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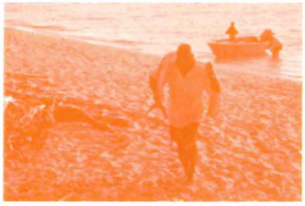

Stock assessment of the Torres Strait Spanish mackerel fishery

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STOCK ASSESSMENT OF THE TORRES STRAIT SPANISH MACKEREL FISHERY

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Non-Technical Summary

T1.2	Stock assessment of the Torres Strait Spanish mackerel fishery

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Objectives:

1. To retrieve and collate all available biological, historical fisheries, and commercial non-indigenous and Islander catch and effort data on the Torres Strait Spanish mackerel fishery.
2. To review, document and report the extent and quality of the collated data and determine the most suitable model for a stock assessment of the Torres Strait Spanish mackerel fishery.
3. To optimise use of all available data to describe current trends in the fishery, and undertake a stock assessment of the Torres Strait Spanish mackerel fishery.
4. To advise on monitoring, reporting and/or further research required to improve or enable future assessments of the Torres Strait Spanish mackerel fishery.

Summary:

Narrow-barred Spanish mackerel, *Scomberomorus commerson*, forms the third largest fishery in the Torres Strait, after the prawn and tropical rock lobster fisheries, and is worth about AUD$1.2 million per year. The fishery operates almost exclusively in the eastern Torres Strait and is also a major source of income and subsistence to Torres Strait Islanders. In addition, as part of the Torres Strait Treaty, Papua New Guinea (PNG) has limited access to the resource according to pre-determined catch sharing arrangements with Australia. Harvest of Spanish mackerel in the Torres Strait, therefore, is shared between Islander, non-indigenous and PNG fishers who have access to the same major fishing grounds, which has led to conflict over allocation of the resource. This assessment arose in response to concerns expressed by stakeholders over the uncertainty surrounding the status of the fishery; driven by questions about the sustainability of current harvest rates, the lack of relevant biological and fishery information, and the aggregated schooling behaviour and predictable seasonal occurrence of Spanish mackerel that renders the species susceptible to over-fishing.

The Torres Strait Spanish mackerel fishery is highly seasonal and localised, where Spanish mackerel are mainly targeted by commercial non-Islander fishers in Bramble Cay from August to December when the fish are aggregated for spawning. Spanish mackerel aged 2 to 4 years form the majority of the catch. Spanish mackerel are also targeted by Islander fishers for sale and subsistence, although the level of participation is relatively low. Commercial non-Islander catches of Spanish mackerel remained relatively constant between 1989 and 2000; reaching a peak in 1997 of about 226 t whole weight. Catches declined significantly in 2001, before increasing in 2002 and 2003. In contrast, commercial Islander catches of mackerel have been variable between 1988 and 2003, reaching a peak in 2003 of 13 t. Historically, Spanish mackerel catches in the Islander sector have mostly come from the

central Torres Strait, although in more recent years significant catches have also been reported from the eastern Torres Strait.

The estimated total catches of Spanish mackerel in Torres Strait have significantly increased since the 1940s. Total catches reached a peak of about 234 t in 1997, following which catches fluctuated down to 109 t in 2001. In 2003, the total catch of Spanish mackerel was estimated to be 178 t. Major uncertainties exist in the total catches, particularly throughout the historical period when compulsory logbooks were not in use and foreign fishing was assumed to occur at unknown levels. Other uncertainties in the estimated total catches exist for the Spanish mackerel catches of non-Islander reef line fishers and the magnitude of the Islander catches.

Standardised catch rates of Spanish mackerel declined from 1989 to 1999, before increasing from 2000 to 2003. Catch rates varied according to temporal, spatial and climatic factors; tending to be higher from October to May. Catch rates were also higher around Bramble Cay and to a lesser degree the eastern Islands, where most of the fishery operates. Not unexpectedly, catch rates were also slightly higher with weaker winds and during dark moon phases.

The Torres Strait Spanish mackerel fishery is most likely being harvested near or exceeding maximum sustainable levels, with biomass levels estimated to be at 26-67% of unfished or virgin biomass levels. Management strategies, therefore, most likely need to be implemented to ensure total catches decline from those in 2003 to ensure the likelihood of the stock size increasing within acceptable levels of risk to avoid being over-fished. These outcomes, however, need to be tempered with the significant uncertainty associated with the various data and model assumptions, although this should not be used as a basis for management inaction, but instead as dictated by the precautionary approach, provide a greater prompt for management intervention.

The uncertainty associated with this assessment and subsequent reference points and management advice derived from the related analysis and models is a function of the quality and extent of the input data. Research and monitoring programs should be directed towards providing the necessary data required for improvements in model parameters and reference point estimation. The Torres Strait Spanish mackerel fishery is monitored by AFMA through the use of compulsory commercial fishery logbooks, Islander docket books, and previously as part of the DPI&F LTMP, although currently there is no routine monitoring of the Spanish mackerel fishery in Torres Strait for biological samples such as ageing data that are required as key input for the age-structured model used to assess the status of the stock. Future assessments of the fishery will only be enhanced by the continuation of a dedicated monitoring program to collect reliable catch, effort and biological data at appropriate spatial and temporal scales. A combination of voluntary fisher and Islander logbooks, as well as periodic observer trips would provide an adequate sampling strategy to ensure that the minimum biological and catch data required for future assessments are collected.

This assessment is the most comprehensive attempt to evaluate the status of the Torres Strait Spanish mackerel fishery. The assessment used all available biological and fisheries data to provide an indication of the current level of exploitation and sustainability of the fishery. At a time when the status of the Torres Strait Spanish mackerel fishery is uncertain and undergoing extensive revision of its current management arrangements, results from this assessment provide stakeholders with an understanding of the status of the fishery to enable future management decisions to be derived from a more informed basis. A major facet of this assessment is that it has highlighted the various sources of uncertainty that exist in the data and model assumptions. Furthermore, the analyses and modeling conducted in this assessment facilitated critical review of the fishery; thereby, making more effective use of the available catch data and past biological research on the species that will assist in setting target management objectives for the fishery.

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1. Introduction

Narrow-barred Spanish mackerel, *Scomberomorus commerson* (Lacépède 1800), is an epi-pelagic, schooling species that inhabits Indo-Pacific waters from the edge of the continental slope to shallow coastal waters (Collette and Russo 1984). Throughout its geographic distribution Spanish mackerel supports important commercial, recreational and artisanal or traditional (*i.e.*, subsistence) fisheries (Collette and Nauen 1983). Globally, there has been a significant increase in the harvest of Spanish mackerel from about 26,000 t in the 1950s to 217,000 t in 2002 (FishStat). Concomitantly, landings of Spanish mackerel have increased throughout northern Australian waters, particularly in the Northern Territory, Western Australia, along the east coast of Queensland and in the Torres Strait (Williams 2002, Mackie *et al.* 2003, AFMA 2004, Buckworth 2004).

Spanish mackerel forms the third most valuable fishery in the Torres Strait, after the prawn and tropical rock lobster fisheries, and is worth about AUD$1.2 million per year (AFMA 2003). The fishery operates almost exclusively in the eastern Torres Strait and is also a major source of income and subsistence to Torres Strait Islanders (Williams and O'Brien 1998). In addition, as part of the Torres Strait Treaty (1985), Papua New Guinea (PNG) has limited access to the resource according to pre-determined catch sharing arrangements with Australia, although is yet to be active in the fishery (AFMA 2004). Harvest of Spanish mackerel in the Torres Strait, therefore, is shared between Islander, non-indigenous and PNG fishers who have access to the same major fishing grounds, which has led to conflict over allocation of the resource (Mapstone *et al.* 2003, Begg and Murchie 2004). Furthermore, despite the significance of the Spanish mackerel resource in the Torres Strait, no formal assessment of the fishery has been undertaken.

This assessment, therefore, arose in response to concerns expressed by all stakeholders over the uncertainty surrounding the status of the Torres Strait Spanish mackerel fishery. These concerns were driven by questions about the sustainability of current harvest rates, the lack of relevant biological and fishery information, and the aggregated schooling behaviour and predictable seasonal occurrence of Spanish mackerel that renders the species susceptible to over-fishing and stock collapse. Concerns about the sustainability of current harvest rates, perceived risks of over-fishing and localized depletions, and recent conflict between stakeholders emphasizes the need for an assessment of the Torres Strait Spanish mackerel fishery to resolve increasing resource allocation and sustainability issues. An assessment of the fishery is considered essential to existing management arrangements and for satisfying the ecological assessment requirements of the Commonwealth Government's Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

Distribution

Spanish mackerel are widely distributed in tropical and sub-tropical waters of the Indo-Pacific from South Africa and the Red Sea, east to Fiji and Japan (Collette and Russo 1984). In Australian waters, Spanish mackerel are distributed from Geographe Bay in Western Australia to St Helens in Tasmania, but are more commonly found around the northern Australian coastline to about 30 °S on the east and west coasts (McPherson 1992, Kailola *et al.* 1993). Spanish mackerel are an epi-pelagic, continental-shelf species, rarely found in waters deeper than 100 m, and are commonly associated with coral reefs, rocky shoals and current lines on outer reef areas and offshore waters to inshore shallow waters of low salinity and high turbidity (Munro 1943, Collette and Nauen 1983, McPherson 1992).

Stock structure

Although there has been considerable research invested in defining the stock structure of Spanish mackerel in northern Australian waters, there still remains considerable uncertainty, particularly regarding the actual stock boundaries and relatedness of fish in the Torres Strait to those in the Gulf of Carpentaria and off the Queensland north east coast (Sumpton and O'Neill 2004). Historically, two stocks of Spanish mackerel were proposed; an east coast stock extending from northern Queensland to New South Wales waters that undertakes seasonal movements throughout its distribution, and a northern Australian stock extending from the Torres Strait to Western Australia (McPherson 1981, O'Brien 1995). Initial genetic studies based on allozymes indicated the presence of a single stock across northern Australia (Lewis 1981, Shaklee *et al.* 1990), while tag-recapture data inferred limited movement, albeit that there were few data (McPherson 1988). In contrast, recent parasitological, otolith chemistry and mtDNA studies have suggested a more complex stock structure than the historical proposition (Lester *et al.* 2001, Moore *et al.* 2003, Ovenden 2004, Buckworth *et al.* 2005). These studies indicate that Spanish mackerel in northern Australian waters conform to a meta-population stock structure, and show a high degree of site attachment (Buckworth *et al.* 2005). Spanish mackerel in Torres Strait most likely comprise an isolated stock from both the Gulf of Carpentaria and Queensland east coast. The geographic extent of the Torres Strait stock, however, is unknown as the recent studies were based on a single sample collected from Bramble Cay (Fig. 1.1).

In this assessment, we assumed that Spanish mackerel in Torres Strait comprised a single stock, extending west of Badu to east of Bramble Cay (9 – 11 30 °S; 141 30 – 144 30 °E) (Fig. 1.1).

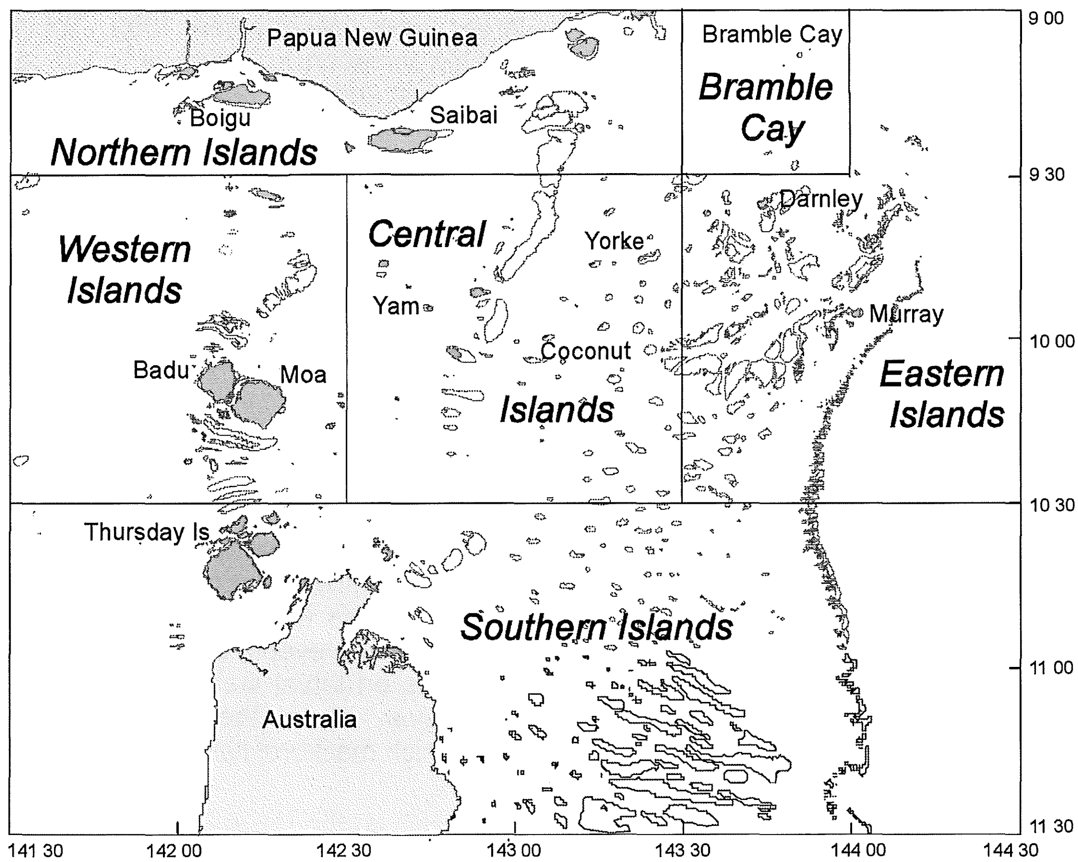

Fig. 1.1. The main fishing grounds and statistical regions used in the assessment of the Torres Strait Spanish mackerel fishery.

Biology and ecology

Spanish mackerel have a protracted spawning season in the Torres Strait, between August and March (McPherson 1986). Peak spawning tends to occur in October, associated with an aggregation of all size groups and equivalent sex ratios (McPherson 1981). Spanish mackerel spawn off reef slopes and edges, forming large spawning aggregations in specific areas, such as Bramble Cay. The species are asynchronous spawners, with individual fish spawning several times over the spawning season, usually in the late afternoon and early evening and during the new and full moon phases (Munro 1942, Jenkins *et al.* 1985, McPherson 1993).

Larvae of Spanish mackerel are commonly associated with reef lagoonal areas (Jenkins *et al.* 1984, 1985, Thorrold 1993), before juveniles (< 10 cm) move to estuary and foreshore nursery and feeding grounds where they tend to remain for the first year of life (McPherson 1981, Jenkins *et al.* 1984). The occurrence of larvae during spring and summer also coincides with maximum planktonic food production, where in combination with higher water temperatures these conditions optimise rapid growth through the early life stages that are vulnerable to predation (Jenkins *et al.* 1985). Little is known, however, about the early life history stages of Spanish mackerel and their habitats and dispersal patterns in the Torres Strait. Juvenile and adult Spanish mackerel are piscivorous predators, feeding mainly on pelagic Clupeoid baitfish such as sardines, anchovies and pilchards, as well as squids and prawns (McPherson 1987).

Spanish mackerel is the largest species of the genus *Scomberomorus*, growing to 240 cm total length (TL) and 70 kg (McPherson 1992). Growth is extremely rapid during the first two years of life before slowing considerably with the onset of maturity (McPherson 1981, Claereboudt *et al.* 2005). Sex-specific growth is also evident in Spanish mackerel, with females tending to live longer and grow to larger sizes (McPherson 1992, Tobin and Mapleston 2004, McIlwain *et al.* 2005). Considerable variation in length is found for any given age of Spanish mackerel, where those from the east and west coasts of Australia have been aged to 17 and 22 years, respectively (Mackie *et al.* 2003, Tobin and Mapleston 2004). Sexual maturity is reached around 90 cm TL (McPherson 1993, Mackie *et al.* 2005).

Spanish mackerel in northern Australian waters appear to be more site-attached than those off the east and west coasts which undertake lengthy seasonal migrations (Buckworth *et al.* 2005). Although seasonality of catches suggests Spanish mackerel in the Torres Strait may also undertake annual migrations, little is known about this behaviour. Tagging experiments conducted in the 1980s, focused principally around Bramble Cay, provided little insight, with few recaptures reported (McPherson 1988).

Environment

Scomberomorus species are found in tropical and temperate coastal waters, generally at or above thermal fronts of about 20 °C. Distribution and movement patterns of Spanish mackerel have been suggested to be related to these fronts (Munro 1943). Furthermore, warm coastal waters and high rainfall associated with El-Niño events are suggested to lead to increased primary production with associated effects on larval survival and recruitment (Tobin, unpublished report). Little is known, however, about the links between the environment and sustainability of the Torres Strait Spanish mackerel fishery.

Fishery description

Commercial fishing for Spanish mackerel in Torres Strait commenced in the 1940s with a few operators supplying fish to Thursday Island (AFMA 2004). Since the 1950s, the number of operators has increased and is now limited to 17 licensed non-Islander fishers, following management intervention in 2003. The fishery is highly seasonal and localised, where Spanish mackerel are mainly targeted in Bramble Cay from August to December when they are aggregated for spawning. Spanish mackerel is also targeted by Islander fishers in the eastern Torres Strait for sale and subsistence, although the level of participation is relatively low, with a greater emphasis on the more valued tropical rock lobster and reef line fisheries (AFMA 2003, Begg and Murchie 2004). A small recreational fishery exists in the Torres Strait with low levels of harvest.

Fishing methods for Spanish mackerel have changed little since the commencement of the fishery (Haysom 2001). Mackerel are predominantly caught by trolling mono-filament lines from small dories (5-6 m) that operate from a larger primary vessel (9-16 m). Hand lines are also used, particularly from those commercial fishers that are dual endorsed to target demersal reef fish. Recreational anglers use similar fishing methods to commercial fishers, but mainly rod and reel. Historically, Spanish mackerel were also targeted by Taiwanese gillnet fishers who caught significant, but unverified quantities off the Gulf of Papua; the effect of which on the Torres Strait fishery was unknown (Chapau and Opnai 1986).

The harvest of marine resources, including Spanish mackerel, is fundamental to the livelihood of Torres Strait Islanders for reasons of tradition, culture, economics and subsistence (Begg and Murchie 2004). Today, commercial fishing is the most economically important industry in the Torres Strait and provides the greatest opportunity for financial independence of Islander communities (AFMA 2003). Historically, Islanders fished on fringing shallow reef-flat habitats of their home reefs, whereas today they have the capacity and economic motivation to fish further afield. Those species that are harvested commercially are typically sold to the community or Council freezer of the fisher's home island (*i.e.*, community fishing), while those that are harvested, but not sold, are kept for subsistence (*i.e.*, traditional fishing) (Johannes and MacFarlane 1991, Mapstone *et al.* 2003, Begg and Murchie 2004).

Management history

Management of the Torres Strait Spanish mackerel fishery is the responsibility of the Australian Fisheries Management Authority (AFMA) and Queensland Department of Primary Industries and Fisheries (DPI&F) on behalf of the Torres Strait Protected Zone Joint Authority (PZJA) and in accordance with the provisions of the Torres Strait Fisheries Act 1984 (AFMA 2004). The management boundary in which the fishery operates includes waters of the TSPZ under Australian jurisdiction and the defined 'outside but near' area to the south (Fig. 1.2). In addition, the fishery operates in waters surrounding several small islands and outcrops (3 nm radius) under Australian jurisdiction to the north of the TSPZ (Williams and O'Brien 1998). In 1999, the fishery was broadened from the harvest of Spanish mackerel only, to also allow that of grey mackerel (*S. semifasciatus*), school mackerel (*S. queenslandicus*), spotted mackerel (*S. munroi*), and shark or salmon mackerel (*Grammatorcynus bicarinatus*).

The fishery is managed through a variety of input controls including constraints on the number of commercial vessels that can operate in the fishery (*i.e.*, limited entry), specification of those vessels and associated fishing gears, and fish size limits (Table 1.1). No management strategies apply to Torres Strait Islanders in the harvest of Spanish mackerel for subsistence, although similar arrangements, besides limited entry, apply to the commercial Islander sector. The fishery is also subject to catch sharing arrangements with PNG under Article 22 of the Treaty. These arrangements allow licensed PNG fishing vessels to operate within the Australian jurisdiction, although this has yet to occur (AFMA 2004).

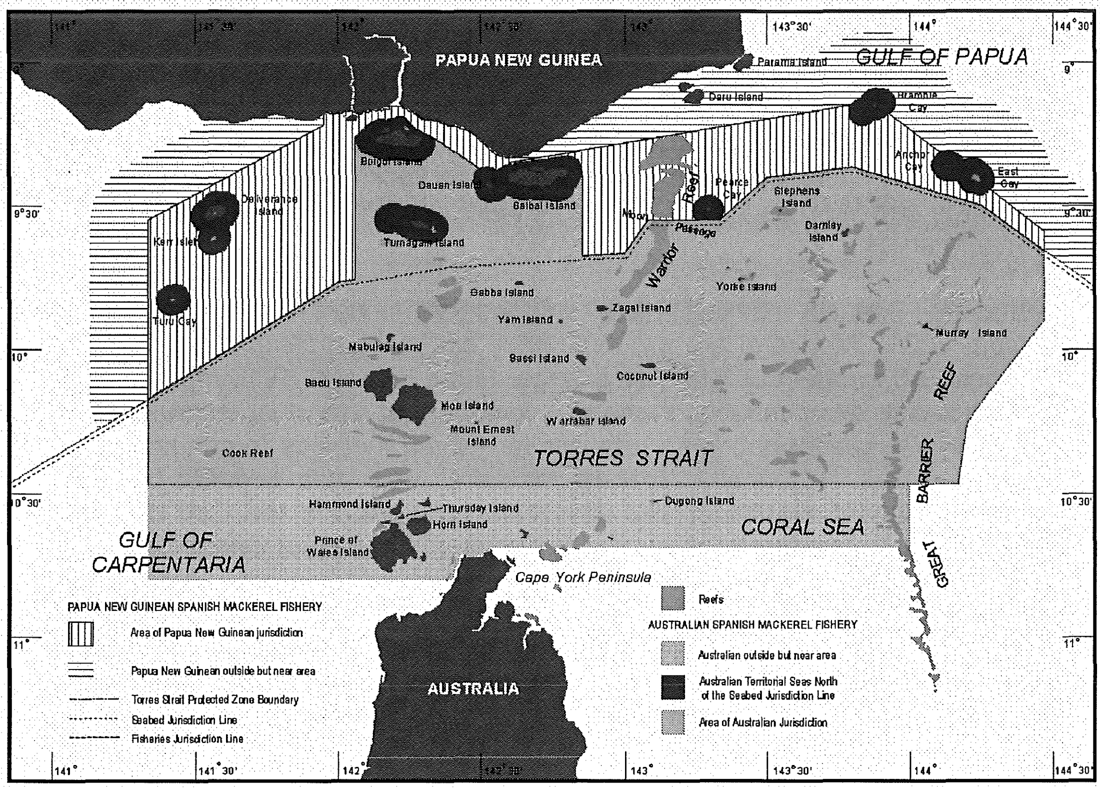

Fig. 1.2. Management area of the Torres Strait Spanish mackerel fishery (AFMA 2004).

Table 1.1. History of management in the Torres Strait Spanish mackerel fishery.

