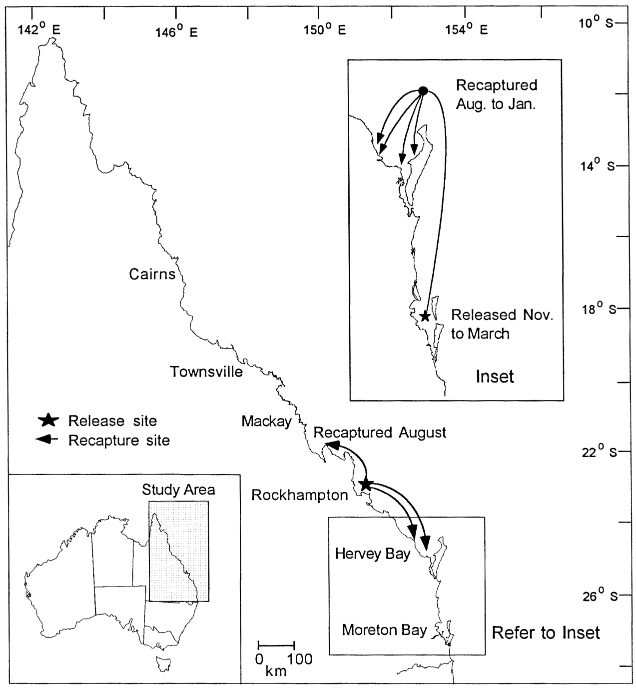

Fig. 2. Movements (>100 km) of school mackerel from tag–recapture data (7% of total recaptures).

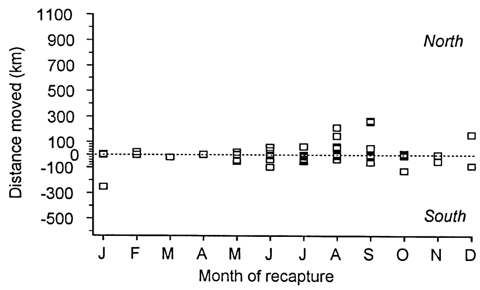

Fig. 3. Monthly directional movements of recaptured school mackerel (n = 102).

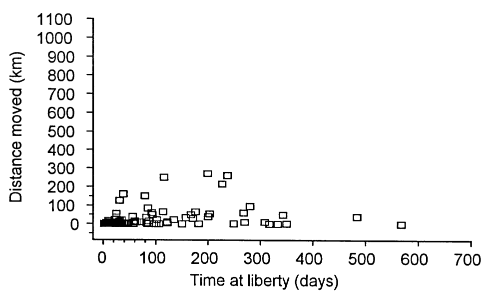

Fig. 4. Movements and times at liberty of recaptured school mackerel (n = 102).

Table 1. Fork lengths (mm) of tagged and recaptured school mackerel for each tagging area
n, number of fish

Area	Fork length of all school mackerel at tagging			Fork length of recaptured school mackerel when first tagged		
	n	Mean	s.d.	*n*	Mean	s.d.
Moreton Bay	1111	451	97	32	478	81
Hervey Bay	268	387	73	15	469	106
Rockhampton	1866	408	70	25	455	75
Mackay	1024	400	46	19	417	58
Townsville	149	430	71	3	477	112
Cairns	9	407	81	—	—	—
Total	4427	417	77	94	458	82

Spotted mackerel

Tagging of spotted mackerel was unevenly distributed among seasons and among areas (χ^2 = 1726.59, d.f. = 15, P < 0.0001). Most fish were tagged during summer in Hervey Bay, with minimal tagging effort at other localities during the remainder of the year. Similarly, most commercial harvest occurred in southern Queensland waters throughout summer and in northern Queensland waters during winter and early spring (Fig. 5). Recaptured spotted mackerel tended to be larger when they were initially tagged than tagged fish not recaptured (t = 1.994, d.f. = 2186, P < 0.0463). The lengths of spotted mackerel tagged and released varied significantly between areas (one-way ANOVA, F = 169.6, d.f. = 6,2099, P < 0.0001). Spotted mackerel released in Hervey Bay, Moreton Bay and New South Wales varied significantly in length from one another and from those in the remaining areas (HSD, d.f. = 2099, P < 0.05). Fish tended to be larger the further south they were tagged. Fish released off Townsville and Mackay were similar in length and were significantly larger than those tagged off Cairns and Rockhampton (Table 2).

Tagged spotted mackerel moved large distances, with approximately 39% of recaptured fish being over 100 km from their release sites (Fig. 6). The largest movement observed for a spotted mackerel was 1100 km. The fish had moved north from Hervey Bay to Innisfail just south of Cairns and was at liberty for 228 days. The fish was tagged in December and recaptured the following July. Movements of recaptured spotted mackerel appeared to be seasonally directed. Tagged spotted mackerel that moved more than 100 km tended to be recaptured in northern Queensland waters during winter and early spring and in southern waters in summer (Fig. 7). Recaptured spotted mackerel moved greater distances the longer they were at liberty (r_s = 0.750, d.f. = 37, P < 0.0001). A significant relationship was observed for spotted mackerel between the two variables (F = 55.21, d.f. = 1,37, P < 0.0001, d = 29.41 + 1.27 t, r^2 = 0.60) (Fig. 8). Spotted mackerel moved greater distances the longer they were at liberty than did school mackerel (ANCOVA, F = 70.64, d.f. = 1,137, P < 0.0001). There was no relationship between the initial tagged lengths of recaptured spotted mackerel and the times the fish were at liberty (r_s = 0.172, d.f. = 36, not significant). Recaptured spotted mackerel moved significantly larger distances from their release sites (202 ± 290 km, mean ± s.d.) than did school mackerel (26 ± 55 km) (modified unequal variances, t = –3.762, d.f. = 39, P < 0.0006). However, recaptured spotted and school mackerel were at liberty for similar periods (spotted: 135 ± 173 days; school: 92 ± 111 days) ($\log_e$ transformation, t = –0.723, d.f. = 141, not significant).