Year	Management
1985	Torres Strait Treaty.
	Torres Strait Fisheries Act dictates joint authority and management of Spanish mackerel fishery between Australia and Papua New Guinea, including catch sharing arrangements.
	Establishment of Torres Strait Protected Zone Joint Authority (TSPZJA) to regulate all fisheries in Torres Strait.
	Transferable licences issued to non traditional inhabitants who could demonstrate history and commitment to fishing in Torres Strait.
	Licences subject to strict vessel replacement regulations related to vessel size.
	Vessels restricted to less than 20 m in length.
	Traditional inhabitants could obtain the commercial fishing license from PZJA.
	Ban on netting of Spanish mackerel.
	Minimum legal size of 45 cm TL for Spanish mackerel.
1988	SM01 logbook introduced (compulsory for non-Islander and PNG fishers)[1].
1990	SM02 logbook introduced (compulsory for non-Islander and PNG fishers).
1998	Fishing methods restricted to trolling, hand-lining and drop-lining.
	Licence holders allowed to carry no more than 50 kg of other finfish besides mackerel.
	Minimum legal size of 45 cm TL for all mackerel.
1999	Traditional inhabitants required to hold a current Torres Strait Traditional Inhabitant Fishing Boat Licence (TIB) or Torres Strait Fishing Boat Licence for commercial fishing in TSPZ.
	Fishery expanded to include spotted, school, shark and grey mackerel.
	Transfer of fisheries management jurisdiction from Queensland to PZJA.
2003	TSF01 logbook introduced (compulsory for non-Islander and PNG fishers).
2004	Islander docket book introduced.
	Minimum legal size increased to 75 cm TL for Spanish mackerel.
	Minimum legal size increased to 60 cm TL for spotted mackerel.
	Minimum legal size increased to 50 cm TL for school, shark and grey mackerel.

[1]Although SM01 logbook program commenced in 1988 for non-Islanders and PNG fishers operating in Torres Strait, the first Logbook Notice 1 was not published until 16 August 1989 (Lilly 2000a, b).

Research history

There has been limited research conducted on Spanish mackerel in the Torres Strait (Table 1.2). Most of the research relates to broader scale studies investigating the stock structure of Spanish mackerel in northern Australian waters (*e.g.*, Lewis 1981, Shaklee *et al.* 1990, Lester *et al.* 2001, Moore *et al.* 2003, Ovenden 2004, Buckworth *et al.* 2005). Also, there have been several preliminary assessments describing the catch patterns in the fishery (McPherson 1986, O'Brien 1995, Williams and O'Brien 1998), but because of data quality issues have been limited in their scope (Haywood and Die 1997). Little is known, therefore, about the fundamental population dynamics of Spanish mackerel in Torres Strait and its resilience to exploitation.

Table 1.2. History of Spanish mackerel research in the Torres Strait.

Year	Author	Research
1943	Munro	Revision of Australian *Scomberomorus* species, including Spanish mackerel.
1981	Lewis	Genetic variation and population structure of northern Australian pelagic species.
1984	Collette and Russo	Morphology, systematics and biology of *Scomberomorus* species, including Spanish mackerel.
1986	Chapau and Opnai	Taiwanese gillnet fishing in the Gulf of Papua.
1986	McPherson	Preliminary review of Torres Strait Spanish mackerel fishery.
1988	McPherson	Spanish mackerel stock structure and movements in Torres Strait.
1990	Shaklee *et al.*	Genetic variation and population structure of Torres Strait Spanish Mackerel.
1992	McPherson	Age and growth of Spanish mackerel in north-eastern Queensland waters including Torres strait.
1995	O'Brien	Preliminary assessment of Torres Strait Spanish mackerel fishery.
1997	Haywood and Die	Assessment of Torres Strait Spanish mackerel fishery. Due to poor data quality assessment not conducted; recommendations made concerning data issues.
1998	Williams and O'Brien	Assessment of Torres Strait Spanish mackerel fishery.
2000a	Lilly	Historical catch and effort data for the Spanish mackerel fishery.
2000b	Lilly	Review of the SM02 logbook for Spanish mackerel fishery.
2001	Lester *et al.*	Stock structure of Spanish mackerel in northern Australia based on parasites.
2003	Moore *et al.*	Stock structure of Spanish mackerel in northern Australia based on parasites.
2004	Begg and Murchie	Islander community freezers catch data for the eastern Torres Strait.
2004	Ovenden	Population genetic analysis of Spanish mackerel stock structure in the Gulf of Carpentaria and Torres Strait
2005	Buckworth *et al.*	Stock structure of Spanish mackerel in northern Australia.
2005	DPI&F	DPI&F Long Term Monitoring Program of Torres Strait Spanish mackerel.
Present	Begg *et al.*	Assessment of Torres Strait Spanish mackerel fishery.

Monitoring history

The Torres Strait Spanish mackerel fishery is monitored by AFMA through the use of compulsory commercial fishery logbooks, Islander docket books, and previously as part of the DPI&F Long Term Monitoring Program (LTMP). Historical data to monitor and evaluate the status of the fishery are also available from the Queensland Fish Board and Island Community Council freezer records. Problems exist with consistency in data recording, quality and continuity for most of the monitoring programs for Spanish mackerel in Torres Strait, leading to significant uncertainty in the assessment, particularly with respect to catch estimates (see Chapters 3 and 4).

AFMA commenced a compulsory Spanish mackerel logbook program (SM01) in 1988 for commercial non-Islander and PNG fishers operating in the Torres Strait (Lilly 2000b). At the same time, fishers were also required to fill out a DPI&F (formerly QFMA) Queensland east coast fishery logbook. In 1990, a revised Spanish mackerel logbook (SM02) was introduced by AFMA, enabling those fishers operating in the Torres Strait and Queensland east coast to use a single logbook, although some fishers still used the east coast logbooks. A review by Haywood and Die (1997) of the AFMA logbook database found that many records were incomplete, while discrepancies existed between the AFMA and DPI&F data, leading to their recommendation that it was impossible to combine the two databases until a considerable amount of data checking was performed. One major discrepancy was that fish numbers were reported in the AFMA logbooks and fish weights in the DPI&F logbooks. In this assessment, we used only the AFMA logbook data to estimate commercial non-Islander catches. Following the Haywood and Die (1997) report, problems identified within the database led to the development of a new database (Lilly 2000a, b); albeit that many of the problems and limitations with the data still exist. In 2003, a general line fishing logbook (TSF01) for both Spanish mackerel and reef line fisheries in Torres Strait was adopted, potentially leading to greater certainty in the more recent catches. Data are reported on a daily basis and includes information on location fished, catch by species, number landed and fishing gear used.

Commercial catch records for Island communities of the eastern and central Torres Strait (Murray, Darnley and Yorke Islands), which target Spanish mackerel, exist in the form of various sales dockets and other disparate sources of Council and private freezer pay books (Begg and Murchie 2004). Individual catch records contain information on species, product type and weight landed, and are assumed to represent daily catches. Data completeness varies among Islands, as does data quality and continuity (Begg and Murchie 2004). Although these records only include those from the eastern and central Torres Strait, these are the main islands involved in the fishery, and thus would be assumed to represent the majority of the Islander harvest (Johannes and MacFarlane 1991, Poiner and Harris 1991). In 2004, AFMA introduced a docket book system to record the Islander commercial catch in a more consistent and detailed manner, including information on location fished.

The Queensland Fish Board collected data from 1936-1980 on its operations and receivals as required by the various Fisheries Acts, and reported these data in an aggregated annual format (Begg *et al.* 2005). Recently, these data were compiled and entered into an appropriate database; with landing weights for each market species reported by district or month (Robins, unpublished data). Few records exist for Spanish mackerel caught from Torres Strait, as most were reported in the total landings from Cairns, where significant catches of mackerel from the Queensland east coast were also landed. In this assessment, we have not attempted to discern the mackerel catches from Torres Strait with those of the east coast as reported in the Fish Board data.

The DPI&F LTMP collects biological information for priority fisheries species on an annual basis to provide data for fishery sustainability reporting and stock assessments. Information is collected on species abundance and population structure including age, length and sex data. Monitoring of the Torres Strait Spanish mackerel fishery was conducted from 2000 to 2002 and involved commercial catch sampling from Bramble Cay (DPI&F 2005) (Table 1.3). Sampling was conducted each year for 14 days in October to coincide with the timing of peak catches and spawning activity (DPI&F 2005). Monitoring ceased in 2003 when recent studies suggested that Spanish mackerel in the Torres Strait formed a discrete stock from those in the Gulf of Carpentaria and along the east coast of Queensland (Lester *et al.* 2001, Moore *et al.* 2003, Ovenden 2004, Buckworth *et al.* 2005). In 2004, AFMA trialled a voluntary fisher logbook designed to record length and sex of Spanish mackerel caught in the non-Islander commercial sector (Table 1.3). In 2005, a CRC Torres Strait research project adopted the DPI&F LTMP protocols to collect information on age, length and sex of Spanish mackerel caught in the commercial non-Islander sector from Bramble Cay in October (Table 1.3).

Data collected from the research and monitoring programs, therefore, were synthesized and reported in this document and form the basis of the assessment for the Torres Strait Spanish mackerel fishery. The main data sources used were those of the AFMA compulsory commercial fishery logbooks, Islander Council freezer records and docket books, and the DPI&F LTMP.

Table 1.3. Number of Spanish mackerel aged and measured in the DPI&F LTMP (2000-2002) and AFMA voluntary fisher logbooks (2004).

Year	Number aged			Number measured			
	Oct	Nov	Total	Sep	Oct	Nov	Total
2000	795	97	892		802	98	900
2001	874		874		909		909
2002	602		602		612		612
2004				721	662	406	1789
2005[1]	710		710		719		719
Total	2981	97	3078	721	3704	504	4929

[1]Data collected in 2005 as part of the CRC Torres Strait project were not included in the assessment.

Objectives

This assessment was conducted in response to the growing concerns of all stakeholders for the sustainability of the Torres Strait Spanish mackerel fishery. The potential meta-population stock structure, highly aggregated schooling and voracious feeding behaviour, and predictable seasonal occurrence allows ease of targeting; thereby making the stock susceptible to over-fishing, localised depletion and stock collapse (Tobin and Mapleston 2004). The objectives of this assessment, therefore, were the following:

1. To retrieve and collate all available biological, historical fisheries, and commercial non-indigenous and Islander catch and effort data on the Torres Strait Spanish mackerel fishery.
2. To review, document and report the extent and quality of the collated data and determine the most suitable model for a stock assessment of the Torres Strait Spanish mackerel fishery.
3. To optimise use of all available data to describe current trends in the fishery, and undertake a stock assessment of the Torres Strait Spanish mackerel fishery.
4. To advise on monitoring, reporting and/or further research required to improve or enable future assessments of the Torres Strait Spanish mackerel fishery.

2. Population dynamics

The main biological data available for Spanish mackerel in Torres Strait were those collected through the DPI&F LTMP in 2000-2002. These data were limited in that they were collected over a 14 day period from Bramble Cay in October and November (Table 1.3). Some length and sex data were also available through an AFMA motivated pilot study of voluntary fisher logbooks in 2004. Estimation of biological parameters used in this assessment, therefore, were derived from the limited data sources available or published relationships for Spanish mackerel in Western Australia, Northern Territory or Queensland east coast waters (Mackie *et al.* 2003, Buckworth 2004, Tobin and Mapleston 2004).

Growth

Fork length – total length relationship

The DPI&F LTMP only collected fork length (FL) data for Torres Strait Spanish mackerel. The estimated fork length – total length relationship derived for Spanish mackerel in Western Australian waters (Mackie *et al.* 2003), therefore, was used to convert FL to total length (TL) measurements according to the following:

$$TL = 42.74 + (1.06FL) \tag{2.1}$$

where, TL and FL are in mm. The relationship was based on data pooled across years (1999-2002), sexes and regions (n=1679; R^2=0.996). All subsequent length data presented in this report were converted to TL and cm.

Total length – weight relationship

Non linear least squares regression models were fitted to sex-specific Spanish mackerel total length (TL, cm) and fish weight (kg) data collected from the DPI&F LTMP (Table 2.1, Fig. 2.1). Data were pooled across months (October-November) and years (2000-2002). Seasonal patterns in length-weight relationships could not be estimated because of the restricted nature of the sampling. A general linear hypothesis test was used to determine the effect of sex on the length-weight relationship (Myers 1990). No significant difference was found between the non linear least squares fittings of male and female Spanish mackerel (F=1.64, p=0.195, df=288). The data, therefore, were pooled across sexes to determine a common total length-weight relationship. The average Spanish mackerel sampled was 7.3 kg.

Table 2.1. Non linear least squares regression models for predicting fish body weight (kg) from total length (TL, cm) ($Wg = a*TL^b$).

(A) Females (n=469). Residual standard error: 0.688139 (std of fit in kg) on 467 d.f. R^2=0.95.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
a	2.96043e-6	4.66237e-7	6.35	<0.0001	2.17e-13	-1.54e-08
b	3.14800	3.30455e-2	95.26	<0.0001	-1.54e-08	1.09e-03

(B) Males (n=408). Residual standard error: 0.466511 (std of fit in kg) on 406 d.f. R^2=0.92.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
a	4.22444e-6	8.32037e-7	5.08	<0.0001	6.92e-13	-3.51e-08
b	3.06788	4.22264e-2	72.65	<0.0001	-3.51e-08	1.78e-03

(C) Data pooled across sexes (n=877). Residual standard error: 0.598966 (std of fit in kg) on 875 d.f. R^2=0.72.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
a	2.71802e-6	2.97337e-7	9.14	<0.0001	8.84e-14	-6.87e-09
b	3.16478	2.31139e-2	136.92	<0.0001	-6.87e-09	5.34e-04

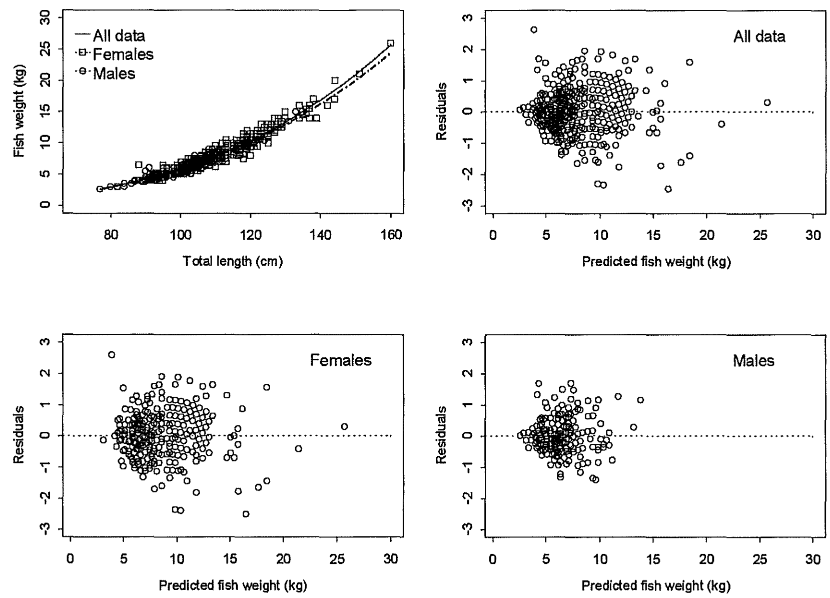

Fig. 2.1. Total length (cm) – weight (kg) sex-specific relationships of Spanish mackerel, data pooled across years (2000-2002).

The fitted models used to predict fish body weight (Wg, kg) from total length (TL, cm) measurements were the following (Table 2.1):

Females: $$Wg = 2.960e-6(TL^{3.148}) \quad (2.2)$$

Males: $$Wg = 4.224e-6(TL^{3.068}) \quad (2.3)$$

All data: $$Wg = 2.718e-6(TL^{3.165}) \quad (2.4)$$

Von Bertalanffy growth relationship

Non linear least squares regression models were fitted to sex-specific Spanish mackerel total length and age data collected from the DPI&F LTMP. The ages (years) of individual Spanish mackerel collected were determined from whole sagittal otoliths. Final age estimates involved multiple reads by multiple age readers. Otoliths collected in 2000 were aged by three readers, twice each by two independent readers and once by a third reader. A sub-sample of 200 otoliths were also sectioned and aged twice by one of the readers to confirm the whole otolith ages. In contrast, otoliths collected in 2001 were initially aged twice by one of the readers, and if the ages disagreed a third read was conducted by the same reader. Otoliths collected in 2002 were aged once by two independent readers, and if the ages disagreed a second read was conducted by one of the readers.

Age reading followed the protocols described in Mackie *et al.* (2003) and modified in Tobin and Mapleston (2004). For each otolith, the number of clear opaque bands (or increments) was counted and a marginal increment category assigned according to the amount of otolith growth after the last clear and visible opaque band (Table 2.2). The age of each otolith was then the total number of opaque bands counted and adjusted for the margin category. If the margin category was assigned a 0 or 1, the age was the number of opaque bands counted and no adjustment was necessary. However, if the margin category was 2 or 3, the age was the number of opaque bands counted plus one.

Table 2.2. Description of marginal increment categories used in the adjustment of final ages according to protocols of Mackie *et al.* (2003) and Tobin and Mapleston (2004).

Margin category	Description
0	Opaque band clearly visible on the margin of the otolith and no translucent material outside the opaque margin.
1	Translucent material is visible outside the opaque band and accounts for 25-33% of the translucent material deposited in the previous year of growth.
2	Translucent material is visible outside the opaque band and accounts for 50% of the translucent material deposited in the previous year of growth.
3	Significant amount of translucent material is visible with some opaque material on the margin, but it is not continuous or consistent.

The final age assigned to each Spanish mackerel was estimated to be the majority between all age readings, otherwise the data were excluded from the analysis. About 2% of the data were excluded (n=53). Final data used in the analysis were pooled across months (October-November) and years (2000-2002) (Table 1.3).

The fitted von Bertalanffy growth models were used to predict total length (TL, cm) from age (years) (Table 2.3, Fig. 2.2). Length based growth curves were estimated for the von Bertalanffy growth parameters according to the following equation:

$$L_t = L_\infty(1 - e^{-K[t-t_0]}) \tag{2.5}$$

where, L_t = length (cm) at age t (years); L_∞ = asymptotic average maximum fish length; K = growth rate coefficient that determines how quickly the maximum length is attained; and t_0 = hypothetical age at which the species has zero length (*i.e.*, fixes position of curve along x-axis and can affect the steepness of the curve) (Haddon 2001).

Table 2.3. Sex-specific von Bertalanffy growth parameters (L_∞, K, t_0) used to predict total length (TL, cm) from age (years).

(A) Females (n=1271). Residual standard error: 5.96494 (std of fit in cm) on 1268 d.f. R^2=0.63.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	158.5940	6.9287	22.89	<0.0001	48.0064	-0.1635	-3.7403
K	0.1523	0.0239	6.38	<0.0001	-0.1635	0.0006	0.0134
t_0	-4.8093	0.5695	-8.44	<0.0001	-3.7403	0.0134	0.3244

(B) Males (n=1096). Residual standard error: 5.20412 (std of fit in cm) on 1093 d.f. R^2=0.52.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	143.9750	8.6145	16.71	<0.0001	74.2103	-0.2361	-8.9224
K	0.1229	0.0277	4.44	<0.0001	-0.2361	0.0008	0.0297
t_0	-7.2967	1.0836	-6.73	<0.0001	-8.9224	0.0297	1.1741

(C) Data pooled across sexes (n=2368). Residual standard error: 6.52214 (std of fit in cm) on 2365 d.f. R^2=0.54.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix		
L_∞	147.0970	4.3218	34.04	<0.0001	18.6776	-0.0835	-1.8171
K	0.16677	0.0197	8.48	<0.0001	-0.0835	0.0004	0.0087
t_0	-4.8576	0.4501	-10.79	<0.0001	-1.8171	0.0087	0.2026

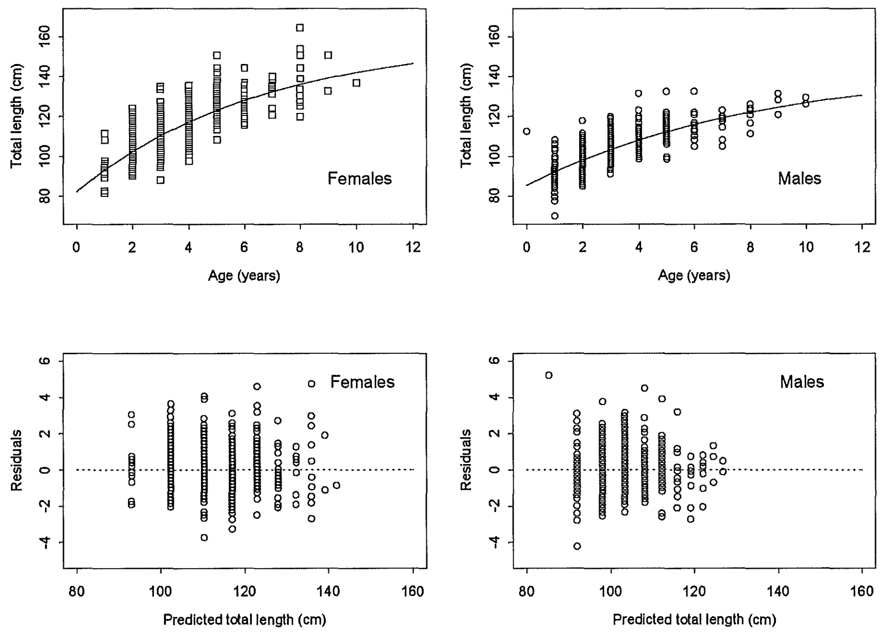

Fig. 2.2. Sex-specific von Bertalanffy growth models used to predict total length (cm) from age (years). Age zero refers to 0+ fish (likewise for other age groups).

Spanish mackerel in Torres Strait grow extremely fast, particularly in the first year of life. Based on the DPI&F LTMP data, Spanish mackerel grew on average to about 93 cm TL in their first year, with the largest one year old fish observed to be about 112 cm TL. The fitted von Bertalanffy growth models for both females and males, however, were influenced by the selectivity of the fishing gear; inherent characteristics of fisheries-dependent data. Although the models demonstrated reasonable reflections of the average maximum size of Spanish mackerel (*i.e.*, L_∞), estimates of K and t_0 appeared to be unrealistic. Different values of t_0 were then fitted to the different growth models to obtain potentially more realistic model estimates. Figure 2.3 demonstrates the change in values of the highly correlated L_∞ and K when different values of t_0 were used. As t_0 increases, growth rate (K) decreases and asymptotic maximum length (L_∞) increases. Different growth models were then fitted separately to the sex-specific data with t_0 fixed at three different values (-0.5, -1.0, -2.0). All of these models, however, under-estimated the lengths of older age groups; unlike the optimum model fits (Fig. 2.2, 2.4).

Sex-specific growth parameter estimates from other studies of Spanish mackerel in waters across northern Australia varied from those for Torres Strait (Table 2.4). Generally, the mean asymptotic maximum length was estimated to be lower than those for Torres Strait Spanish mackerel, except for the potentially more geographically similar Northern Territory stock (Buckworth 2004). The fitted models used to predict total length (TL, cm) from age (years) of Torres Strait Spanish mackerel, therefore, were the following (Table 2.3):

Females: $$L_t = 158.59(1 - e^{-0.152[t+4.81]}) \tag{2.6}$$

Males: $$L_t = 143.98(1 - e^{-0.123[t+7.30]}) \tag{2.7}$$

All data: $$L_t = 147.10(1 - e^{-0.167[t+4.86]}) \tag{2.8}$$

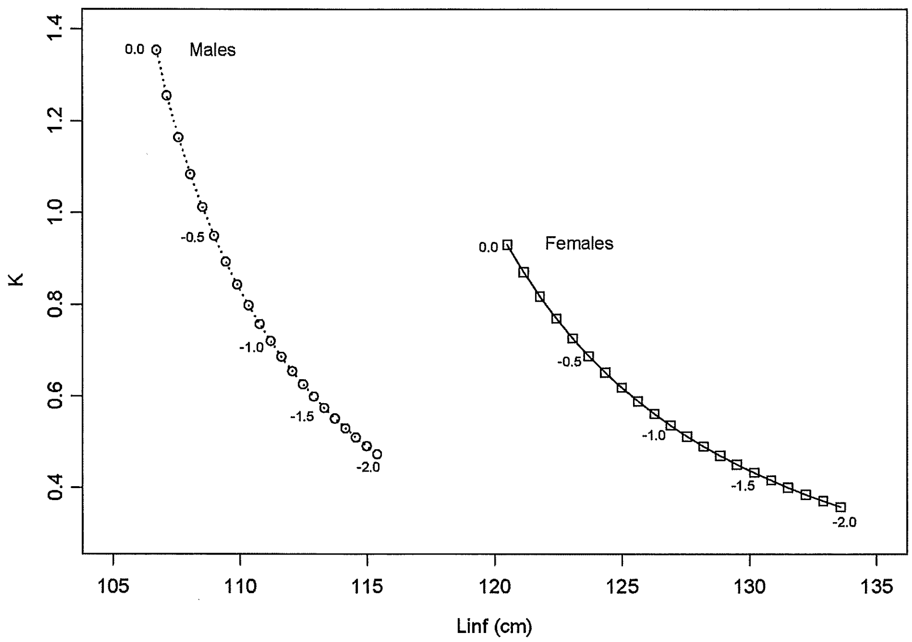

Fig. 2.3. Change in values of von Bertalanffy growth parameters *K* and L_∞ when fitting different values of t_0 for female and male Spanish mackerel.

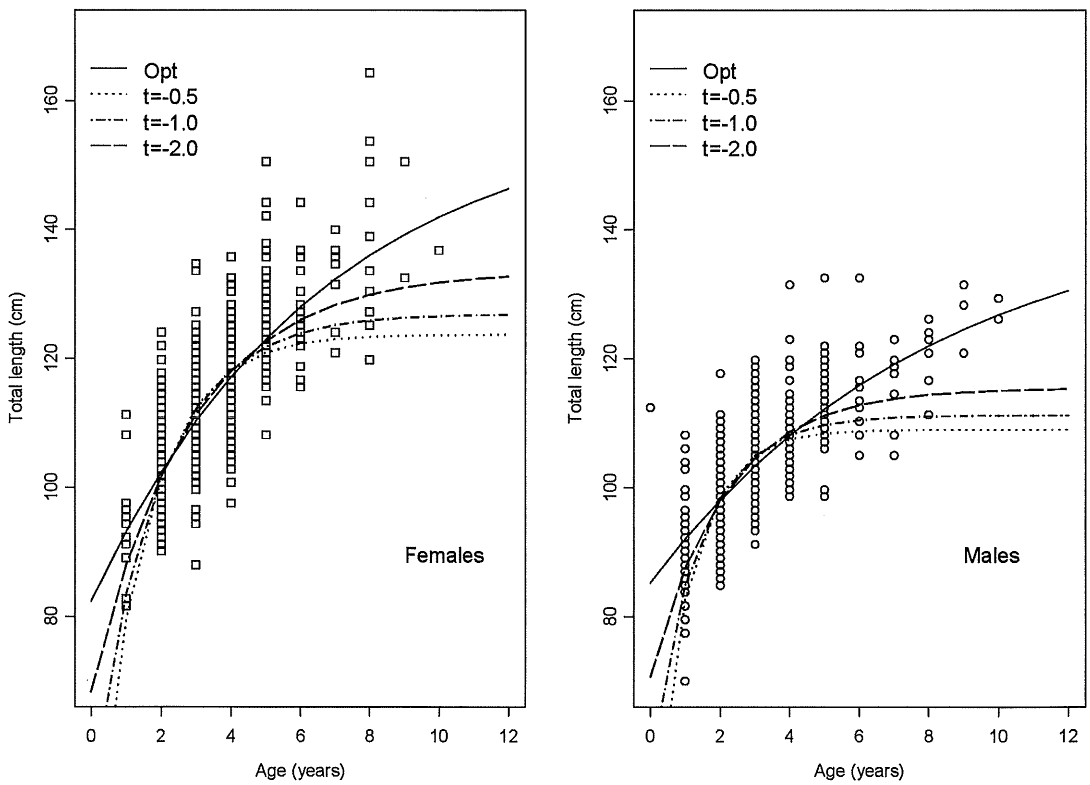

Fig. 2.4. Change in von Bertalanffy predicted growth patterns for fixed values of t_0 (-0.5, -1.0, -2.0) for female and male Spanish mackerel. Optimum growth model is shown for comparison.

Table 2.4. Sex-specific von Bertalanffy growth parameters (L_∞, K, t_0) estimated for Spanish mackerel from waters in northern Australia. All L_∞ estimates in FL (cm). NT = Northern Territory; QLD = Queensland; WA = Western Australia.

Sex	Region	L_∞	K	t_0	n	Source
Females	NT	151.6	0.12	-6.31	206	Buckworth (2004)
	East QLD	124.8	0.51	-0.39	248 (811)	Ballagh *et al.* (2006)[1]
	North-east QLD	155.0	0.17	-2.22	1429[2]	McPherson (1992)
	WA: Kimberley	121.9	0.65	-0.26	324	Mackie *et al.* (2003)
	WA: Pilbara	125.9	0.63	-0.29	417	Mackie *et al.* (2003)
	WA: West coast	120.5	0.66	-0.26	156	Mackie *et al.* (2003)
Males	NT	128.6	0.10	-9.80	161	Buckworth (2004)
	East QLD	104.7	0.75	-0.18	187 (601)	Ballagh *et al.* (2006)[1]
	North-east QLD	127.7	0.25	-1.72	1429[2]	McPherson (1992)
	WA: Kimberley	106.7	0.85	-0.21	336	Mackie *et al.* (2003)
	WA: Pilbara	115.5	0.69	-0.29	344	Mackie *et al.* (2003)
	WA: West coast	114.1	0.76	-0.21	121	Mackie *et al.* (2003)

[1]Age estimates based on back-calculation (Ballagh *et al.* 2006). Numbers in parentheses are number of annuli measured.
[2]Sample size for individual sexes not specified. The total number of males and females aged were 1429 fish.

Maximum age and length

The oldest Torres Strait Spanish mackerel aged in the DPI&F LTMP (2000-2002) data was a 12 year old, 128 cm TL, 12 kg fish (sex unknown). The oldest, largest and heaviest females were 10 years old (137 cm TL), 164 cm TL (8 years), and 26 kg (age unknown, 161 cm TL), respectively. In contrast, the oldest and largest males were 10 years old (126, 129 cm TL), and 133 cm TL (5, 6 years), respectively. The 6 year old fish was also the heaviest male aged (15 kg).

Sex ratio

Length based sex ratios were estimated for Spanish mackerel collected in 2000-2002 and 2004 from the DPI&F LTMP and AFMA voluntary fisher logbooks, respectively. Data were pooled across months (October-November) and years (2000-2002) (Table 1.3; Appendix 1). An increasing trend of greater numbers of females in the population at larger sizes was observed in the data (Fig. 2.5).

A generalised linear model (GLM) for binary regression (McCullagh and Nelder 1989) was used to predict the probability (P) of a Spanish mackerel being female. The probability P was modelled using a logistic-link (*i.e.*, logit) function and binomial error distribution, and related through a logistic regression function with total length (TL) as a covariate according to the following:

$$P(Female \mid n) = \frac{e^{\alpha+\beta TL}}{1+e^{\alpha+\beta TL}} \tag{2.9}$$

where, n = number of Spanish mackerel in each length class; TL = total length (cm); and α and β are model parameters to be estimated from the data. The model identified significant changes in the probability of a Spanish mackerel being female with length (Table 2.5, 2.6, Fig. 2.6).

The final length based sex ratios were based on observed data and an assumed 50:50 sex ratio up until 105 cm TL; the length at which the proportion of females began to consistently increase. Observed data were then used for increasing 5 cm length intervals (*i.e.*, ≤105 cm

50%; 106-110 cm 57%; 111-115 cm 72.5%; 116-120 cm 82.5%; 121-125 cm 87.5%; 126-130 cm 92.5%; >130 cm 100% females).

Table 2.5. Analysis of deviance for binary model (covariate – TL, cm) in determining the probability of a Spanish mackerel being female. Data were pooled across months and years (2000-2002 and 2004). R^2=0.16.

Fitted term	d.f.	Deviance	Mean deviance	Chi square	Probability
TL	1	733.09	733.09	610.91	<.0001
Residual	4154	4979.09	1.20		
Total	4155	5712.18			

Table 2.6. Parameter estimates and standard errors from the binary regression analysis of the probability of a Spanish mackerel being female.

Parameter	Estimate	S.E.	T Statistic	Probability	Covariance matrix	
Constant	-10.8814	0.4694	-23.18	<0.0001	0.220351853	-0.00209798632
TL	0.1056	0.0045	23.56	<0.0001	-0.002097986	0.00002008014

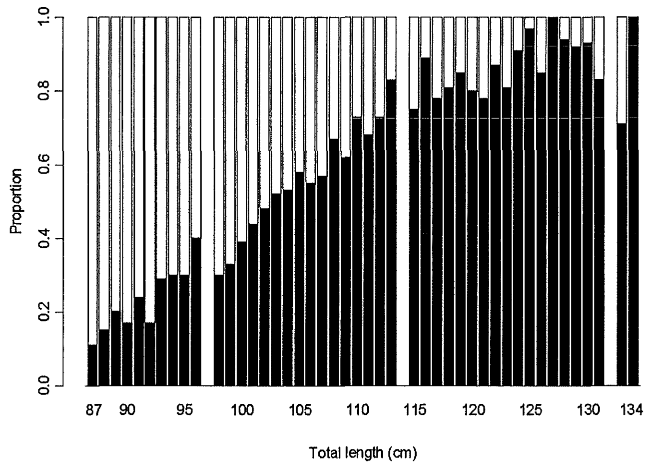

Fig. 2.5. Length based sex ratio for female (solid bars) and male (open bars) Spanish mackerel from DPI&F LTMP (2000-2002) and AFMA voluntary fisher logbooks (2004) (n=4156; 2304 females, 1842 males). Total length 87: fish ≤ 87 TL cm (n=35); Total length 134: fish ≥ 134 TL cm (n=53).

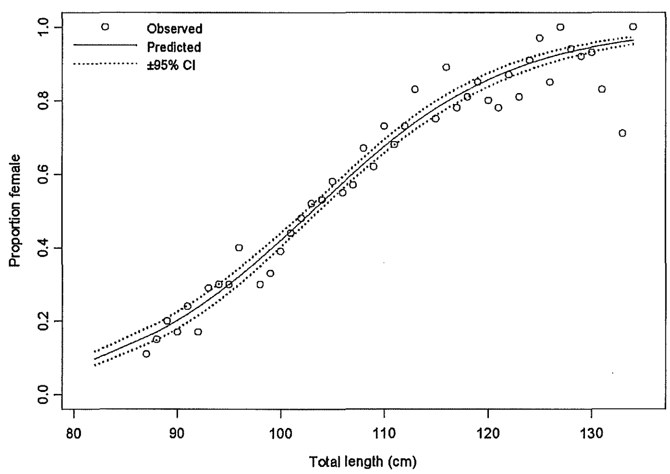

Fig. 2.6. Binary regression model used to predict the probability of a Spanish mackerel being female based on total length (TL, cm).

Age structure

Torres Strait Spanish mackerel collected from the DPI&F LTMP and AFMA voluntary fisher logbooks ranged in length from 70 cm to 164 cm TL (Fig. 2.7). Females tended to be larger in the catches than males, with a mean length of 109 cm TL, pooled across years. The mean length of males was about 101 cm TL. Generally, the length distributions for both sexes were consistent across years (Fig. 2.7).

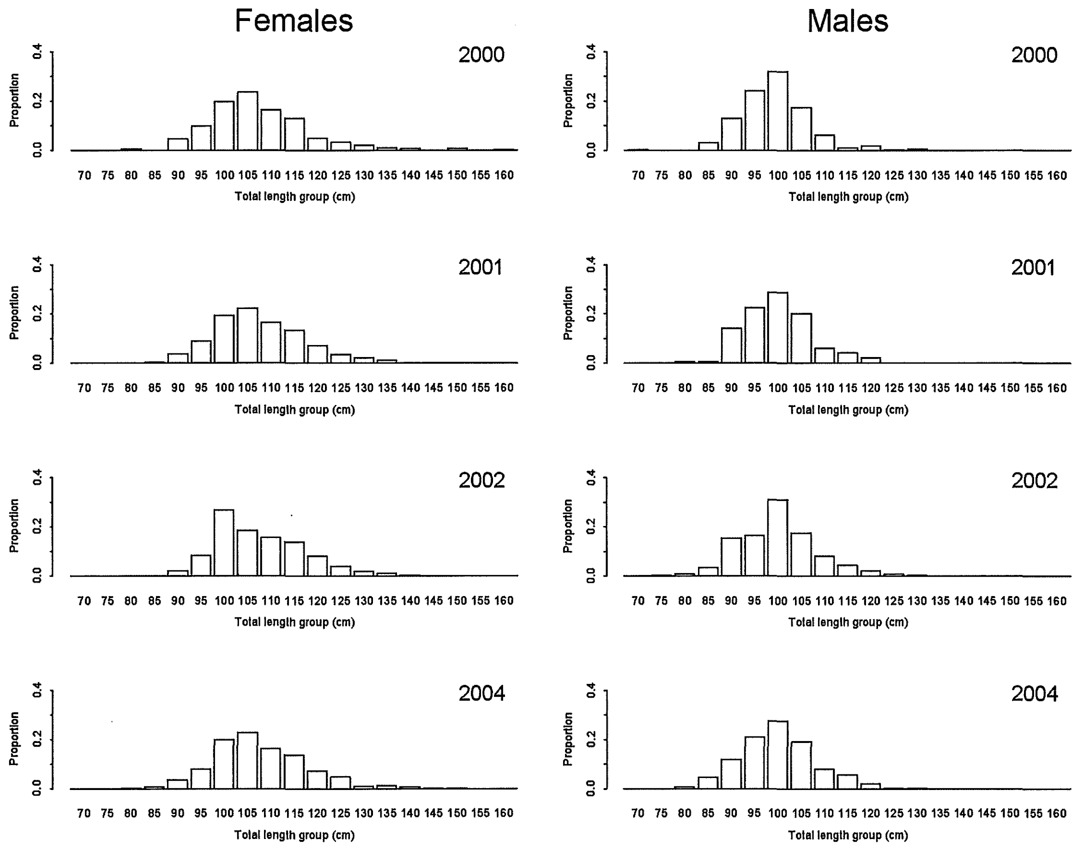

Fig. 2.7. Sex-specific length frequency distributions of Spanish mackerel collected from DPI&F LTMP (2000-2002) and AFMA voluntary fisher logbooks (2004).

The observed age structures for Torres Strait Spanish mackerel in 2000-2002 were used as input into the stock assessment model (Table 2.8). The Torres Strait Spanish mackerel fishery was dependent on relatively young fish, with 2-4 year olds being the dominant age groups (Fig. 2.8). Sex-specific age length distribution keys (ALKs) were also derived for Spanish mackerel from total length and age data collected from the DPI&F LTMP (2000-2002) (see Appendix 1).

Table 2.8. Final age structures (proportions) of Spanish mackerel from 2000-2002. These were used as input into the assessment model.

Year	Proportion of catch-at-age group +											
	1	2	3	4	5	6	7	8	9	10	11	12
2000	0.017	0.541	0.325	0.067	0.027	0.011	0.002	0.007	0.001	0.001	0.000	0.000
2001	0.022	0.372	0.359	0.162	0.048	0.022	0.006	0.005	0.002	0.002	0.000	0.000
2002	0.040	0.450	0.234	0.161	0.058	0.028	0.012	0.012	0.003	0.000	0.000	0.002

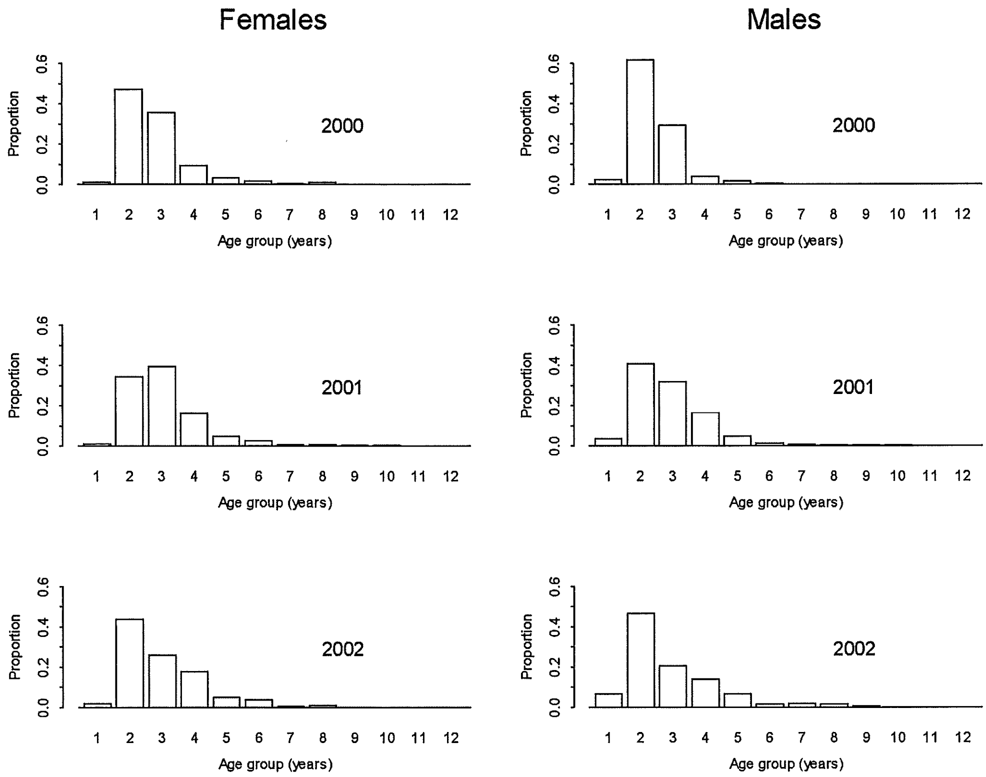

Fig. 2.8. Sex-specific age frequency distributions of Spanish mackerel collected from DPI&F LTMP (2000-2002).

Maturity

Maturity estimates for Spanish mackerel in Torres Strait were examined using macroscopically determined maturity data collected from the DPI&F LTMP (Table 2.9). Data were pooled across the assumed peak spawning months (October-November) and years (2000-2002). No male gonads were staged and less than half of the females measured had their gonads weighed (Table 2.9). Ovaries of female Spanish mackerel sampled were categorised into 9 macroscopic stages based on the maturity staging scheme of McPherson (1993) (Table 2.10). Stages 4-9 were considered to indicate mature females (McPherson 1993).

Pooling the macroscopic data across all years and months found that no females were identified as immature, with all ovaries assigned a maturity stage of 4-9 (Fig. 2.9). More than 50% were in post-ovulatory condition (Stage 6) and about 40% had ripe (Stage 7) ovaries indicative of imminent spawning. The smallest female Spanish mackerel found to be mature were 82 cm TL and their ovaries were staged at 5 and 6. Both these females were 1+ years of age suggesting Torres Strait Spanish mackerel mature early in life.

Table 2.9. Number of Spanish mackerel collected from the DPI&F LTMP (2000-2002).

Year	Number measured		Number staged		Number gonads weighed	
	Females	Males	Females	Males	Females	Males
2000	459	441	444	-	165	147
2001	501	408	346	-	99	79
2002	336	275	240	-	172	-
Total	1296	1124	1030	-	436	226

Table 2.10. Macroscopic staging scheme used to determine maturity of female Spanish mackerel collected from the DPI&F LTMP (2000-2002). Stages 4-9 indicates mature females. Staging scheme described in McPherson (1993).

Macroscopic stage		Description
1	Virgin	Very small and straplike. Translucent to white.
2	Resting	Firm and round. Oocytes microscopic. Translucent pink exterior, tending orange/pink interior.
3	Early development	Firm and round. Scattered oocytes (yolk vesicle stage) becoming visible. Light yellow to white.
4	Developing	Shape less rounded, more 'flabby' if placed on a flat surface. Opaque oocytes increasing in size with translucent areas between oocytes. Yellow to white.
5	Mature	Opaque oocytes occupy entire ovary. Distinct light orange exterior, slightly darker interior.
6	Post-ovulatory	Opaque oocytes as previous stage with scattered translucent hydrated oocytes. Shape distinctly flabbier than Stage 5, blood vessels very prominent and stretched. White/yellow exterior, white/pale orange interior.
7	Ripe	Ovaries firm, rounded turgid appearance. Translucent hydrated oocytes predominate, ovary wall thin and translucent. Ovary lumen empty. Grey/pink exterior and interior.
8	Running ripe	Appearance of above externally. Ovary lumen filled with translucent oocytes. Oocytes released with slight pressure on abdomen.
9	Spent	Flabby shape. Ovary lumen relatively large, ovary lamellae small. Opaque or translucent oocytes rare. Distended veins common. Light yellow/white exterior, more light/yellow/orange interior.

McPherson (1993) found the smallest female Spanish mackerel off the Queensland east coast to be mature at about 88 cm TL (~79 cm FL). In contrast, Mackie *et al.* (2005) found the smallest mature female and male Spanish mackerel off the Western Australian coast to be about 72 cm TL (~64 cm FL) and 56 cm TL (~49 cm TL), respectively. They also estimated the mean length at maturity (L50) for female and male Spanish mackerel off the west coast from logistic regression analyses to be about 90 cm TL (~81 cm FL) and 71 cm TL (~63 cm FL), respectively. The probability *P* of a Spanish mackerel being mature was modelled using a logistic-link (*i.e.*, logit) function and binomial error distribution, and related through a logistic regression function with FL as a covariate according to the following (Mackie *et al.* 2005):

Females:
$$P(Mature \mid n) = \frac{e^{-10.349+0.0128FL}}{1+e^{-10.349+0.0128FL}} \qquad (2.10)$$

Males:
$$P(Mature \mid n) = \frac{e^{-8.469+0.0135FL}}{1+e^{-8.469+0.0135FL}} \qquad (2.11)$$

where, *P* = probability mature; *n* = total number of Spanish mackerel in each length class; and *FL* = fork length (mm).

Converting these mean lengths to ages using the inverse sex-specific von Bertalanffy growth function, the mean ages at 50% maturity (A50) for female and male Spanish mackerel off the west coast were estimated to be about 1.4 and 0.8 years old, respectively. The A50 for female Spanish mackerel off the Queensland east coast was about 2 years of age (Welch *et al.* 2002). Data collected from the DPI&F LTMP for Torres Strait Spanish mackerel were insufficient to estimate mean lengths and ages at maturity for either sex.

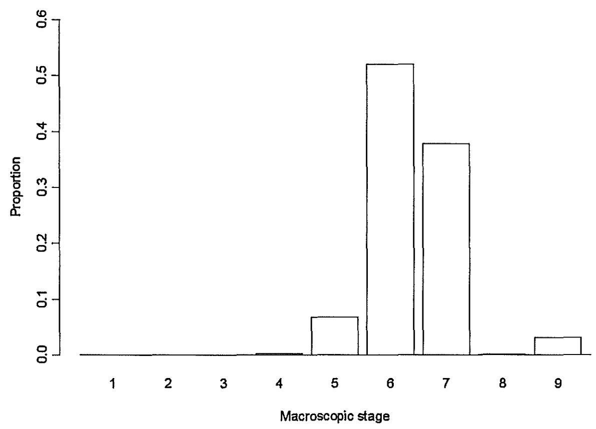

Fig. 2.9. Proportion of female Spanish mackerel assigned a macroscopic stage of reproductive development collected from the DPI&F LTMP (2000-2002) (n=1030). More than 90% of the data were assigned a maturity stage 6-7. No females were considered to be immature (Stages 1-4).

Fecundity

No fecundity or egg count data were available for Torres Strait Spanish mackerel, although as for all scombrids, were expected to be extremely high (Margulies 1993). Gonad weights, however, were recorded for 436 females and 226 males as part of the DPI&F LTMP (Table 2.9). Gonadosomatic indices (GSI) were calculated according to the following:

$$GSI = \frac{G}{Wg} \tag{2.12}$$

where, G = gonad weight (g); and Wg = fish body weight (kg).

Female ovaries ranged from 2 g to 2000 g (Mean±SD: 410.2±254.3 g) and GSIs from 0.67 to 133.33 g gonad weight/kg body weight (48.66±20.82). In contrast, male testes ranged from 15 g to 500 g (28.0±92.0 g) and GSIs from 3.85 to 66.67 g gonad weight/kg body weight (28.04±11.72). GSI values indicated females invested more into reproductive development than males per kg of body weight. Positive correlations between body weight and gonad weight were also observed for both sexes (Table 2.11, Fig. 2.10).

Table 2.11. Linear regression model for converting body weight (Wg, kg) to gonad weight (G, g) (G = a + b*Wg).