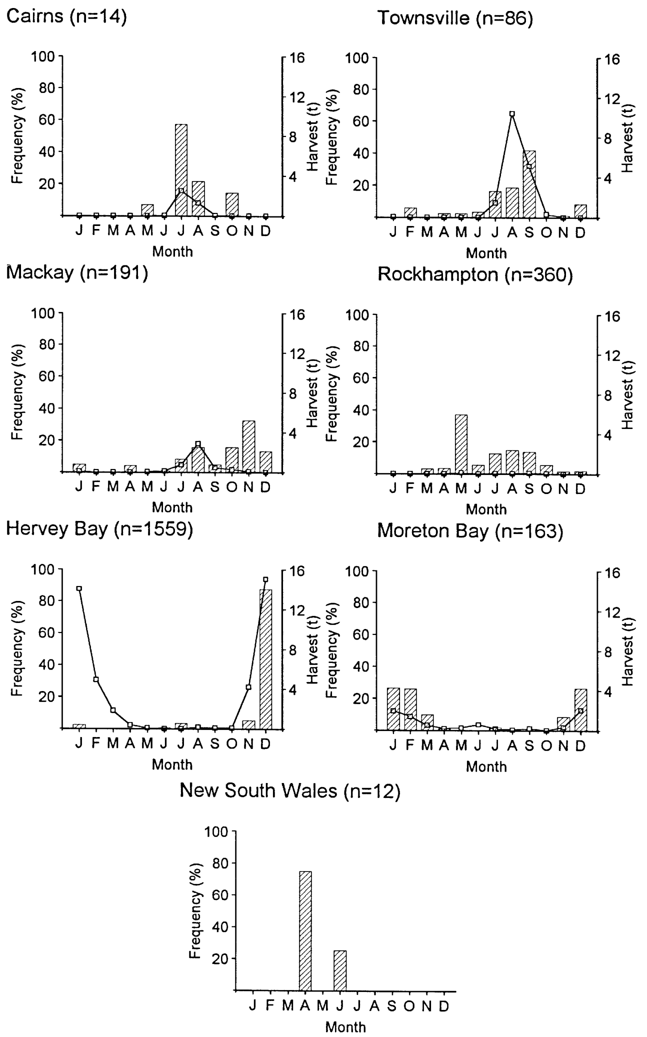

Fig. 5. Monthly distribution of (hatched bars) numbers tagged and (open squares) mean commercial harvest of spotted mackerel by area.

Table 2. Fork lengths (mm) of tagged and recaptured spotted mackerel for each tagging area
n, number of fish

Area	Fork length of all spotted mackerel at tagging			Fork length of recaptured spotted mackerel when first tagged		
	n	Mean	s.d.	*n*	Mean	s.d.
New South Wales	12	868	52	—	—	—
Moreton Bay	146	659	85	3	730	82
Hervey Bay	1475	584	81	31	605	69
Rockhampton	302	462	89	3	445	5
Mackay	88	506	87	2	565	21
Townsville	72	522	96	—	—	—
Cairns	11	367	25	—	—	—
Total	2106	567	101	39	600	86

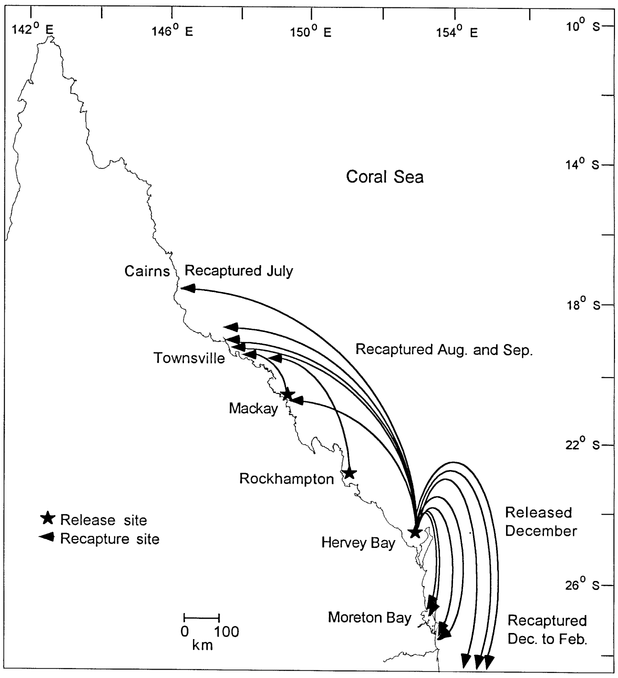

Fig. 6. Movements (>100 km) of spotted mackerel from tag–recapture data (39% of total recaptures).

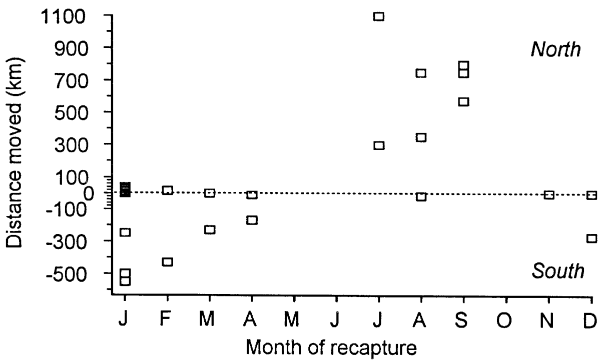

Fig. 7. Monthly directional movements of recaptured spotted mackerel (n = 39).