(A) Females (n=436). Residual standard error: 185.1 (std of fit in g) on 434 d.f.; R^2=0.47; F-statistic: 387.1 on 1 and 434 d.f.; p<0.0001.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
Intercept	-118.5627	28.3017	-4.1892	<0.0001	800.98831	-88.24997
Wg	64.5984	3.2834	19.6744	<0.0001	-88.24997	10.78058

(B) Males (n=226). Residual standard error: 70.45 (std of fit in g) on 224 d.f.; Multiple R^2=0.42; F-statistic: 160.1 on 1 and 224 d.f.; p<0.0001.

Parameter	Estimate	S.E.	T statistic	Probability	Covariance matrix	
Intercept	-60.3772	19.4678	-3.1014	0.0022	378.99523	-57.54059
Wg	38.5283	3.0452	12.6520	<0.0001	-57.54059	9.27346

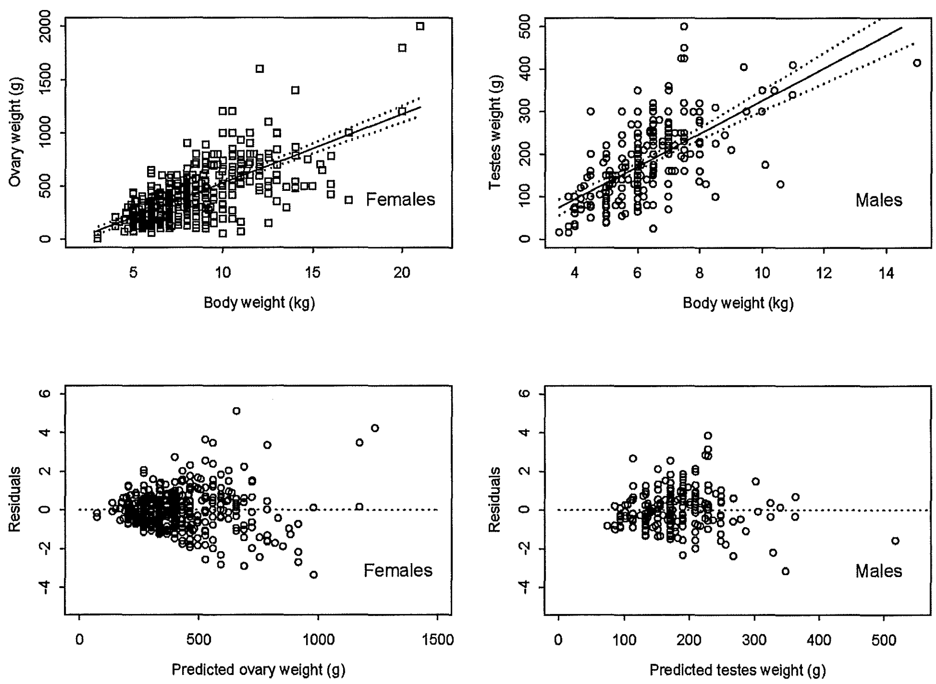

Fig. 2.10. Sex-specific linear regression models used to predict gonad weight (g) from body weight (kg). Dashed lines in upper plots represent 95% confidence intervals.

The fitted models, therefore, used to predict gonad weight from body weight of Torres Strait Spanish mackerel were the following (Table 2.11):

Females: $$G = -118.563 + 64.598Wg \quad (2.13)$$

Males: $$G = -60.377 + 38.528Wg \quad (2.14)$$

where, G = gonad weight (g); and Wg = fish body weight (kg).

Although the fecundity of Torres Strait Spanish mackerel can not be estimated directly due to the lack of egg count data, other studies have described the relationship between body weight and fecundity of Spanish mackerel from other regions. In a recent stock assessment of Queensland east coast Spanish mackerel, Welch *et al.* (2002) used fecundity estimates derived from McPherson (1993). These estimates were based on the number of hydrated oocytes per gram of ovary in immediately pre-spawning fish, which were about 76539 eggs/kg. This estimate was not used in this assessment, however, because it failed to account for size or age differences amongst spawning fish. In contrast, Mackie *et al.* (2003) estimated the relationships between batch fecundity and fork length or whole body weight in a stock assessment of Spanish mackerel in Western Australia according to the following:

$$F = 0.0011FL^{2.90} \quad (2.15)$$

$$F = 31087Wg^{1.38} \quad (2.16)$$

where, F = batch fecundity (number of eggs); FL = fork length (mm); and Wg = fish body weight (kg). The relationships were derived from Spanish mackerel 857 mm to 1143 mm FL and 5.3 kg to 12.7 kg.

In this assessment we used gonad weight data from Spanish mackerel collected in Torres Strait as part of the DPI&F LTMP. Gonad weight was used as an index of egg production (*i.e.*, spawning biomass).

Natural mortality

Natural mortality (M) is a key parameter in most stock assessments, but is one of the most uncertain and difficult to estimate (Begg *et al.* 2005). In the recent Queensland east coast Spanish mackerel assessment, model results were extremely sensitive to estimates of M, with widely varying interpretations of stock status (Welch *et al.* 2002). As direct measurements of M are difficult to obtain and can only be estimated directly for unexploited stocks (Sparre and Venema 1998), most assessments have attempted to approximate life history proxies which can be assumed proportional to M (Pauly 1980, Hoenig 1983, Pauly 1983). In this assessment, two methods were used to estimate the M of Torres Strait Spanish mackerel following the approach used in a recent assessment of the Australian east coast spotted mackerel fishery (Begg *et al.* 2005).

Hoenig's (1983) method was used to estimate M from the assumed age of the oldest fish in the population according to the following:

$$M = e^{1.44-0.982\log(\mathit{Maximum\ Age})} \tag{2.17}$$

where, *Maximum Age* of Torres Strait Spanish mackerel was assumed to be 12 years old based on the oldest fish aged in the DPI&F LTMP. In contrast, other studies from the east and west coasts of Australia have aged Spanish mackerel to 17 and 22 years, respectively (Mackie *et al.* 2003, Tobin and Mapleston 2004). Based on Hoenig's method, M for Torres Strait Spanish mackerel was about 0.37.

Pauly's (1983) method was also used to estimate M based on the von Bertalanffy growth parameters and ambient temperature according to the following:

$$M = 0.8e^{(-0.0152-0.279\log L_\infty+0.6543\log K+0.4634\log T)} \tag{2.18}$$

where, L_∞ = asymptotic average maximum fish length (147.1 cm); K = growth rate coefficient (0.167); and T = mean ambient seawater temperature (27.51867 °C). The von Bertalanffy growth parameters were those derived from fitting age and length data pooled across sexes (Table 2.3, Equation 2.8). T was estimated as the mean sea surface temperature (SST) for Torres Strait between October 2000 and October 2002. The estimator was lowered by 20% because of the assumed increase in survival for a schooling fish species (Pauly 1983). Based on this method, M for Torres Strait Spanish mackerel was about 0.28.

In this assessment we used the Hoenig (1983) based estimate of 0.37 which equates to an annual instantaneous mortality rate of 31% (*i.e.*, 69% survival), and was similar to that used in the Queensland east coast Spanish mackerel assessment (*i.e.*, M = 0.34) (Welch *et al.* 2002). Pauly's based estimate was similar to that used as an input sensitivity to the assessment model (see Chapter 6).

Stock-recruitment steepness

The relationship between spawning stock size and recruitment is another key parameter in most stock assessments, but is also highly uncertain and difficult to estimate (Begg *et al.* 2005). Not surprisingly, to directly estimate the stock-recruitment relationship for an exploited population involves an extensive time series of data, both on the spawning stock and recruitment; data sources which are not available for Torres Strait Spanish mackerel. Consequently, we used data from other related species to derive a proxy stock-recruitment relationship, similar to the approach used in the recent assessment of spotted mackerel (Begg *et al.* 2005).

Myers *et al.* (1999) examined over 700 stock-recruitment relationships from fisheries around the world and found that the maximum annual reproductive rate (r_{max}) was relatively constant within species and varied little among species. These results formed the basis for the assumed stock-recruitment relationship used for Torres Strait Spanish mackerel. Stock-recruitment steepness (h) related to r_{max} according to the following:

$$h = \frac{r_{max}}{4 + r_{max}} \tag{2.7}$$

where, h = steepness measuring the expected recruitment at 20% of the virgin spawner stock size (Myers *et al.* 1999). Stocks with high steepness tend to have higher resilience to fishing than stocks with low steepness. From Myers *et al.'s* (1999) study we estimated that the average steepness for a variety of tuna and mackerel species was about 0.52 (Table 2.12). In the assessment, therefore, we assumed that this value was also reflective of the stock-recruitment relationship for Torres Strait Spanish mackerel.

Table 2.12. Estimated maximum annual reproductive rates (r_{max}) at low population sizes for Scombridae species (mackerel and tuna) (Myers *et al.* 1999). The r_{max} of 4.46 ≈ 0.52 steepness (h) was used in the base assessment for Torres Strait Spanish mackerel.

Scombridae species	r_{max}	h
Atlantic bluefin tuna (*Thunnus thynnus*)	5.2	0.56
Bigeye tuna (*Thunnus obesus*)	5.3	0.57
Chub mackerel (*Scomber japonicus*)	2.4	0.38
Southern bluefin tuna (*Thunnus maccoyii*)	2.9	0.42
Yellowfin tuna (*Thunnus albacares*)	9.3	0.70
Average (back-transform $\log_e(r_{max})$)	4.5	0.52

3. Fishery

Annual commercial catches of Spanish mackerel in Torres Strait were estimated from historic Queensland Fish Board data, compulsory AFMA individual fisher logbooks, and Islander individual sales dockets. All mackerel catch data were converted to whole fish weight using the product conversion factors (fillet=1.608; trunk=1.176; gilled and gutted=1.048) derived for Spanish mackerel (Mackie and Lewis 2001). If the product type was not specified in the logbooks or sales dockets then it was assumed to be whole fish and no conversion factor was applied. Also, numbers of mackerel caught were converted to whole fish weight based on the average fish weight derived for each species where both weight and numbers were recorded in the logbooks (Table 3.1). Unfortunately, the number of records where this occurred was limited (n=55 and 9 for Spanish and unspecified mackerel, respectively) as numbers of fish caught, rather than weight, were typically the unit of catch reported in the AFMA logbooks for the fishery. The estimated average weight for Spanish mackerel of 8.5 kg from the logbooks, however, was similar to the estimate from the DPI&F LTMP (see Chapter 2; 7.3 kg).

Table 3.1. Mackerel species reported in the compulsory commercial logbooks and Islander docket books. Average fish weight (kg) derived from individual catch records for Spanish and unspecified mackerel. Average weight for unspecified mackerel also assumed for grey, school and shark mackerel. Average weight for spotted mackerel derived from Queensland east coast spotted mackerel assessment (Begg *et al.* 2005).

Common name	Species name	Species code	Average weight (kg)
Grey mackerel	*Scomberomorus semifasciatus*	37441018	6.8
School mackerel	*Scomberomorus queenslandicus*	37441014	6.8
Shark mackerel	*Grammatorcynus bicarinatus*	37441025	6.8
Spanish mackerel	*Scomberomorus commerson*	37441007	8.5
Spotted mackerel	*Scomberomorus munroi*	37441015	1.9
Unspecified mackerel		37441790	6.8

Catch and effort data for the fishery were also analysed according to 6 statistical or "fishing" regions to reflect the historical significance of the major fishing grounds (Table 3.2, Fig. 1.1). In addition, annual catch data were reported in financial or fishing years (*i.e.*, "fishing year" 2003 equates to July 2003-June 2004), reflecting the biology and seasonal fishing patterns for Spanish mackerel. Although the AFMA logbook program commenced in 1985, only part of the commercial catches were represented in the initial years because of low compliance (Williams and O'Brien 1998). The AFMA logbook data used in this assessment, therefore, were from July 1989 to June 2004 (*i.e.*, fishing years 1989-2003).

Table 3.2. Fishing regions used in the analysis of Spanish mackerel catch and effort data, and corresponding DPI&F reporting grids.

Fishing region	DPI&F statistical grid	Latitude (°S)	Longitude (°E)
Bramble Cay	D1	143.5-144.0	9.0-9.5
Eastern Torres Strait	E1,E2,E3,D2,D3	141.5-142.5	9.5-10.5
		144.0-144.5	9.0-9.5
Central Torres Strait	B2,B3,C2,C3	142.5-143.5	9.5-10.5
Northern Torres Strait	AB1,A1,B1,C1	141.5-143.5	9.0-9.5
Southern Torres Strait	AB4,AB5,A4,A5,B4,B5,C4,C5,D4,D5,E4,E5	141.5-144.5	10.5-11.5
Western Torres Strait	AB2,AB3,A2,A3	141.5-142.5	9.5-10.5

Commercial sector

Queensland Fish Board data

Mackerel have been commercially caught from Queensland waters since at least 1945, as reported in the Queensland Fish Board data (Begg *et al.* 2005). No mackerel species identification, however, was provided in these data, although anecdote suggests most were Spanish mackerel. The Fish Board data extend from 1945 to 1980, after which there were no commercial catches recorded from Queensland waters until the AFMA and CFISH logbook programs commenced in 1985 and 1988, respectively.

Although not reported in the Fish Board data, in the 1940s commercial fishing began to increase in Torres Strait where Bramble Cay was a regular destination for mackerel fishers and in the 1950s operators began to supply product to the wider Queensland east coast market (Williams 1994). In 1953, two Cairns-based vessels (St Hilaire and Trader Horn) were conducting extended fishing trips for mackerel in Torres Strait, leading to increased participation of commercial operators during the 1960s and fishing practices that are still conducted today (O'Brien 1995, Haysom 2001).

Mackerel catches from Torres Strait are difficult to discern in the Fish Board data as they are aggregated to the port of landing (Robins, unpublished data). Only in 1958, was about 1 t of mackerel reported to have been landed at Thursday Island. Most of the mackerel catches from Torres Strait, therefore, would have been reported in the total landings from Cairns, where significant catches of mackerel from the Queensland east coast were also landed. Historical catch data from the Torres Strait, therefore, is limited to a few years of partial logbook information of the Trader Horn when in 1957, 1959, 1960 and 1962, a total of 34, 52, 40 and 70 t of Spanish mackerel were harvested, respectively (McPherson 1986). As other vessels were also operating in the Torres Strait during this period, the actual total harvest of Spanish mackerel would invariably have been greater. McPherson (1986) also reported estimates of total harvest of Spanish mackerel in 1975, 1976, 1977 and 1979 as 68, 81, 69 and 57 t, respectively, although there are concerns with the credibility of these data. In this assessment, we have not attempted to discern the mackerel catches from Torres Strait with those of the east coast as reported in the Fish Board data, but instead estimate the historical catches from interpolated hind-cast catches derived from the more recent AFMA compulsory logbook data. The historical catches reported in McPherson (1986) were used as a model sensitivity test in the assessment (see Chapters 4 and 6).

AFMA compulsory logbook data

Spanish mackerel are commercially targeted in Torres Strait by non-Islander mackerel and dual endorsed mackerel/reef line fishers, and are incidentally caught by reef line, lobster and prawn fishers (Table 3.3). For the purposes of this assessment, we classified mackerel fishers as those whose pooled total catches (1989-2003) were comprised of more than 75% mackerel; reef line fishers as those whose total catches were less than 25% mackerel; and dual endorsed fishers as those whose total catches were between 25% and 75% mackerel. Commercial non-Islander catches of mackerel remained relatively constant between 1989 and 2000; reaching a peak in 1997 of about 226 t (Table 3.3). Catches declined significantly in 2001, increasing in 2002 and 2003. Catches of mackerel in the reef line, lobster and prawn fisheries have been poorly reported in the logbooks, hence the years of missing data; although these catches most likely average less than 4 t each year.

Spanish mackerel is the main target species in the fishery, with limited amounts (0.7-6.3 t) of grey, school, shark, spotted and unspecified mackerel contributing to the total catches each year (Fig. 3.1). Reporting of unspecified mackerel is most likely the result of species mis-identification problems or ease of reporting by fishers and a lack of awareness about the importance of reporting at a finer taxonomic scale (Begg *et al.* 2005). For the remainder of this assessment, we refer to only the Spanish mackerel catches as they account on average for about 98% of the annual total mackerel catches in the fishery.

Table 3.3. Non-Islander commercial fishery (mackerel, dual, reef line, lobster, prawn) catch of total mackerel (t), fishing years 1989-2003.

Fishing	Non-Islander Torres Strait Commercial Fishery Total Mackerel Catch (t)				
year	**Mackerel**	**Dual**	**Reef**	**Lobster**	**Prawn**
1989	184	39	3		
1990	187	16	<1		
1991	208	12	2		
1992	192	8	1		
1993	136	2	1	0.2	
1994	170	26	2	0.3	
1995	209			0.3	
1996	183	8		1.4	
1997	200	26		0.5	
1998	192	16		0.1	0.1
1999	182	26		0.1	0.4
2000	173	20		0.1	0.2
2001	96	<1		0.3	0.7
2002	141	4	4	0.6	0.2
2003	142	12	10	0.4	0.1
Average	*173*	*15*	*3*	*0.4*	*0.3*

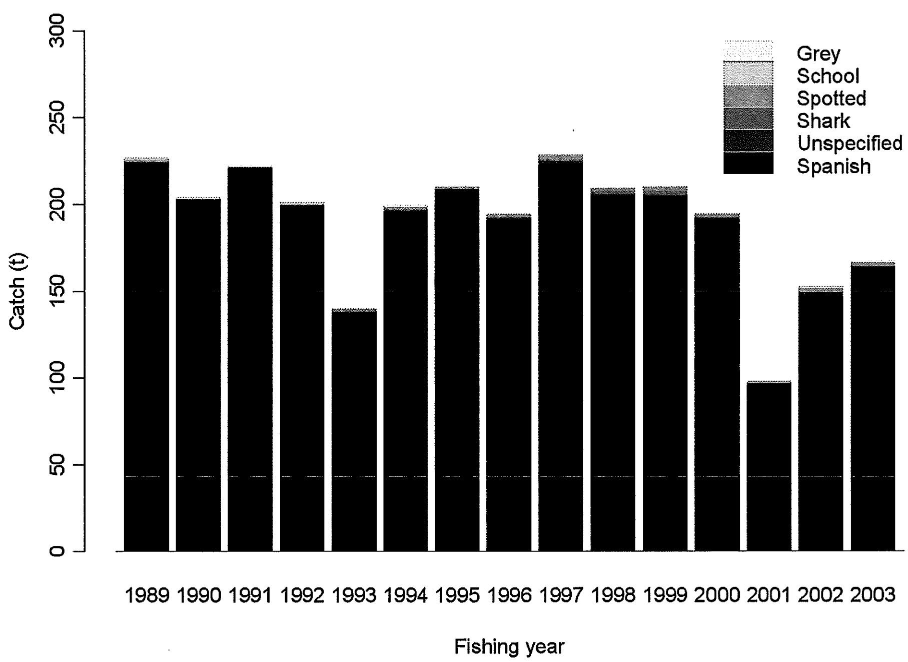

Fig. 3.1. Annual non-Islander commercial catch (t) of all mackerel species from Torres Strait, fishing years 1989-2003. Unspecified = unknown mackerel catch reported in logbooks.

Spanish mackerel supports a highly localised and seasonal commercial fishery in Torres Strait. Each year more than 80% of the Spanish mackerel catch is taken from Bramble Cay and the eastern Torres Strait between August and November (Fig. 3.2-3.4). The fishery operates around deeper water coral reefs in these regions where the water is clearer than to the west and troll fishing more effective (McPherson 1986). Spanish mackerel is predominantly caught by mackerel fishers using trolling lines, while reef fishers incidentally catch mackerel on handlines. The strong tidal currents and persistent south-east tradewinds, coupled with the exposed reef waters in which the fishery operates, ameliorates the difficulties of troll fishing in these regions (McPherson 1986). During the autumn and winter months, catch rates are reportedly lower and average fish size smaller (McPherson 1986). Frozen fillets are the preferred market product type for Spanish mackerel, although some are gilled and gutted or trunked.

Patterns in fishing effort reflected those of catches. Fishing effort was based on the number of records where Spanish mackerel was reported in the AFMA finfish logbooks (*i.e.*, catch weight or numbers>0). In addition, prior to the logbook change in 1992 when daily catches by dory were introduced, we assumed that each fishing operation (*i.e.*, boat) used their full complement of dories to fish each day; resulting in possible over-estimation of fishing effort in 1989-1991. The number of finfish boats reported to have caught Spanish mackerel remained relatively stable from 1989-1999, declined in 2000-2001, and increased in 2002-2003 (Fig. 3.5). On average 16 boats reported catching mackerel each year, reaching a peak in 2002 of 26 boats. Typically, the number of boats fishing in each region was relatively stable (Fig. 3.6). Days fished followed a similar annual pattern, averaging 1085 operation days or 2889 dory days each year between 1989-2003 (Fig. 3.7, 3.8). Mackerel and dual endorsed fishers tended to operate in Bramble Cay and eastern Torres Strait, while reef fishers incidentally caught mackerel in the eastern Torres Strait where they normally operate (Fig. 3.9). Reflective of the catches, fishing effort for Spanish mackerel was concentrated in Bramble Cay and the eastern Torres Strait during the peak spawning months of August to November (Fig. 3.10, 3.11).

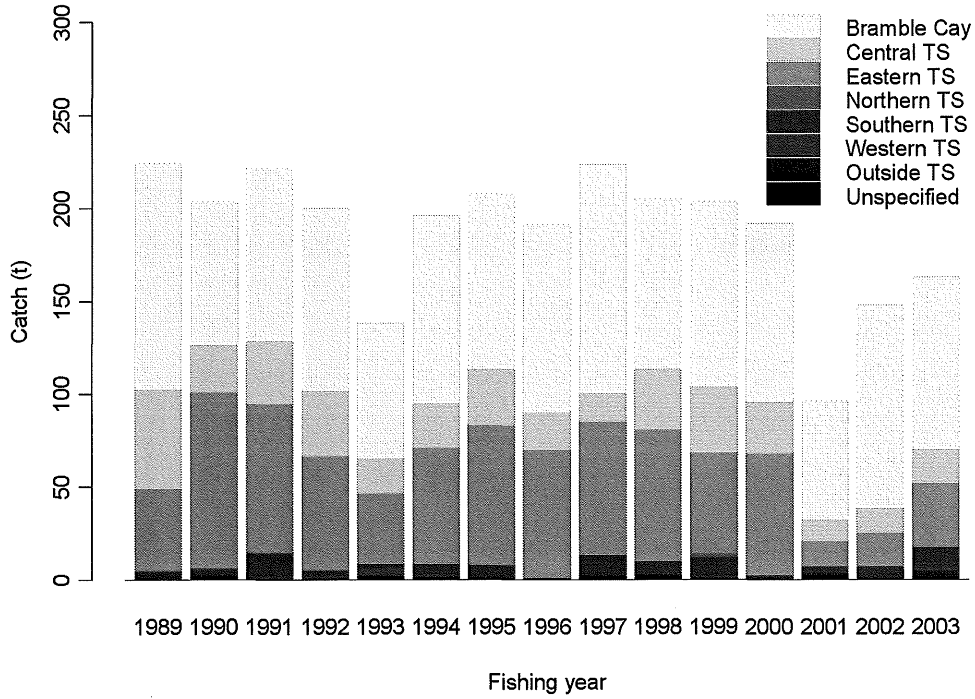

Fig. 3.2. Annual regional non-Islander commercial catch (t) of Spanish mackerel from Torres Strait (TS), fishing years 1989-2003. Outside TS = region outside assessment area. Unspecified = region not reported in logbooks.

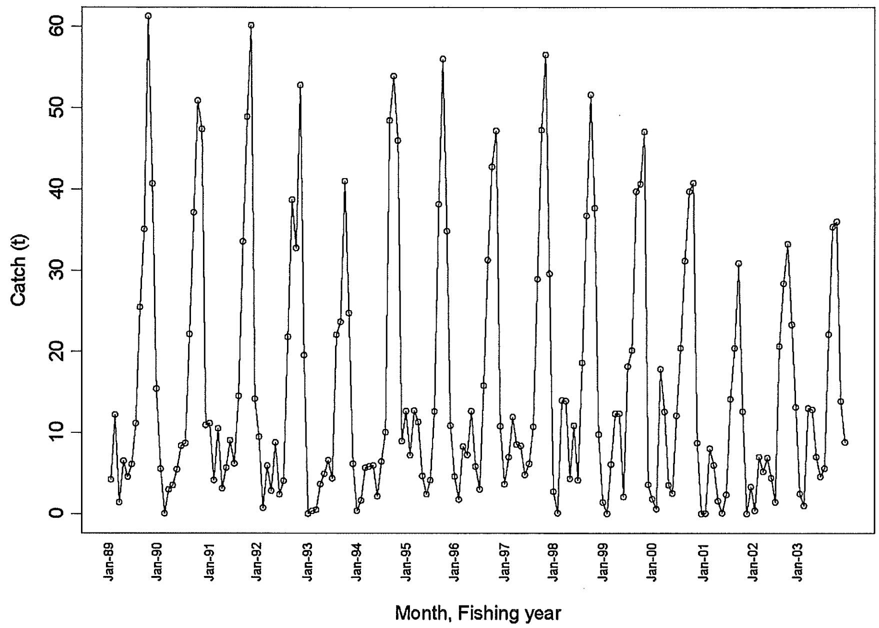

Fig. 3.3. Annual monthly non-Islander commercial catch (t) of Spanish mackerel from Torres Strait, fishing years 1989-2003. Peak catch each year occurs in October or November.

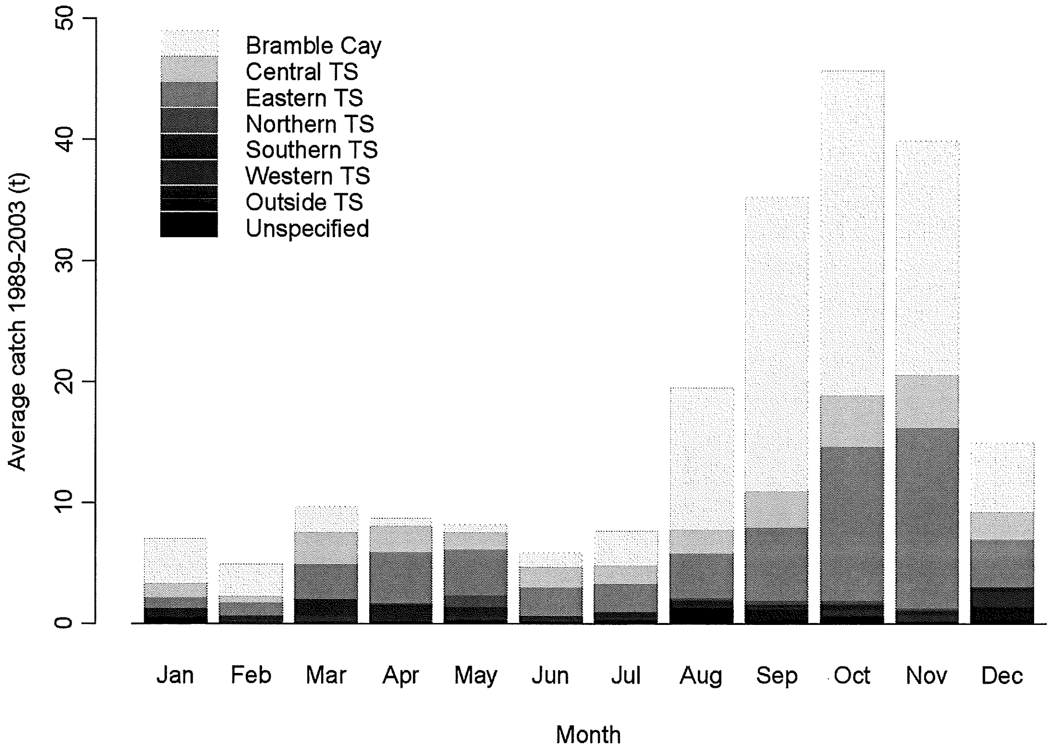

Fig. 3.4. Average monthly non-Islander commercial catch (t) of Spanish mackerel from Torres Strait (TS), fishing years 1989-2003. Unspecified = region not reported in logbooks.

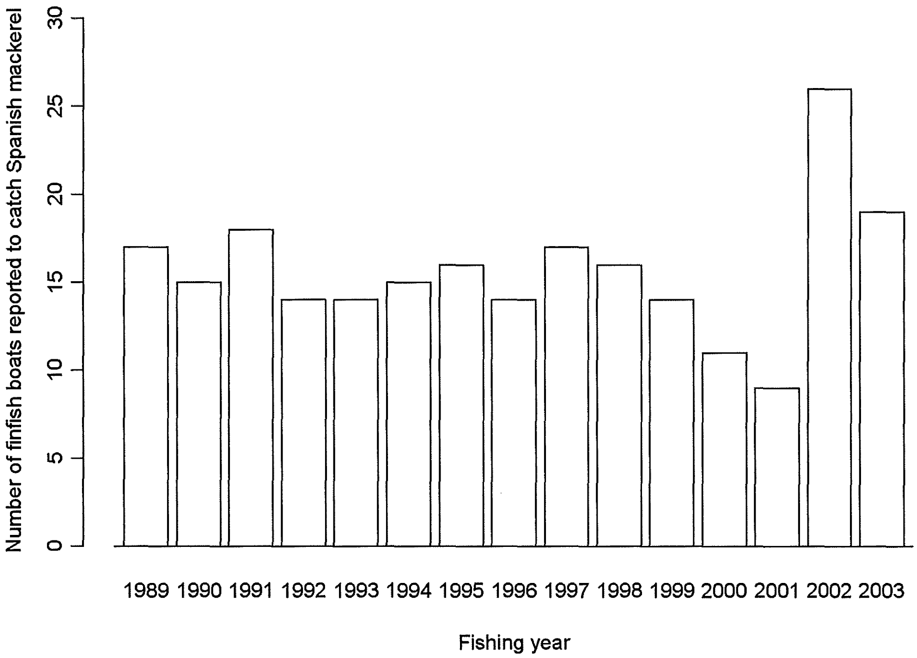

Fig. 3.5. Annual number of non-Islander commercial finfish boats reported to have caught Spanish mackerel from Torres Strait, fishing years 1989-2003.

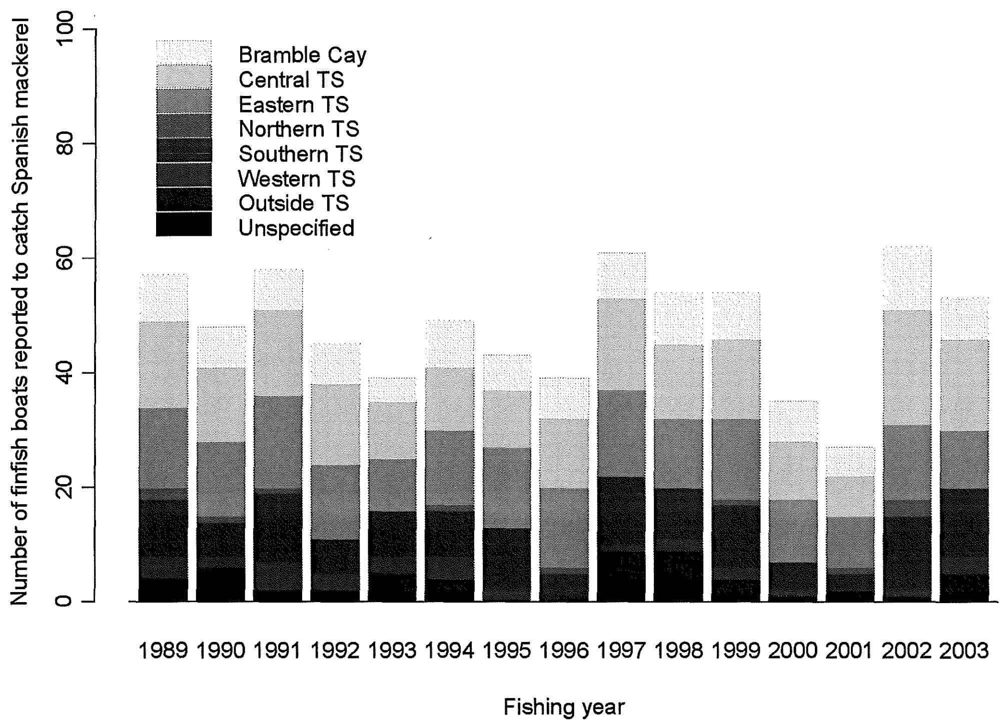

Fig. 3.6. Annual number of non-Islander commercial finfish boats by region reported to have caught Spanish mackerel from Torres Strait (TS), fishing years 1989-2003. Unspecified = region not reported in logbooks.

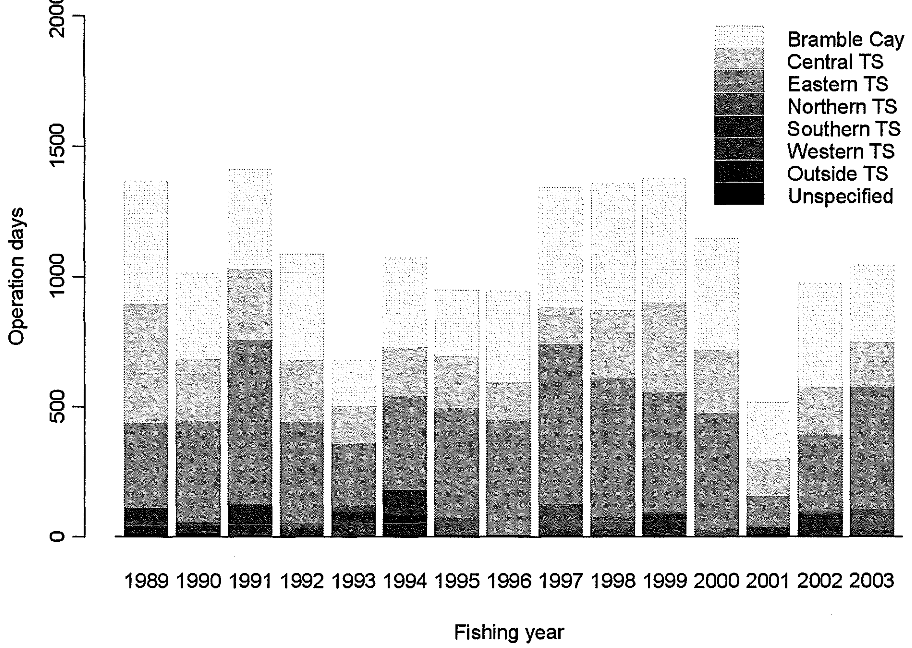

Fig. 3.7. Annual number of non-Islander commercial finfish operation days by region reported to have caught Spanish mackerel from Torres Strait (TS), fishing years 1989-2003. Unspecified = region not reported in logbooks.

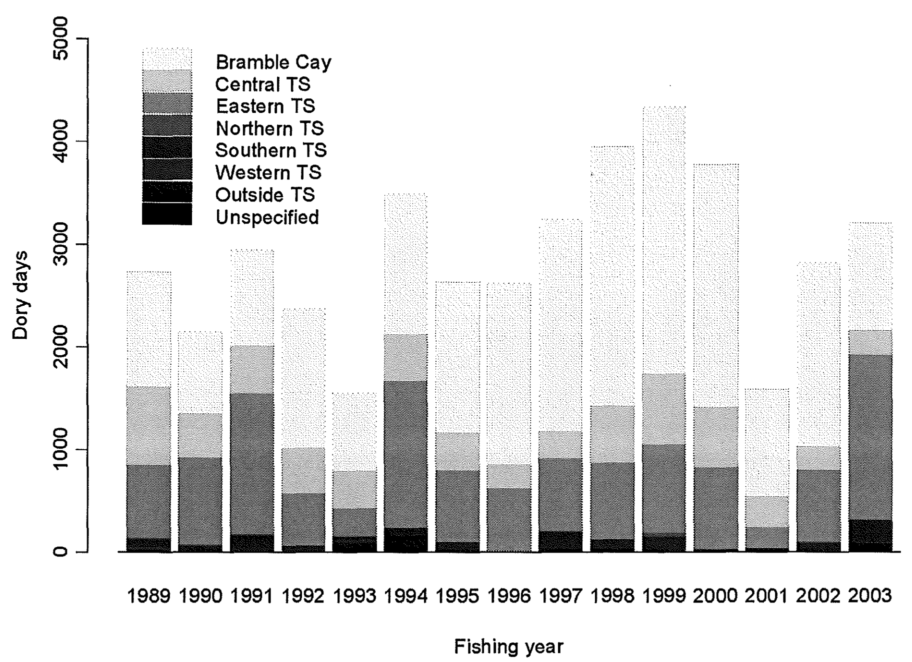

Fig. 3.8. Annual number of non-Islander commercial finfish dory days by region reported to have caught Spanish mackerel from Torres Strait (TS), fishing years 1989-2003. Unspecified = region not reported in logbooks.

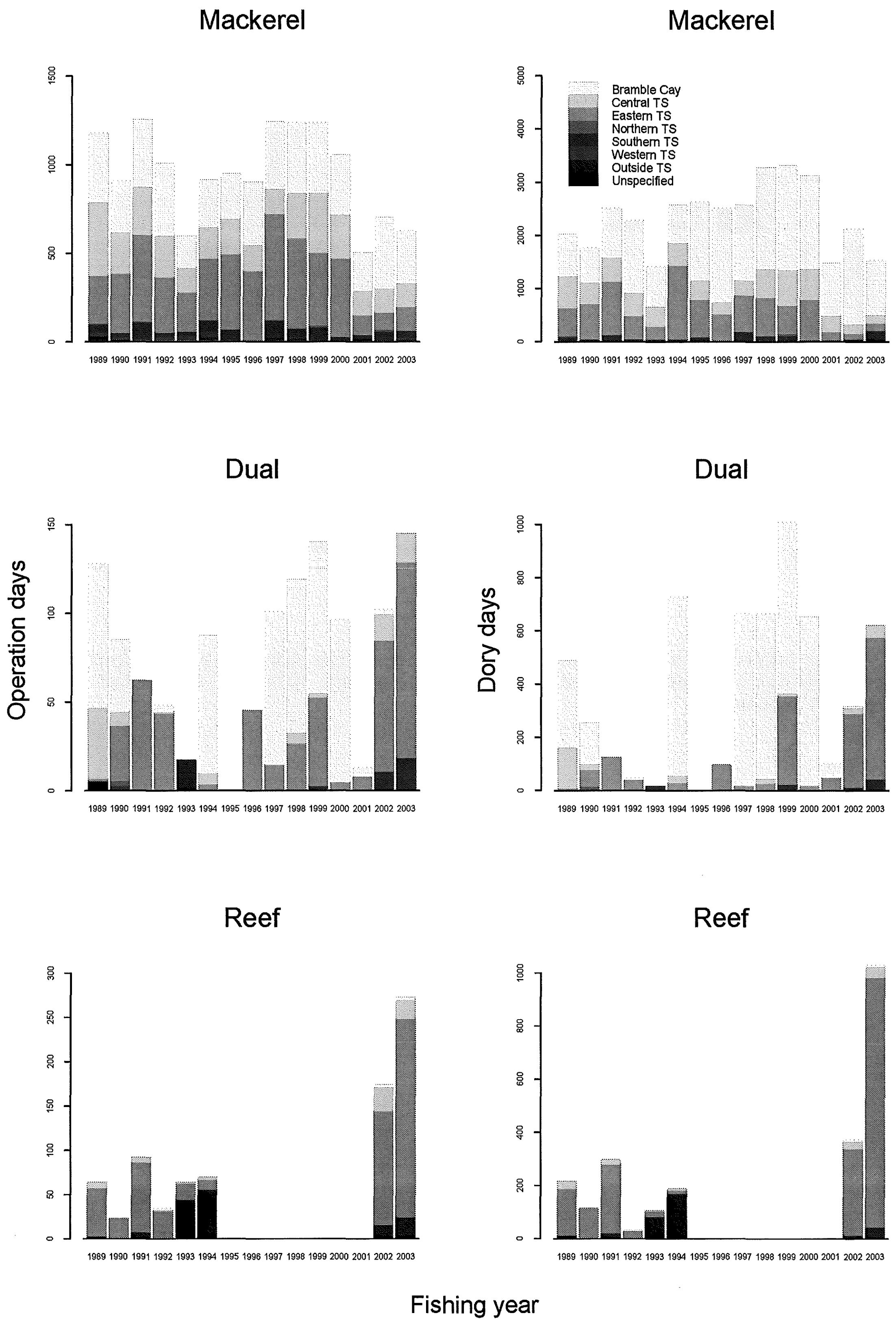

Fig. 3.9. Annual number of non-Islander commercial finfish operation and dory days by region and fisher type reported to have caught Spanish mackerel from Torres Strait (TS), fishing years 1989-2003. Unspecified = region not reported in logbooks.

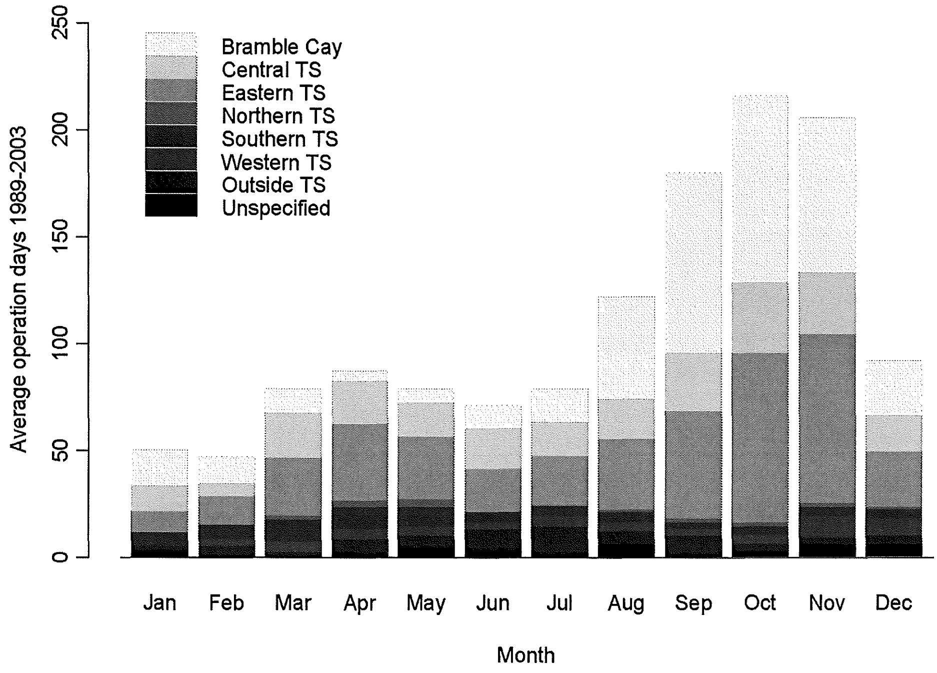

Fig. 3.9. Average monthly number of non-Islander commercial finfish operation days by region reported to have caught Spanish mackerel from Torres Strait (TS), fishing years 1989-2003. Unspecified = region not reported in logbooks.

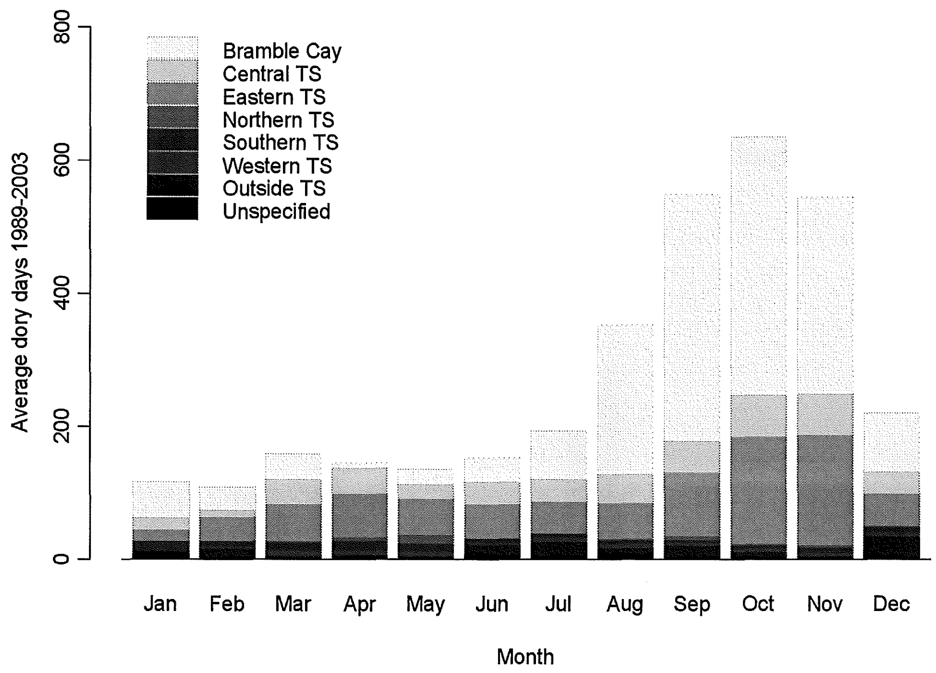

Fig. 3.10. Average monthly number of non-Islander commercial finfish dory days by region reported to have caught Spanish mackerel from Torres Strait (TS), fishing years 1989-2003. Unspecified = region not reported in logbooks.

Islander freezer and docket book data

Spanish mackerel are also targeted commercially by Torres Strait Islanders, although less so than the non-Islander sector. Several mackerel species are caught in Torres Strait, although only Spanish and unspecified mackerel were reported in the Islander freezer records and more recent docket books (Fig. 3.11). For the purposes of this assessment we assumed that all mackerel reported in the freezer records or docket books were Spanish mackerel. Commercial Islander catches of mackerel have been variable between 1988 and 2003, reaching a peak in 2003 of 13 t (Fig. 3.11). The apparent increase in catch in the latter years coincided with an increased availability of catch records; questioning whether the catch trends were a true reflection of the Islander sector or more an extension of the data (Begg and Murchie 2004). Data from the Islander freezer records and docket books were also only collected from Darnley (Erub), Murray (Mer) and Yorke (Masig) Islands, although these are the main island communities operating in the mackerel fishery. Stephen (Ugar) Island, which does not have a community freezer, but has fishers who actively target Spanish mackerel, tend to sell their catch to the freezer operators on Darnley and Yorke Islands. Reported catches of Spanish mackerel from the Islander sector, therefore, are most likely under-estimates of the actual Islander harvest.

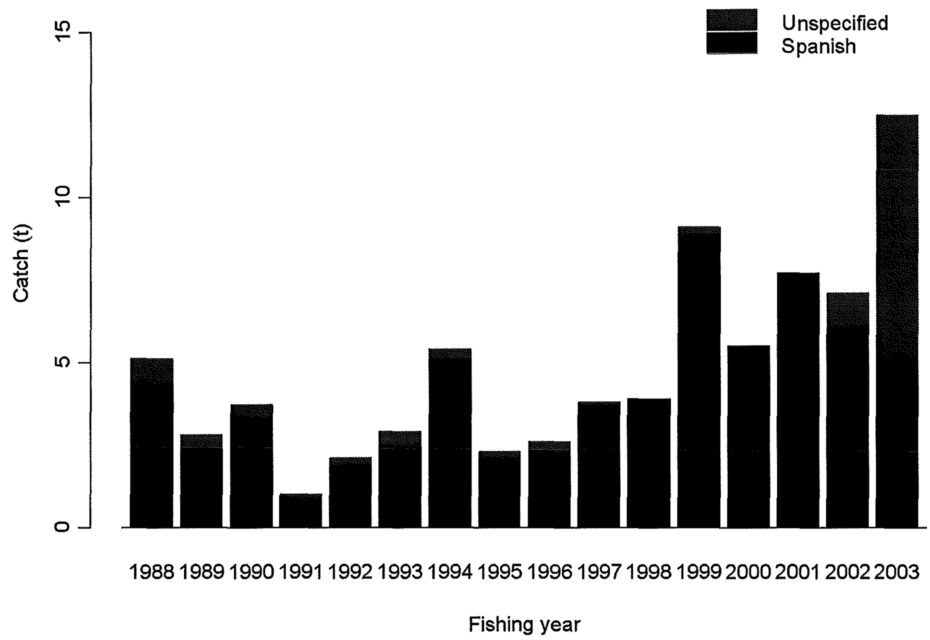

Fig. 3.11. Annual Islander commercial catch (t) of all mackerel species from Torres Strait, fishing years 1988-2003. Unspecified = unknown mackerel catch reported in docket books.