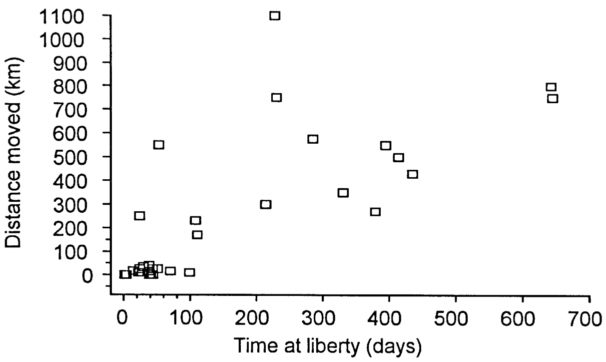

Fig. 8. Movements and times at liberty of recaptured spotted mackerel (n = 39).

Discussion

Movement patterns

Movements of school mackerel were restricted and no seasonal movement patterns were exhibited. Recapture information provided evidence that little mixing may occur between school mackerel in different areas along the Queensland coastline. These limited movements, and temporal overlap of tagging effort and commercial fishing harvest, indicated the possible existence of a number of stocks throughout the study area. Movements north of Townsville are unknown. Movements of a few school mackerel from Moreton Bay and Rockhampton to Hervey Bay, however, suggested the existence of a single stock or a possible common feeding ground for separate stocks off central and southern Queensland. However, only tentative inferences could be made owing to the low number of recaptured fish that participated in these movements.

Recaptured spotted mackerel moved along the Queensland east coast, although movements north of Cairns are unknown. The distances moved by spotted mackerel and the seasonal shift with location of recaptured fish provided evidence of migratory behaviour. These movements, together with spatial and temporal patterns of tagging effort and commercial fishing harvest, are indicative of fish comprising a single stock undertaking a seasonal migration.

The observed movements of recaptured school and spotted mackerel were assumed to be real and not a reflection of variable fishing effort. Recreational fishing effort for mackerel is evenly distributed throughout Queensland coastal waters except in Moreton Bay, where effort was greater (Cameron and Begg, unpublished). In addition, commercial and recreational fisheries for mackerel are highly seasonal and localized, occurring only when the fish are available.

Cyclic migration appears to be a characteristic of some *Scomberomorus* species. Annual migrations by spotted mackerel are similar to those of narrow-barred Spanish mackerel in Australian east-coast waters. A significant proportion of narrow-barred Spanish mackerel participates in a southerly migration in December at the end of the spawning season, with a return migration occurring during September each year (McPherson 1981). Analogous patterns are observed in the Northern Hemisphere for king mackerel (*S. cavalla*). Two migratory groups have been identified from tagging exercises in south-eastern United States waters: a Gulf of Mexico stock and an Atlantic stock, with a transition zone along the southern coast of Florida (Sutter *et al.* 1991; Schaefer and Fable 1994).

School and spotted mackerel have different movement patterns that may aid their coexistence. The large-scale annual migration undertaken by spotted mackerel results in minimal overlap with school mackerel in time and space. As a result, any competition for space and food is restricted to localized seasonal periods when spotted mackerel move into or pass through an area inhabited by school mackerel.

Recapture rates

Recapture rates for school and spotted mackerel were similar to those in tagging studies of other *Scomberomorus* species. McPherson (1981) observed a return rate of 2.5% for narrow-barred Spanish mackerel tagged in Australian waters between the Torres Strait and northern New South Wales. Similarly, the average recapture rate for king mackerel tagged in waters of the south-eastern United States was 2.9% (Fable 1990). Sutter *et al.* (1991), however, observed a recapture rate of 8.4% for tagged king mackerel, attributing their success to the specific use of internal anchor tags as opposed to the commonly used dart tags. A tag retention experiment on king mackerel demonstrated little difference in return rates between internal anchor tags and dart tags for the first 180 days, but beyond that no dart tags were recovered (Fable 1990).