Historically, Spanish mackerel catches in the Islander sector have mostly come from the Central Torres Strait (Yorke Island), although in more recent years significant catches have also been reported from the Eastern Torres Strait (Darnley and Murray Islands) (Fig. 3.12). The increased catches from the Eastern Torres Strait are most likely due to better reporting in the docket books, as well as increased targeting of Spanish mackerel by Murray Island fishers. The seasonal catches of Spanish mackerel also tend to reflect the historical fishing patterns of the individual island communities (Fig. 3.12). In the Central Torres Strait, Spanish mackerel are mostly caught during the spring spawning months (October-December), reflective of the catch patterns of the non-Islander commercial sector, and the October-

November seasonal closure period in the tropical rock lobster fishery, which are actively targeted by Yorke Island fishers. In the Eastern Torres Strait, Islander fishers mostly catch Spanish mackerel during late autumn and early winter (March-July) before targeting reef fish in the latter months of the year (Begg and Murchie 2004).

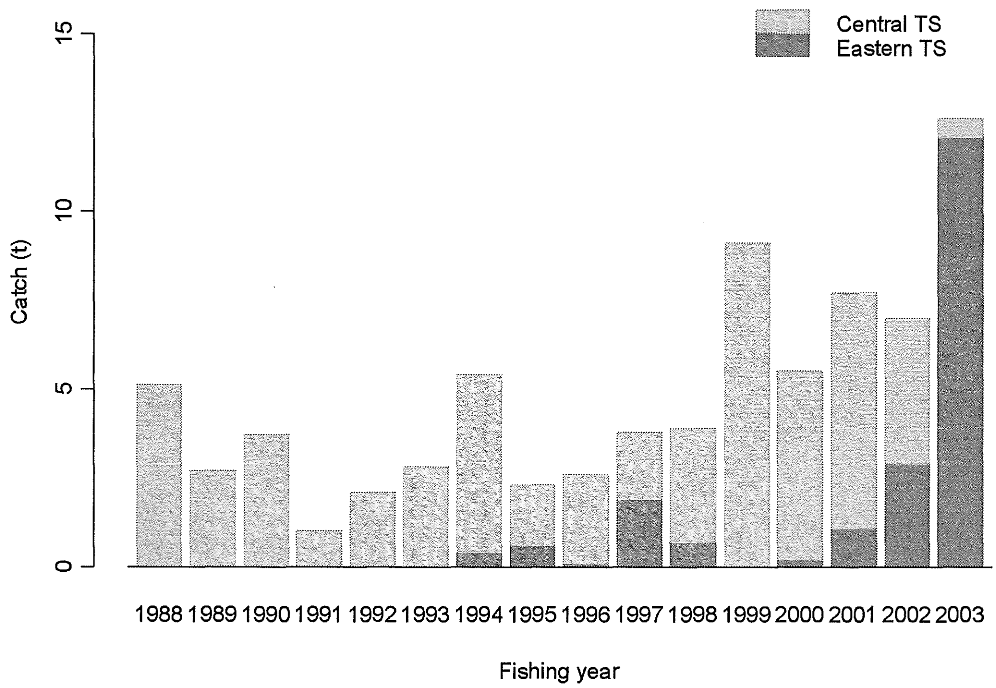

Fig. 3.12. Annual regional Islander commercial catch (t) of mackerel from Torres Strait (TS), fishing years 1988-2003.

Similar to the non-Islander sector, fishing effort in the Islander sector was based on the number of records where Spanish mackerel was reported in the freezer logbooks (*i.e.*, catch weight >0). We also assumed that each individual catch record (*i.e.*, each sales docket) was equivalent to one day of fishing effort by an individual Islander fisher (Begg and Murchie 2004). On average (1988-2003), a total of 34 Island fishers reported catching mackerel each year, with up to 62 fishers in 2002 (Fig. 3.14). A similar increase in days fished was observed from 1988 to 2003, averaging 276 fisher days, with a peak in 2003 of 455 days (Fig. 3.15). As for the catch data, the apparent increase in Islander effort in the latter years may be the result of increased reporting, as well as changing fishing patterns (Begg and Murchie 2004).

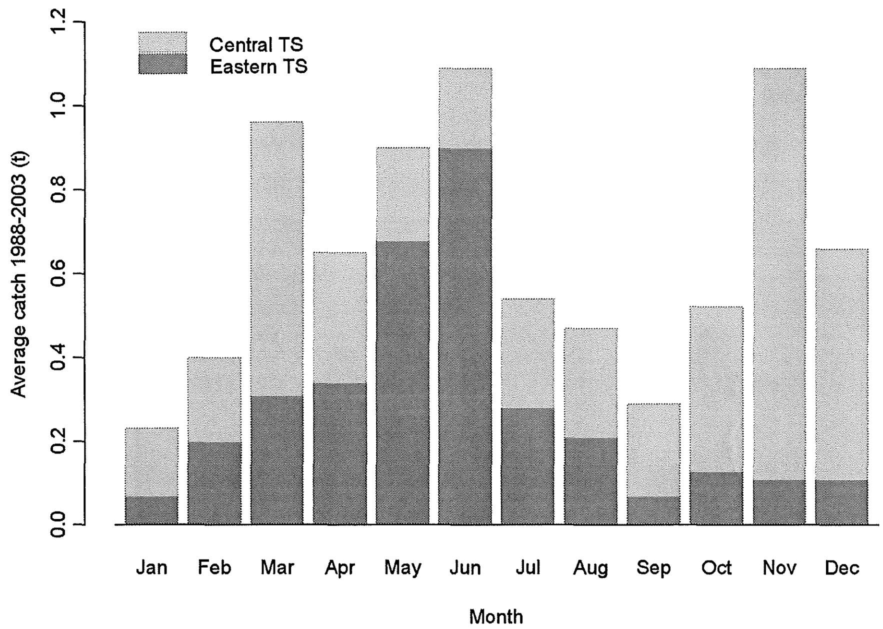

Fig. 3.13. Average monthly Islander commercial catch (t) of mackerel from Torres Strait (TS), fishing years 1988-2003.

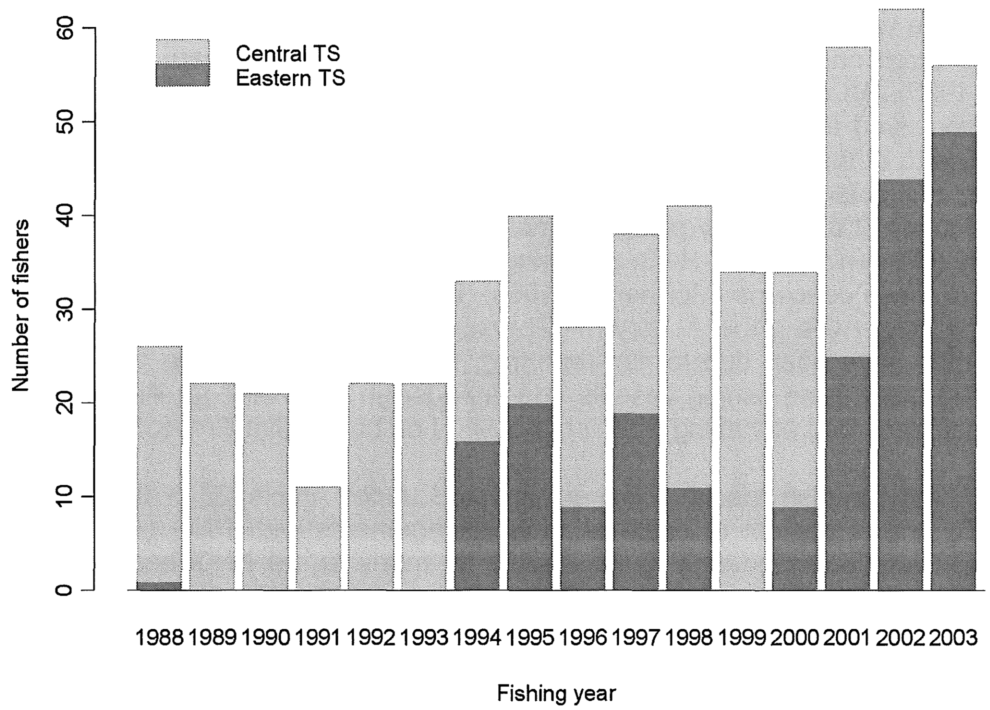

Fig. 3.14. Annual number of Islander fishers by region reported to have caught mackerel from Torres Strait (TS), fishing years 1988-2003.

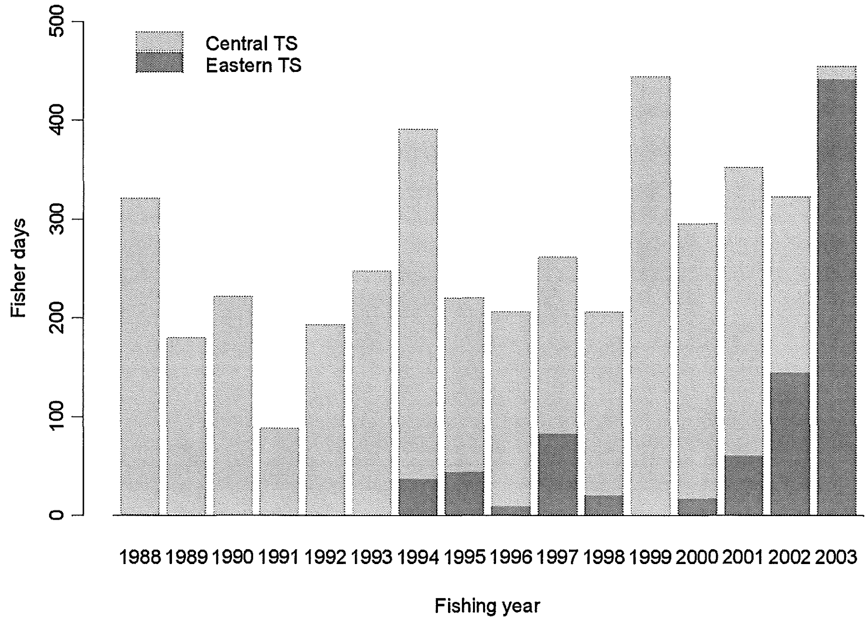

Fig. 3.15. Annual number of Islander fisher days by region reported to have caught mackerel from Torres Strait (TS), fishing years 1988-2003.

Foreign fishing fleets

Historically, there were anecdotal reports of foreign fishing fleets catching Spanish mackerel in the Torres Strait and adjacent waters of the Gulf of Papua (Chapau and Opnai 1986, McPherson 1986). An apparent decline in Torres Strait mackerel was observed during the 1980s and perceived to be related to the commencement of Taiwanese gillnet operations immediately north of the TSPZ during this period (McPherson 1986). Anecdotal reports also indicated that a substantial proportion of the Spanish mackerel catch in Torres Strait at that time showed signs of damage by pelagic gillnets suggesting the foreign fleet was impacting on the fishery (O'Brien 1995). In 1983, a tagging study of Spanish mackerel was undertaken in response to these concerns (McPherson 1986), but few tagged fish were recaptured and none from the Taiwanese gillnet fishery (McPherson 1988). Although the lack of recaptured tagged fish may have been due to non-reporting, it is notable that since 1988 there have been over 100 Indonesian fishing vessels apprehended in the TSPZ for illegal fishing with only one vessel recorded as having Spanish mackerel on board (Jim Prescott, pers. comm.).

The Torres Strait Spanish mackerel fishery is listed under Article 22 of the Torres Strait Treaty (1985) and is subject to catch sharing arrangements with PNG (AFMA 2004). In recent years, these arrangements have allowed as many as 20 PNG boats to be cross-endorsed to operate within the Australian jurisdiction. In 2003, PNG agreed to reduce their number of licenced fishing boats and limit the number of days they could access Australian waters to catch Spanish mackerel. To date, however, PNG has not taken up these licences (AFMA 2004).

Although there is a need to assess the impact of neighbouring fisheries on the Torres Strait Spanish mackerel fishery and interactions of potential stock mixing between these fisheries (Williams and O'Brien 1998), in this assessment, we did not account for any catches from the foreign fishing fleets.

Traditional sector

An unknown, but assumed relatively small quantity of Spanish mackerel is harvested by Torres Strait Islanders for subsistence (AFMA 2003). Spanish mackerel and lesser quantities of the other mackerel species, particularly shark mackerel, are caught throughout the year by trolling, with the best catches made during the spawning season in October and November (Johannes and MacFarlane 1991). Previous reports have estimated the Islander traditional catch at about 10 t each year (Williams and O'Brien 1998), although this estimate is most likely representative of the Islander commercial sector's catch. Supporting this assumption was the study of Poiner and Harris (1991), upon which the above estimate was most likely based, who observed that most of the Spanish mackerel caught from Yorke Island was sold to the Island Council freezer. In this assessment we assumed that all Spanish mackerel caught by Torres Strait Islanders were harvested for sale, and hence their catches were assumed to be incorporated in the Islander freezer and docket book data.

Recreational sector

Little data exists on the recreational catches of Spanish mackerel in Torres Strait, although it is assumed to be negligible (Williams and O'Brien 1998). Only one unspecified mackerel caught by a Thursday Island angler was reported in the Queensland and National recreational fishing surveys conducted in 1997, 1999, 2000 and 2002; although this was also reflective of the limited sampling in the region (Higgs 2001, Henry and Lyle 2003). Recreational fishing for Spanish mackerel, including that from charter vessels, is mostly conducted by non-traditional inhabitants from Thursday Island. In this assessment we assumed the recreational catches of Spanish mackerel were insignificant and hence were not accounted for in the total catch estimates (see Chapter 4).

By-product and by-catch

Few by-product or by-catch species are caught when targeting Spanish mackerel. Trolling is a relatively selective method of fishing for Spanish mackerel, with limited numbers of grey, shark, spotted and school mackerel supplementing the target catch (see Fig. 3.1). In addition, several reef fish species are often captured, particularly coral trout, which are also retained as by-product for sale. By-catch levels in the fishery are very low, consisting mainly of fish that are outside the relevant size limits for the particular target or by-product species (Anonymous 2004).

Post release mortality

Little is known about the post release mortality of line caught and subsequent release of Spanish mackerel, although anecdote suggests this to be significant. In this assessment we assumed that all fish captured were retained, and hence, did not account for post release mortality.

4. Total catches

The annual total catches for the Torres Strait Spanish mackerel fishery that were used in this assessment included data from the non-Islander and Islander commercial sectors. The fishery was assumed to have commenced in 1940 and catches were estimated to 2003. Recreational and traditional catches were assumed to be negligible and not accounted for in the estimates of total catch (see Chapter 3).

Total catches of Spanish mackerel included:
- Non-Islander commercial catches from AFMA compulsory logbooks (1989-2003).
- Islander commercial catches from Council freezer records and AFMA docket books (1989-2003).
- Average total catches for years in which no data were available based on both a non-linear model (GAM) and linear regression model (1940-1988).

Non-Islander commercial catches of Spanish mackerel were based on AFMA compulsory logbook data for mackerel, reef line, prawn and lobster endorsed fishers (Table 4.1). Dual endorsed mackerel and reef line fishers were also included in the commercial catch estimates. Due to reporting issues with the logbooks (*i.e.*, Haywood and Die 1997), the average dual endorsed catch (1989-1994, 1996-2003) was imputed for 1995 when no data were available (*i.e.*, 15 t). Similarly, owing to difficulties with reconciling Spanish mackerel catches from AFMA and Queensland logbooks for reef line fishers there were several years when no catches were reported in the AFMA logbooks (1995-2001). For these years the average dual endorsed Spanish mackerel catch reported in the AFMA logbooks was used (*i.e.*, 3 t). An incidental catch of 1 t of Spanish mackerel from prawn and lobster fishers was also included in the total catch estimates.

In this assessment, we have not attempted to discern the mackerel catches from Torres Strait with those of the east coast as reported in the Queensland Fish Board data, but instead estimate the historical catches (1940-1988) from generalised additive model (GAM) and linear interpolated hind-cast catches derived from the more recent AFMA compulsory logbook and Island docket book data. Total catches were interpolated for each year backwards from the average total catch between 1989 and 1991 (*i.e.*, 221 t) to a value of zero in 1939 (Table 4.1).

In addition, we used the historical catches reported in McPherson (1986) for the years 1957, 1959, 1960, 1962, 1975-1977 and 1979 (see Chapter 3). In those years where there were no data available (1940-1956, 1958, 1961, 1963-1974, 1978, 1980-1988) a GAM was used to estimate the average total catches. The GAM was fitted to the nominal total catches for the years reported in McPherson (1985) and the AFMA logbooks (1989-2003) and interpolated backwards to a value of zero in 1939 (Table 4.1). Average model estimates for each year were assumed to represent the respective annual total catch.

The estimated total catches of Spanish mackerel in Torres Strait, therefore, have assumed to significantly increase since the 1940s (Table 4.1, Fig. 4.1). Total catches reached a peak of about 234 t in 1997, following which catches have fluctuated down to 109 t in 2001. Major uncertainties exist in the total catches, particularly throughout the historical period when compulsory logbooks were not in use and foreign fishing was assumed to occur at unknown levels. Other uncertainties in the estimated total catches exist for the Spanish mackerel catches of non-Islander reef line fishers and the magnitude of the Islander catches.

Table 4.1. Estimated total catch (t) of Spanish mackerel, fishing years 1940-2003. Reported and estimated catches for mackerel, dual, reef, lobster and prawn non-Islander commercial fishers, as well as Islander fishers in Torres Strait. Total catch estimates based on linear interpolation and GAM fit to historical data, and used as a high and low historical catch sensitivity test in the assessment. The GAM based estimates were used in the base model run of the assessment (see Chapter 6).

Fishing	Estimated Total Spanish Mackerel Catch (t)						
year	Mackerel	Dual	Reef	Lobster/Prawn	Islander	Total	Total (GAM)
1940	0	0	0	0	0	4	3.306
1941	0	0	0	0	0	9	5.725
1942	0	0	0	0	0	14	8.136
1943	0	0	0	0	0	18	10.536
1944	0	0	0	0	0	23	12.919
1945	0	0	0	0	0	27	15.284
1946	0	0	0	0	0	32	17.625
1947	0	0	0	0	0	36	19.939
1948	0	0	0	0	0	41	22.222
1949	0	0	0	0	0	45	24.469
1950	0	0	0	0	0	50	26.678
1951	0	0	0	0	0	54	28.844
1952	0	0	0	0	0	59	30.962
1953	0	0	0	0	0	63	33.030
1954	0	0	0	0	0	68	35.044
1955	0	0	0	0	0	72	36.999
1956	0	0	0	0	0	77	38.891
1957	34	0	0	0	0	81	34
1958	0	0	0	0	0	86	42.468
1959	52	0	0	0	0	90	52
1960	40	0	0	0	0	95	40
1961	0	0	0	0	0	99	47.005
1962	70	0	0	0	0	104	70
1963	0	0	0	0	0	108	49.267
1964	0	0	0	0	0	113	50.201
1965	0	0	0	0	0	117	51.097
1966	0	0	0	0	0	122	52.026
1967	0	0	0	0	0	126	53.061
1968	0	0	0	0	0	131	54.276
1969	0	0	0	0	0	135	55.742
1970	0	0	0	0	0	140	57.534
1971	0	0	0	0	0	144	59.723
1972	0	0	0	0	0	149	62.382
1973	0	0	0	0	0	153	65.585
1974	0	0	0	0	0	158	69.404
1975	68	0	0	0	0	162	68
1976	81	0	0	0	0	167	81
1977	69	0	0	0	0	171	69
1978	0	0	0	0	0	176	92.169
1979	57	0	0	0	0	180	57
1980	0	0	0	0	0	185	108.499
1981	0	0	0	0	0	189	117.685
1982	0	0	0	0	0	194	127.286
1983	0	0	0	0	0	198	137.094
1984	0	0	0	0	0	203	146.903
1985	0	0	0	0	0	207	156.504
1986	0	0	0	0	0	212	165.690
1987	0	0	0	0	0	216	174.254
1988	0	0	0	0	0	221	181.988
1989	184	39	3	1	3	230	230
1990	187	16	1	1	4	209	209
1991	208	12	2	1	1	224	224
1992	192	8	1	1	2	204	204
1993	136	2	1	1	3	143	143
1994	170	26	2	1	5	204	204
1995	209	**15**	**3**	1	2	230	230
1996	183	8	**3**	1	3	198	198
1997	200	26	**3**	1	4	234	234
1998	192	16	**3**	1	4	216	216
1999	182	26	**3**	1	9	221	221
2000	173	20	**3**	1	5	202	202
2001	96	1	**3**	1	8	109	109
2002	141	4	4	1	7	157	157
2003	142	12	10	1	13	178	178

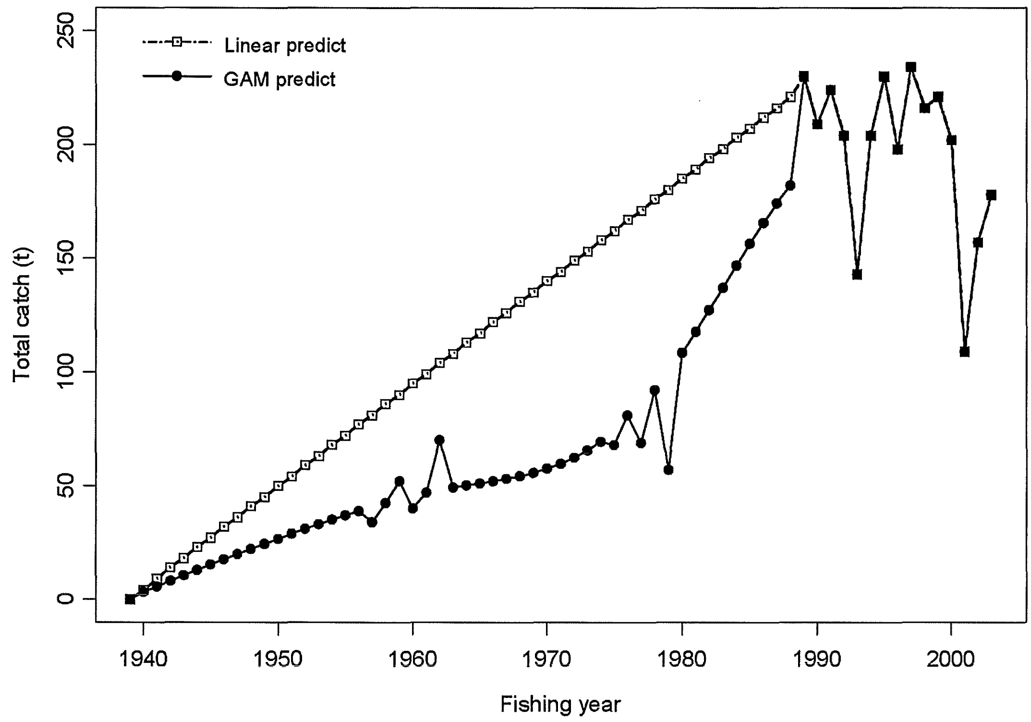

Fig. 4.1. Estimated total catch (t) of Spanish mackerel, fishing years 1940-2003. Reported and estimated catches for mackerel, dual, reef, lobster and prawn non-Islander commercial fishers, as well as Islander fishers in Torres Strait. Total catch estimates based on linear interpolation and GAM fit to historical data.

5. Standardised catch rate analysis

A relative index of abundance for the underlying fish stock to be modelled is an essential input to many stock assessment models. Catch rate or catch-per-unit-effort (CPUE) is commonly used as an index of abundance as it is assumed to be proportional to the product of catchability (q) and abundance (N) of the fish stock (Hilborn and Walters 1992). Hence, provided catchability (*i.e.*, proportion of the stock taken by one unit of effort) is constant over time, catch rate can be used as a valid index of abundance (Haddon 2001). However, catchability is often not constant, but differs due to temporal and spatial variation with changes in fleet composition, fisher experience and behaviour, areas fished and weather conditions.

Trends in catch rate over time may reflect changes in the proportion of the population caught, changes in abundance of the target species, or both, owing to catch being a function of fishing effort and abundance of the fished population (Quinn and Deriso 1999). Stock assessments based on unstandardised (*i.e.*, raw) catch and effort data can produce biased predictions owing to efficiency changes in types and levels of fishing effort through time and between fishing operations or sectors (Begg *et al.* 2005). Ideally, an abundance index should be estimated from data obtained by fishery-independent monitoring methods, but these are often costly and difficult to conduct (Maunder and Punt 2004), particularly for relatively low-value fisheries such as the Spanish mackerel fishery in the remote regions of the eastern Torres Strait (see Chapter 7). Consequently, fishery-dependent data are commonly used to estimate indices of abundance resulting in inherent problems associated with changing catchability over time. Furthermore, similar pelagic schooling fisheries to the Torres Strait Spanish mackerel fishery have a history of over-fishing and stock decline with little indication of stock problems provided through unstandardised measures of fishery-dependent catch and effort data (Begg *et al.* 2005). Problems exist with using unstandardised and fishery-dependent data as indicators of stock status because of the schooling behaviour of the resource where catch rates may remain high even if fish stocks are being seriously depleted; a situation known as hyperstability (Hilborn and Walters 1992).

In order to use catch rate as an index of abundance, therefore, it is necessary to adjust (or remove) factors which influence the index of abundance, other than abundance itself (Maunder and Punt 2004). This process is often referred to as *catch-effort standardisation* (Beverton and Holt 1957, Cramer and Ortiz 2001, Punt *et al.* 2001, O'Neill *et al.* 2003, Rodriuez-Mar *et al.* 2003, Maunder and Punt 2004, Ortiz and Diaz 2004, Begg *et al.* 2005). The use of generalised linear models (GLMs) is the most common approach for standardising catch rate where these have been used to standardise Queensland trawl catches (O'Neill *et al.* 2003) and in adjusting climate and gear effects on the catch rate of Australian east coast spotted mackerel (Begg *et al.* 2005). Generalised linear mixed effect models (GLMMs) and linear mixed effect models (LMEs) have recently been used to extend the scope of linear models by allowing effects in the model to be random (Maunder and Punt 2004). For example, Ortiz and Diaz (2004) treated the interaction effect between year and other factors as random and applied GLMMs to standardise the catch rate of albacore tuna (*Thunnus alalunga*), while Rodriguez-Mar *et al.* (2003) used a similar approach for standardising catch rates of bluefin tuna (*Thunnus thynnus*).

In this assessment, GLMMs were used to standardise the annual catch rate of Torres Strait Spanish mackerel. The analysis considered a number of different climate variables thought to affect the catchability (and subsequent catch rate) of Spanish mackerel including the Southern Oscillation Index (SOI), wind speed and direction, sea surface temperature (SST) and lunar phase. In Begg *et al.* (2005), these variables were found to significantly affect the catchability of spotted mackerel, and hence were included in this analysis for Spanish mackerel. Weather and sea conditions are commonly associated with variable catch rates, where fishers report that unfavourable conditions often result in lower catches. Spanish mackerel catches along the Queensland east coast have also been suggested to be related to lunar phase, with high catches and spawning aggregations occurring during the dark moon phases (Tobin and Mapleston 2004). In contrast, higher catch rates of spotted mackerel were associated with rising moon phases (Begg *et al.* 2005). Standardised annual catch rates were used in this assessment as a relative index of population abundance.

Methods

Climate data

Data on the monthly SOI, and daily 9 a.m. recorded wind speed, wind direction and mean sea level pressure (MSLP) were collated by the Australian Bureau of Meteorology (BOM). Weekly average one-degree grid SST data were also obtained from the NOAA website (http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.GLOBAL/.Reyn_Smith OIv2/.weekly/.sst/).

SOI data were obtained from the BOM website (http://www.nrm.qld.gov.au/silo/ppd/PPD_frameset.html). The SOI was calculated from monthly fluctuations in air pressure differences between Tahiti and Darwin using the Troup SOI method as follows:

$$SOI = 10\frac{(P_{diff} - P_{diffav})}{SD(P_{diff})} \tag{5.1}$$

where, P_{diff} = average monthly Tahiti MSLP minus average monthly Darwin MSLP; P_{diffav} = long-term average of P_{diff} for the respective month; and $SD(P_{diff})$ = long-term standard deviation of P_{diff} for the respective month. The SOI ranges from about –35 to +35. Sustained negative values of the SOI often indicate El Niño events, which are characterised by warming of the central and eastern tropical Pacific Ocean, a decrease in the strength of the Pacific Trade Winds and a reduction in rainfall over eastern and northern Australia (Begg *et al.* 2005). In contrast, positive values of the SOI (*i.e.*, La Niña events) are associated with cooling of the central and eastern tropical Pacific Ocean, stronger Pacific Trade Winds and higher rainfall and warmer sea temperatures to the north of Australia. The most recent strong El Niño and La Niña events were in 1997/98 and 1988/89, respectively. A moderate La Niña event occurred in 1998/99, which weakened back to neutral conditions before reforming for a shorter period in 1999/2000. The SOI is usually computed by BOM on a monthly basis because a finer temporal scale is not suitable for climate estimation purposes.

Daily wind speed and direction data at 9 a.m. were obtained from three weather stations (Thursday, Coconut and Horn Islands) in the Torres Strait; assumed to be representative of the conditions experienced by the Spanish mackerel fishery. Although wind data are also recorded daily at 3 p.m., these were excluded from the analysis due to a large proportion of missing data. The wind data were transformed into two components: one measuring the strength of the east-west on-off shore winds ($Wind_{east\text{-}west}$); and the second measuring the strength of the north-south along-shore winds ($Wind_{north\text{-}south}$). Wind direction is recorded in 360° scales. The following equations were used to quantify the wind components:

$$Wind_{east-west} = Speed_{km/hr} \sin(Direction_{degrees}) \tag{5.2}$$

$$Wind_{north-south} = Speed_{km/hr} \cos(Direction_{degrees}) \tag{5.3}$$

where, $Direction_{degrees}$ = zero when the wind was from due north. The daily 9 a.m. wind data were averaged between the three weather stations and linked to the respective daily commercial non-Islander logbook data and Islander freezer records for the standardisation catch rate analysis.

The average SSTs analysed were produced weekly on a one-degree grid. Within the Torres Strait, there are 8 grid cells where SST data were available (Fig. 5.1). Because the weekly SST remains fairly constant in these 8 grids, weekly SST was averaged over these locations and linked to the respective daily commercial non-Islander logbook data and Islander freezer records for the standardisation catch rate analysis. SST data were also advanced 3 months to capture the seasonal characteristics in the Torres Strait. SST was computed using optimum interpolation analysis which was developed by Richard Reynolds of NOAA (Reynolds 1988, Reynolds and Marsico 1993). The analysis used data from buoy, ship, satellite and simulated sea ice coverage data. Before the analysis, satellite data were adjusted using the methods in Reynolds (1988) and Reynolds and Marsico (1993).

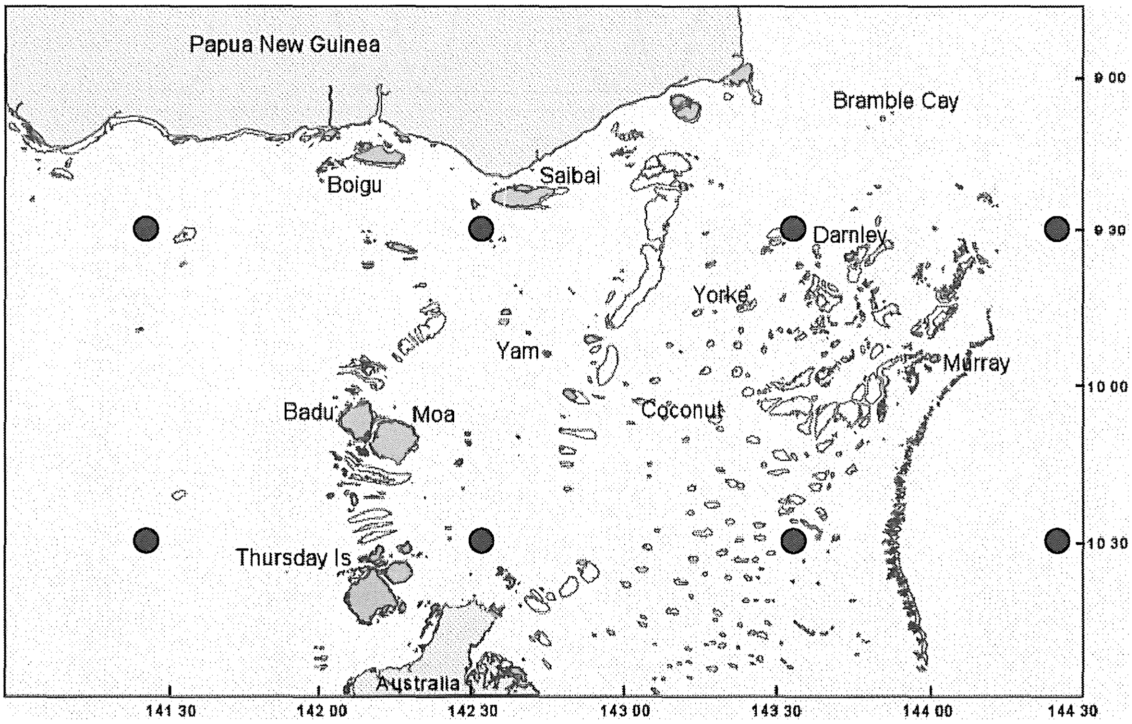

Fig. 5.1. SST locations in the Torres Strait estimated from NOAA satellite images.

Variation in catch rates was also tested against a calculated luminance measure (ranging between 0 = New moon and 1 = Full moon) (Courtney *et al.* 2002, Begg *et al.* 2005). This luminance measure followed a cycle sinusoidal pattern and was replicated and advanced by 7 days (~ 0.25 lunar phase) to approximate the cosine of the luminance (Fig. 5.2). Together these patterns were periodic and model a cyclic variation in catch rates corresponding to new moon, rising moon, full moon and waning moon phases. For further details see Begg *et al.* (2005).

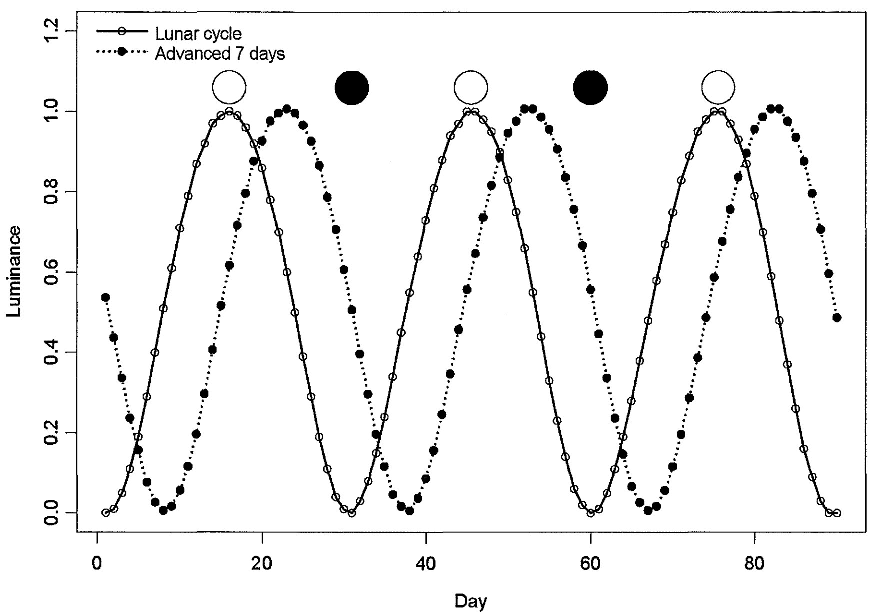

Fig. 5.2. Luminance measures over 90 days demonstrating the luncar cycle. Solid line indicates the luminance measure of the lunar cycle and dotted line is the luminance measure advanced 7 days of the lunar cycle. The circles on the top of the figure show the moon phases. Peaks of the solid line indicate the luminance measure of the full moon and the valleys luminance measure of the new moons. Peaks of the dotted line indicate the meaure of the rising moons and the valleys the falling moons.

Catch data

The catch rate standardisation was based on catch and effort data from the AFMA compulsory commercial finfish logbooks and Islander freezer records and docket books from July 1989 to June 2004 (*i.e.*, fishing years 1989 to 2003). Although both lobster and prawn fishers have reported minor catches of Spanish mackerel, these data were not used in the analysis because of discontinuities in the time series. Similarly, Spanish mackerel catches from the reef line sector were also not included in the catch rate analysis because of missing data between 1994 and 2001. Furthermore, only data from fishers who reported catches from at least 7 of the 15 years were included in the analysis to avoid spurious and incidental catches that may confound the standardisation results. The common unit of effort used in the analysis was dory day and the unit of catch was kilograms. The data consisted of only those mackerel catches where fish were caught and retained (*i.e.*, catches > 0). No data were available on searching effort or on fishing effort when no Spanish mackerel were caught.

Statistical analysis

The relative standardised catch rate of Torres Strait Spanish mackerel was estimated using a GLMM (Pinheiro and Bates 2000), assuming a log-normal error distribution. The response variable was based on individual commercial non-Islander or Islander catches over a unit of time for a given region. The analysis involved two steps. The initial step involved using step-wise regression analysis and analysis of deviance to select a set of candidate (*i.e.*, significant) variables to describe the observed catch rate. Analysis of deviance derived from the step-wise regression demonstrated the significant variables to be included in the model. Once a set of significant variables were obtained from the step-wise approach, a GLMM was used for incorporating random vessel effects and estimating the relative standardised catch rate. The Wald test was used to determine if the selected variables were still significant in the final model.

Statistical regions were included in the analysis to account for spatial variation in Spanish mackerel abundance at a given time. Likewise to account for temporal variation, fishing years and months were included in the analysis. Fishing (*i.e.*, financial) years, rather than calendar years, were used in the analysis as this period better depicts when spawning and recruitment to the fishery occurs.

For the purpose of this assessment, commercial non-Islander fishers were classified into two sectors depending on their catch compositions (see Chapter 3). Mackerel fishers were classified as those fishers whose catches were comprised of more than 75% mackerel, while dual endorsed fishers were those whose catches were between 25% and 75% mackerel. Catches by all Torres Strait Islanders were grouped as one sector. Catch rates were considered to vary between sectors; therefore, by including fisher type as a variable in the analysis it allowed us to adjust potential catch rate differences between the sectors.

Catch rates were also assumed to differ both within and between individual vessels. Therefore, we considered it necessary to include individual fishing vessel in the standardisation. Vessel was treated as a random variable because of assumed differences in individual catchabilities over time with fisher experience, changing crew, gear technology, etc. Including vessel as a random variable in the model allowed the GLMM to capture "within vessel between times" variation (Venables and Dichmont 2004).

Catch rate or CPUE is the product of biomass and catchability (Quinn and Deriso 1999):

$$CPUE = Bqe^{\varepsilon} \tag{5.4}$$

where, B = biomass or abundance of Spanish mackerel; q = catchability; e = fishing effort; and ε = error term. However, because q is typically not constant over time and is affected by numerous variables, Equation 5.4 can be re-written as:

$$CPUE = B\prod_i\prod_j X_{ij}^{\alpha_{ij}}\prod_i\prod_j Z_{ij}^{\varsigma_{ij}}e^{\varepsilon} \tag{5.5}$$

where, X = fixed variables; Z = random variables; α_{ij} = fixed coefficients; ς_{ij} = random coefficients; i = number of variables; j = number of classes within each variable; and ε = error term with normal distribution of mean 0 and constant variance σ^2.

A log transformation of Equation 5.5 gives a linear mixed regression model of the form:

$$Ln(CPUE) = \ln(B) + \sum_i\sum_j \alpha_{ij}\ln(X_{ij}) + \sum_i\sum_j \varsigma_{ij}\ln(Z_{ij}) + \varepsilon \tag{5.6}$$

In this assessment, X = fishing year, month, region, fisher type and climate variables (*e.g.*, SOI, SST, wind east-west composition, wind north-south composition and two lunar phases); and Z = vessel name. The exponentiated fishing year coefficients adjusted for bias correction (*i.e.*, $\exp(\alpha+\sigma^2/2)$) were used as the annual catch rate index of abundance, standardised for the other terms in the model (Maunder and Punt 2004).

Catch rate standardisation was conducted using Splus 6.1 and code for the final model was defined as follows:

```
lme(log(Catch)~log(Dory.days) + Fishing.year + Month + Region + Fisher.type + Avg.mth.SST + SOI + Wind.EW + Wind.NS + Lunar.phase + Lunar.phase.adv7days, random=~1|Vname, data=std.data, na.action=na.exclude)
```

Results

Climate data

Typically, El Niño conditions have been prevalent in the Torres Strait between 1989 and 2003, with negative SOI values observed for 11 of the 15 years; indicative of below average rainfall (Fig. 5.3). Prevailing strong south east trade winds from April to November are also characteristic of the conditions experienced by fishers in the Torres Strait (Fig. 5.4), generally restricting Islander fishers who operate from small dories (< 5 m) to regions around their home islands during these months (Begg and Murchie 2004). A strong seasonal pattern in SST is also typical of the Torres Strait, although the temperate range is limited to about 25 °C and 30 °C (Fig. 5.5).

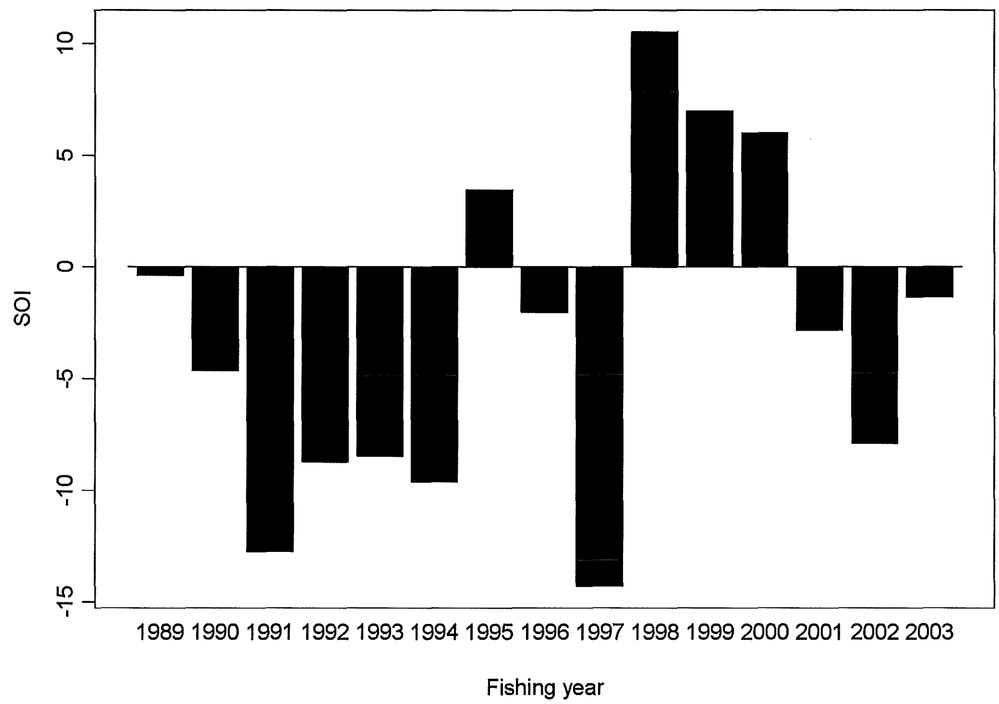

Fig. 5.3. The Southern Oscillation Index (SOI) between 1989 and 2003. Years with negative SOI (El Niño) often associated with below average rainfall and years with positive SOI (La Niña) often associated with above average rainfall.

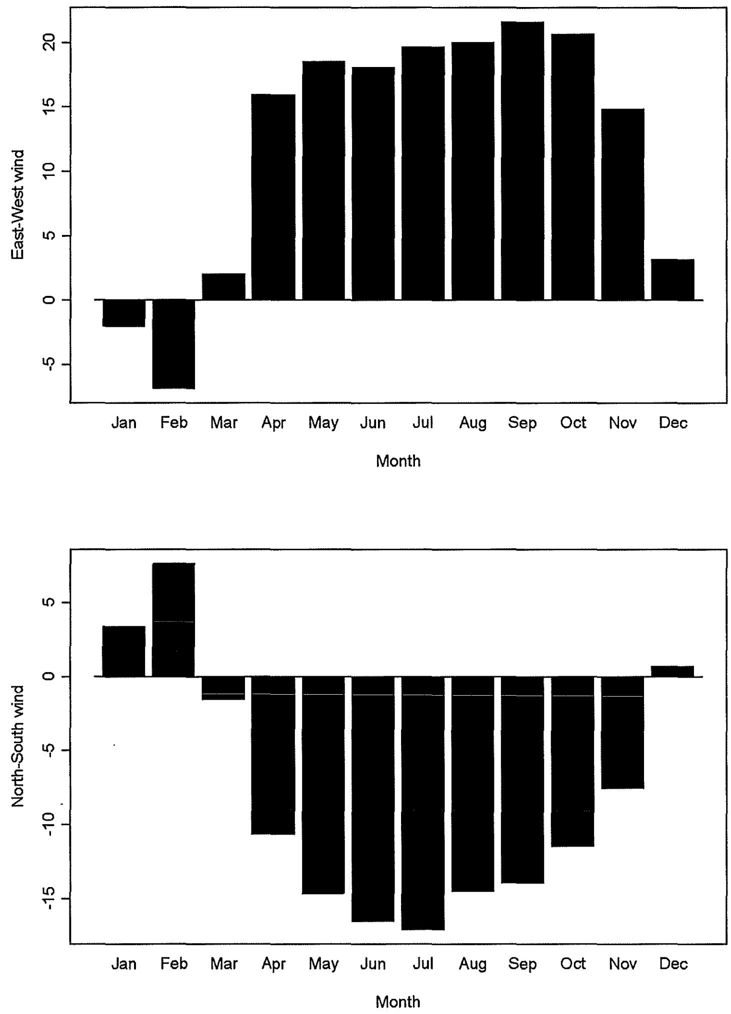

Fig. 5.4. Average monthly east-west and north-south winds from daily 9 a.m. records at Thursday, Coconut and Horn Islands (fishing years 1989-2003). Positive values represent winds from the east and north. Negative values represent winds from the west and south.

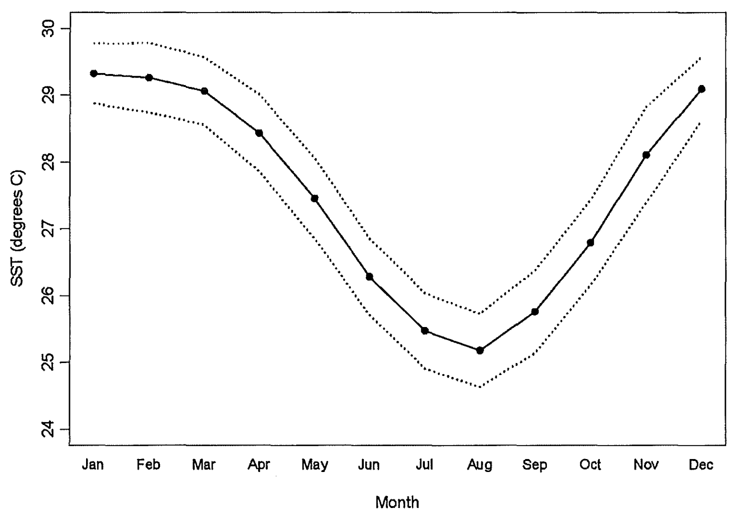

Fig. 5.5. Average (±SD) monthly sea surface temperature (SST; °C) from weekly one-degree grid locations in Torres Strait (fishing years 1989-2003).

Catch data

Analysis of deviance indicated that vessel, fisher type, region, month, fishing year, moon phase, wind speed, SST and SOI were all significant variables influencing catch rates of Spanish mackerel in Torres Strait (Table 5.1). Only the seasonal SST variable did not appear to affect catch rates, accounting for less than 0.1% of the total variance. Fisher type and Region were the most important explanatory variables, accounting for about 67% of the total variance. All significant variables were used in the final GLMM for the catch rate standardisation (Table 5.2).