Estimation of tag loss was attempted in the present study by double-tagging. The few recaptures prevented any conclusions from being drawn beyond the fact that tag loss does occur. The collaborative nature of this study prevented the use of internal tags owing to greater insertion complexity and the possibility of higher mortality rates caused by unskilled taggers. Fable (1990) noted that recreational anglers were limited to using dart tags to mark king mackerel as they found it difficult to use the scientifically preferred internal anchor tags.

Inherent problems associated with collaborative tagging programmes through variable tagging experience, operating conditions, and perceptions of the condition of tagged fish before release may be potential causes of tag loss and tag-induced mortality, resulting in reduced recapture rates. In this study, mackerel greater than 700 mm in length were difficult to handle and were often observed to convulse immediately upon landing and die shortly after. Moe (1966) stressed that speed was the most important factor for successful tagging of king mackerel and that a maximum limit of 40 s out of the water would ensure survival of tagged individuals. School or spotted mackerel kept out of water for more than 20 s were generally not tagged and released.

The lengths at release of recaptured school and spotted mackerel were greater than the lengths at release of tagged mackerel not recaptured. This suggests either that the catchability of these mackerels increased with size or that the rate of tag-induced mortality was lower for the larger fish. Although we believe adequate numbers of fish comprising a range of lengths and representing each mackerel population were tagged, the recapture rates might have been increased if a greater number of larger mackerel had been tagged.

Recapture rates may have been influenced by failure to report recovered tags. Direct evidence of non-reporting of tag recaptures by a few commercial and recreational fishers was observed in this study. Fishers claimed to discard recaptured tags owing to their personal resentment of scientific research or fisheries management or to their belief that tagging had been focused on, or would benefit, a fishing sector other than their own. Similarly, Fable (1990) suggested that reduced recapture rates of king mackerel resulted from a decline in the initial enthusiasm shown by fishers and resentment over subsequent management closures.

Management and stock discrimination

This structured collaborative tagging programme provided an opportunity to collect valuable scientific data on the movements of school and spotted mackerel that could have been obtained by independent scientists only through a far more expensive and labour-intensive exercise. Although there were low numbers of recaptures in this study, restricted movements of school mackerel indicated the existence of a number of stocks, whereas movements of spotted mackerel were characteristic of fish comprising a single stock undertaking a seasonal migration. Temporal and spatial patterns of commercial harvest and tagging effort reflected the movement of tagged mackerel and strengthened the suggested stock structures of school and spotted mackerel in Australian east-coast waters.

Identification of a species stock structure is an essential requirement for conservation and fisheries management (Rounsefell 1975; Smith *et al.* 1990). The inability to define stock boundaries could unknowingly prejudice otherwise well designed management efforts (Kutkuhn 1981). Such prejudice could occur in the spotted mackerel fishery, where any management measures imposed in a defined area within the migratory boundaries of the species would have the potential to affect fisheries for the species in other regions. Management of spotted mackerel should be addressed through consultation with all fisheries stakeholders throughout Queensland. In contrast, management actions for school mackerel could proceed at a regional level owing to the suggested existence of several stocks.

The Gulf of Mexico and Atlantic stocks of king mackerel are managed in relation to a line of separation between the stocks that moves seasonally along the east coast of Florida. Discrimination of these groups has major fishery implications because the stock status and management measures vary between them (Brown *et al.* 1987). In Queensland, few fisheries are deliberately managed on the basis of stock structure; those fisheries are based on some stocks shared across jurisdictional boundaries and policies for translocation of fish of identified stocks. Most fisheries are managed on the basis of either distribution of the target species, commercial and recreational activity, physical environment and proximity to land, or fishing apparatus/methodology. The present study will enable potential impacts of management decisions to be evaluated, not only within regions but throughout most of the Australian east-coast distribution of school and spotted mackerel.

It is important that stock identification be recognized as a continuing process, evolving as management needs for stock assessment change but always being viewed against the background of a rational examination of all available data (Brown *et al.* 1987). Given the nature of tagging studies, additional more sensitive techniques that examine biological population parameters and genetic or environmental relationships are required to describe stock boundaries more definitively.

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