Table 5.1. Forward stepwise analysis of deviance demonstrating significant variables to be included in final catch rate standardisation analysis.

Fitted terms	d.f.	Deviance	Residual deviance	% Total deviance	Probability
Log(Dory days)	1	733.48	27546.19	6.30	<.0001
Fishing year	14	860.31	26685.88	7.38	<.0001
Month	11	917.80	25768.08	7.88	<.0001
Region	5	3202.73	22565.36	27.49	<.0001
Fisher type	2	4601.62	17963.74	39.50	<.0001
SST	1	14.23	17949.50	0.12	<.0001
Advanced 3 month SST	1	2.29	17947.21	0.02	0.1242
SOI	1	28.15	17919.07	0.24	<.0001
Wind EW	1	150.90	17768.17	1.30	<.0001
Wind NS	1	18.54	17749.64	0.16	<.0001
Moon phase	1	27.25	17722.39	0.23	<.0001
Advanced 7 day moon phase	1	391.44	17330.95	3.36	<.0001
Vessel	26	701.95	16629.00	6.02	<.0001
Residual	17165				
Total	17231				

Table 5.2. Wald test showing significant factors in final GLMM used for catch rate standardisation analysis.

Fitted terms	Num d.f.	Den d.f.	F-value	Probability
Intercept	1	17166	3802.90	<.0001
Log(Dory days)	1	17166	108.99	<.0001
Fishing year	14	17166	31.83	<.0001
Month	11	17166	49.39	<.0001
Region	5	17166	74.48	<.0001
Fisher type	2	26	157.55	<.0001
SST	1	17166	19.56	<.0001
SOI	1	17166	25.22	<.0001
Wind EW	1	17166	146.43	<.0001
Wind NS	1	17166	20.37	<.0001
Moon phase	1	17166	24.17	<.0001
Advanced 7 day moon phase	1	17166	387.09	<.0001

The different fishing sectors targeting Spanish mackerel in the Torres Strait showed dissimilar catch rate trends between 1989 and 2003 (Fig. 5.6). The time series reflected the data availability and associated variability for the different sectors (mackerel: n=13774; dual: n=1585; Islander: n=2213 data records). Catch rates of dedicated mackerel fishers steadily declined from 1990 to 1999, before increasing from 2000. In contrast, the catch rates of dual (*i.e.*, mackerel/reef line) fishers were reasonably steady, except in 1996 which was unusually high and may have been influenced by low sample numbers (*i.e.*, only 60 records). The catch rates of Torres Strait Islanders remained fairly steady between 1989 and 1996, increasing to a peak in 2002, followed by a decline in 2003.

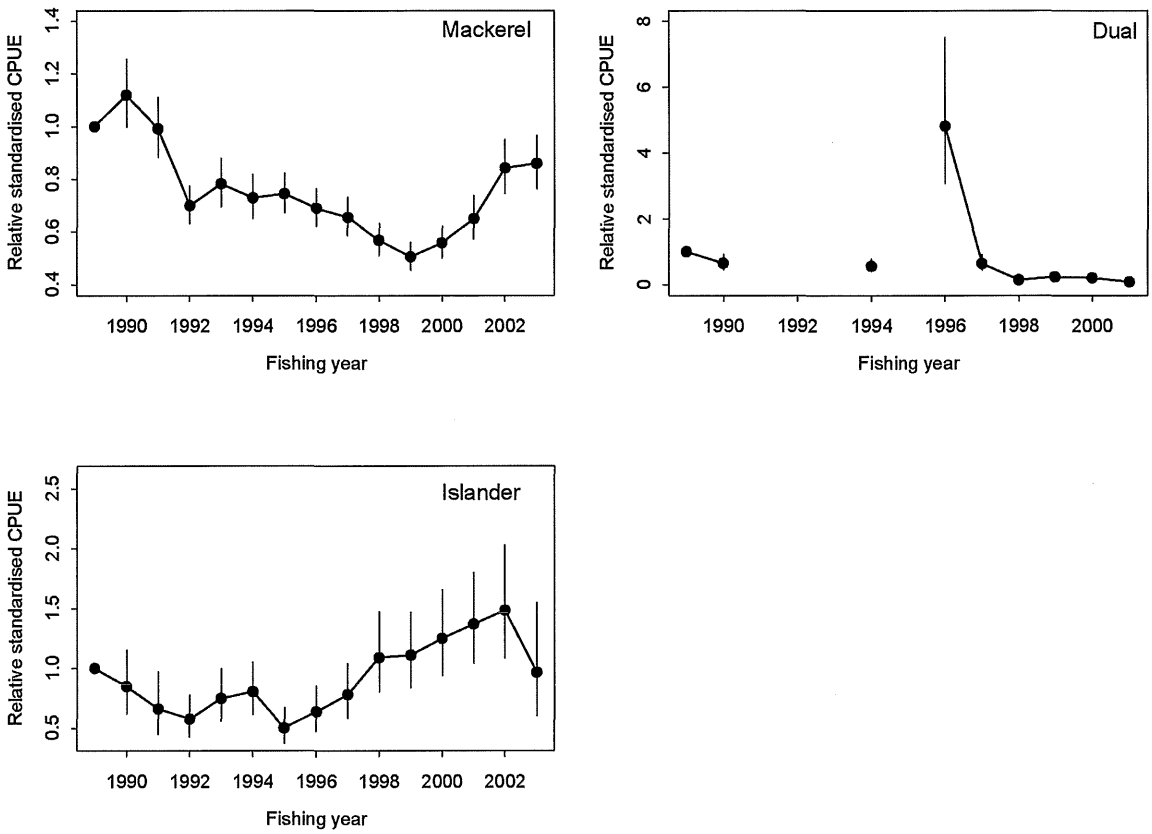

Fig. 5.6. Annual relative mean (±approximate 95% CI) standardised catch rates (CPUE). CPUEs standardised to 1989=1 for mackerel, dual (mackerel/reef line) and Islander fisher type.

The unified catch rate analysis including all fisher types showed that the catch rate trend was similar to that of the mackerel fishers; no doubt a reflection of the disproportionate amount of data for this sector compared to the dual and Islander fishers (Fig. 5.7). Standardised catch rates declined from 1989 to 1999, before increasing from 2000 to 2003. The observed unstandardised catch rates showed a similar trend, although there were differences within years (Fig. 5.7). Catch rates of Spanish mackerel in Torres Strait varied according to temporal, spatial and climatic factors (Fig. 5.8). Catch rates tended to be higher from October to May when Spanish mackerel are aggregated for spawning for most of these months (see Chapter 1). Catch rates were also higher around Bramble Cay and to a lesser degree the eastern Islands, where most of the fishery operates (see Chapter 3). The estimated average fishing power was more than two-fold greater for mackerel than dual fishers, who in turn were almost twice as efficient as Islander fishers (Fig. 5.8). Catch rates were slightly higher with weaker winds and during dark moon phases.

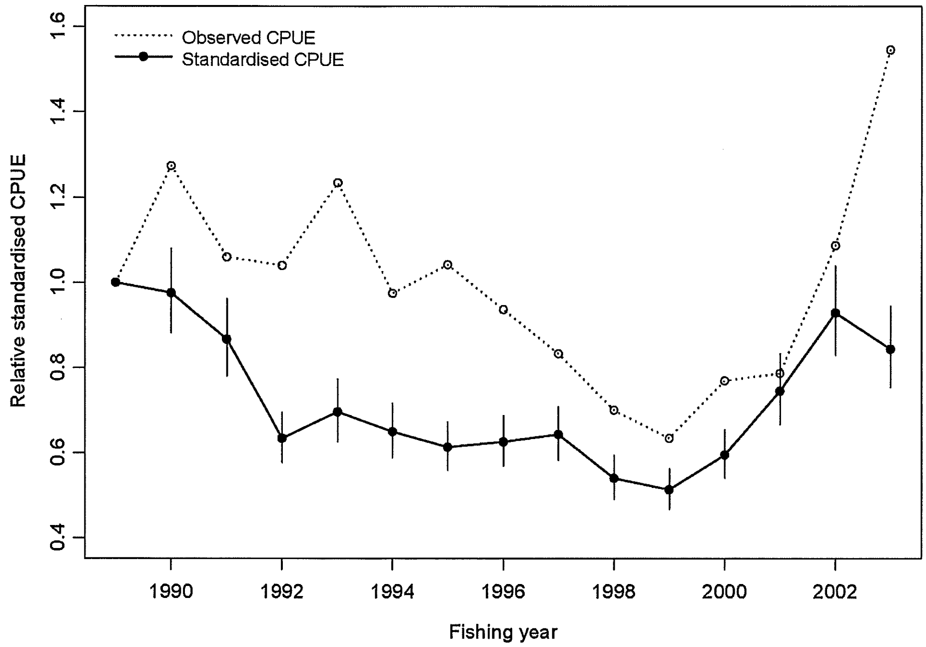

Fig. 5.7. Annual relative mean observed and standardised (±approximate 95% CI) catch rates (CPUE) pooled across regions and fishing sectors, fishing years 1989-2003. CPUEs standardised to 1989=1. Standardised CPUE used as index of abundance in the assessment.

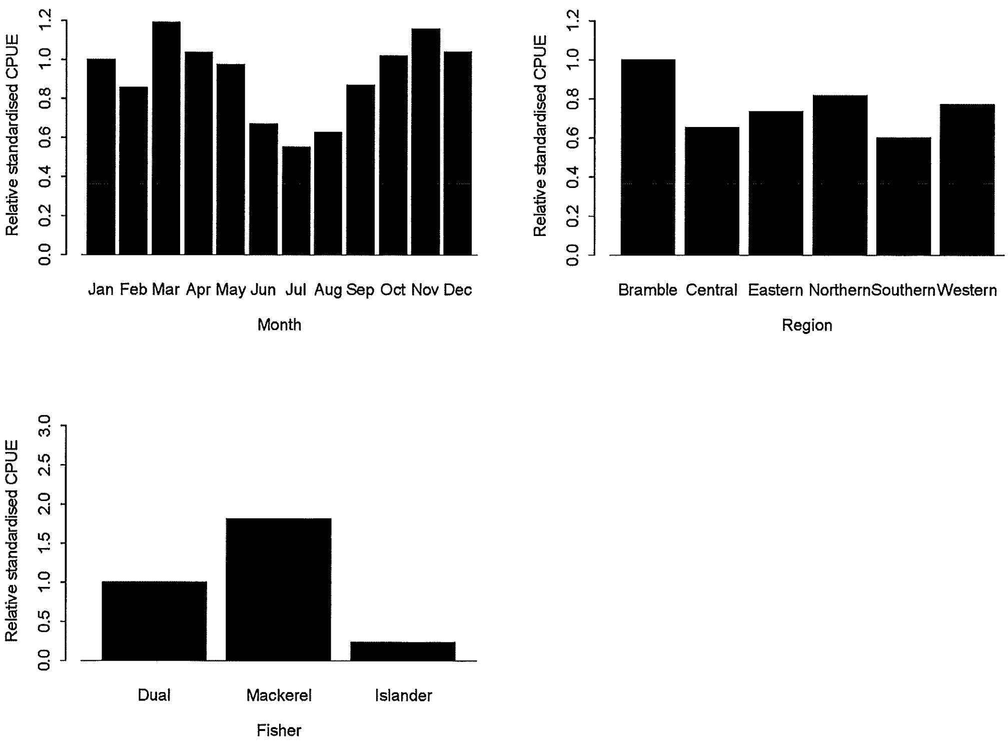

Fig. 5.8. Relative mean standardised catch rates (CPUE). CPUEs standardised to January, Bramble Cay and Dual (*i.e.*, mackerel/reef line) fisher type, respectively.

Diagnostic plots indicated that the GLMM provided a reasonable fit to the catch rate data (Fig. 5.9). The standardised residuals had a satisfactory normally distributed pattern. The observed distribution of the untransformed catch rates was highly skewed, supporting the CPUE log transformation (Fig. 5.9). An alternative GLMM with a logit link function and Gamma error distribution was also examined. No significant differences in the trends of the relative catch rates were found between the two models, although the residuals of the gamma error distribution GLMM were positively skewed. Therefore, the GLMM assuming a log-normal error distribution was considered more suitable for describing the catch rate data, with the associated year coefficients used as the relative index of abundance for this assessment (Table 5.3).

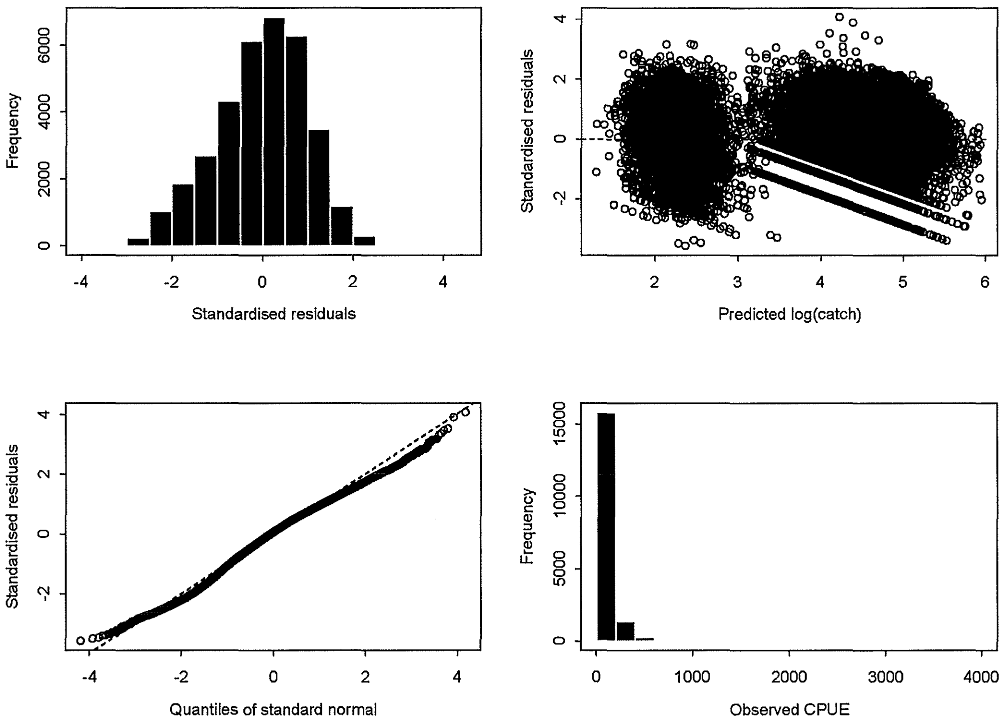

Fig. 5.9. Diagnostic plots of final log-normal GLMM used for catch rate standardisation analysis.

Table 5.3. Annual relative mean standardised (SE) and observed catch rates (CPUE), fishing years 1989-2003. CPUEs standardised to 1989=1. Standardised CPUE used as index of abundance in the assessment.

Fishing year	Standardised CPUE	SE	Observed CPUE
1989	1.0000	0.0000	1.0000
1990	0.9759	0.0516	1.2736
1991	0.8665	0.0533	1.0596
1992	0.6339	0.0470	1.0399
1993	0.6964	0.0536	1.2343
1994	0.6497	0.0499	0.9749
1995	0.6136	0.0468	1.0418
1996	0.6260	0.0477	0.9366
1997	0.6433	0.0496	0.8329
1998	0.5407	0.0484	0.7004
1999	0.5133	0.0467	0.6345
2000	0.5955	0.0480	0.7694
2001	0.7450	0.0565	0.7867
2002	0.9289	0.0571	1.0870
2003	0.8436	0.0572	1.5463

Discussion

One of the major problems associated with using catch rate as an index of abundance is the risk of hyperstability or hyperdepletion. When the catch rate remains high, but the actual underlying population abundance declines, this situation is known as hyperstability; a dangerous characteristic for a fishery to exhibit (Begg *et al.* 2005). In contrast, when the catch rate declines, but the actual population abundance remains stable, a situation known as hyperdepletion exists. Hyperstability is often expected in fisheries based on schooling species and where searching for fish is highly efficient, resulting in fishing effort being concentrated in areas where fish are most abundant (Hilborn and Walters 1992). The Torres Strait Spanish mackerel fishery exhibits common characteristics of a hyperstable fishery, with the majority of the fishery being concentrated on large spawning aggregations around Bramble Cay. Therefore, although we have standardised the catch rates of Spanish mackerel in a robust manner, there remains concerns over the actual relationship between the catch rate and underlying population abundance.

Hyperstability in a fishery can be minimised with more accurate measures of fishing effort, including detailed information on search times and days when zero catches occur (Begg *et al.* 2005). Although effort data in this assessment were standardised to dory day, better indices of abundance may be derived at finer temporal scales such as catch per dory hour (Haywood and Die 1997), resulting in an improvement on our catch rate analysis used in this assessment. Catch and effort data for the Torres Strait Spanish mackerel fishery, however, are currently limited and at relatively coarse spatial and temporal scales, but are the only available time series of any consistency and duration that can be used to characterise the status of the population and conduct the stock assessment.

6. Stock assessment

Prior to this assessment, there have been no formal stock assessments conducted for the Torres Strait Spanish mackerel fishery. Limited catch and effort data and/or associated difficulties and uncertainties with these data have restricted previous assessments to simple interpretations of trends in unstandardised catch statistics (McPherson 1986, O'Brien 1995, Haywood and Die 1997, Williams and O'Brien 1998). McPherson (1986) analysed the catch rate for one vessel that fished in Torres Strait from 1968 to 1983 and noted an annual decline in fish numbers landed, with a corresponding decline in abundance after 1980 postulated to be attributable to the effects of a neighbouring Taiwanese gillnet fishery. Other informal assessments have suggested that annual catch rates of Spanish mackerel have remained relatively stable since the introduction of the AFMA commercial logbooks, although varying seasonally, with peak catch rates in October (O'Brien 1995, Williams and O'Brien 1998). Haywood and Die (1997), however, also recommended that inconsistencies in the database be corrected before a reliable stock assessment is conducted (see Chapter 1). The development of a new database (Lilly 2000b), although not rectifying all of the problems identified by Haywood and Die (1997), enabled this assessment to be conducted.

In this assessment, we applied a sex-specific, age-structured population dynamics model to evaluate the status of the Torres Strait Spanish mackerel fishery. The model built upon an assessment model developed for Northern Territory and Queensland east coast Spanish mackerel (O'Neill and McPherson 2000, Hoyle 2002, Welch *et al.* 2002, Hoyle 2003, Buckworth 2004) and more recently, for spotted mackerel (Begg *et al.* 2005). A range of biological and effort reference points were assessed to evaluate various potential management strategies for the Torres Strait Spanish mackerel fishery. Total catches, catch rates as an index of abundance, age structures, and key population dynamic parameters such as natural mortality, stock recruitment steepness and maturity, as detailed in previous chapters, were used as input to the assessment.

Methods

Age-structured population dynamics model

An age-structured population dynamics model was used to calculate yearly exploitable population numbers and biomass of Torres Strait Spanish mackerel. The model was first developed for Spanish mackerel in the Northern Territory (Buckworth 2004), and was recently adapted for the Queensland east coast Spanish mackerel (O'Neill and McPherson 2000, Hoyle 2002, Welch *et al.* 2002, Hoyle 2003) and spotted mackerel fisheries (Begg *et al.* 2005). The model was modified to apply to Torres Strait Spanish mackerel using an age-structured approach that considered the survival of 1+, ..., 12+ old male and female fish. Unlike the model used in the spotted mackerel assessment which also considered the survival of 0+ fish, the model used in this assessment was modified to estimate $N_{1,1940}$ (*i.e.*, number of 1+ year old fish in the virgin stock) due to the lack of 0+ fish in the age structure data.

The main data sources for the model were the total catches (Table 4.1), catch rates (Table 5.3) and age structures (Table 2.8, Fig. 2.4). The annual total catches included data from the commercial non-Islander and Islander sectors. The fishery was assumed to have commenced in 1940. The parameters estimated in the age-structured model, as well as those that were fixed or assumed, are outlined in Table 6.1. The main assumptions of the model were:

- Single unit stock.
- Stock equilibrium in 1940.
- Biological parameters and relationships representative of underlying population.

- Stock recruitment steepness = 0.52.
- No recruitment deviations from stock-recruitment relationship.
- Constant annual natural mortality.
- Constant average fish growth.
- Maximum fish age of 12 years.
- Constant maturity.
- Constant fecundity.
- Constant selectivity.
- Accurate representation of total catch.
- Standardised catch rate proportional to abundance.

The model was fit to the observed catch age structures (as a proportion) from the fishing years 2000 to 2002, and standardised catch rates from 1989 to 2003 to calculate yearly exploitable population numbers and biomass. Sensitivity analysis was conducted to test the effects of the key parameters on the results (Table 6.2). Only one sensitivity parameter was changed at a time, and 13 different scenarios were examined. Natural mortality (*M*), stock-recruitment steepness (*h*), age structure and catch rate data were each examined for their influence on model results. In addition, total catches based on high historical catches (*i.e.*, linear interpolation of catch data) were tested (Table 6.2 and see Fig. 4.1). For further details on the model see Begg *et al.* (2005).

Table 6.1. List of parameters used in the stock model.

Estimated parameters	Fixed parameters (assumed known)
Virgin recruitment: $N_{1,1940}$	Annual natural mortality M: 0.37
Length at 50% selectivity: $Length_{50}$	Stock-recruitment r_{max}: 4.5
Length at 95% selectivity: $Length_{95}$	Length-weight relationship: see Chapter 2
	Growth curve: see Chapter 2
	Maximum age group: 12+

Table 6.2. A total of 13 different sensitivities were run with the age-structured stock model. Natural mortality (*M*), stock-recruitment steepness (*h*), age structure, catch rate (CPUE) data and other factors were examined for their influence on model results. The base case included the GAM fitted catch data.

Model sensitivity run	*M*	r_{max}	Age data	CPUE data	Others
1	0.37	4.5	Yes	Yes	Base case
2	0.44	4.5	Yes	Yes	
3	0.30	4.5	Yes	Yes	
4	0.26	4.5	Yes	Yes	Based on max age 17 years
5	0.37	9.3	Yes	Yes	
6	0.44	9.3	Yes	Yes	
7	0.30	9.3	Yes	Yes	
8	0.37	2.4	Yes	Yes	
9	0.44	2.4	Yes	Yes	
10	0.30	2.4	Yes	Yes	
11	0.37	4.5	Yes	Yes	Linear interpolation of catch data
12	0.37	4.5	Yes	No	Linear interpolation of catch data
13	0.37	4.5	Yes	No	

Reference points

The calculations of management equilibrium reference points were based on optimizing the dynamics of the age-structured stock model through harvest rates (*i.e.*, fishing mortality). The dynamics of the models were optimized for three reference points: 1) harvest rate (U) or fishing mortality (F) at maximum sustainable yield (MSY) (F_{MSY}); 2) $0.75F_{MSY}$; and 3) fishing mortality equal to half that of natural mortality F=0.5M. Note that F relates to annual instantaneous fishing mortality (log scale) and U relates to annual harvest rates (proportional scale), where F = -log(1-U). The first reference point for F_{MSY} is universally accepted as a limit (Garcia and Staples 2000). The second and third reference points are considered as target levels of fishing because of the uncertainty around the actual value of MSY and its variability from year to year. Although historically it had generally been accepted that levels of F could equal levels of M, repeated experiences with fishery collapses have indicated that far more conservative levels are required (Patterson 1992, Staples 1996, Richards *et al.* 1998). Patterson (1992) found that 80% of pelagic fisheries had collapsed when F=M, and proposed a more conservative F=0.6M standard. In August 2000, the Northern Territory Department of Business, Industry and Resource Development (DBIRD) held a stock assessment workshop on Spanish mackerel resources led by Dr Carl Walters from the University of British Columbia, Canada, who recommended that management strategies for Spanish mackerel use levels of F=0.5M as a target reference point to indicate a safe long-term sustainable catch. Similarly, in this assessment we used 0.5M as a potential target reference point. Furthermore, Staples (1996) highlighted that appropriate biomass reference points with acceptable risks for some pelagic fish stocks may be as high as 40-60% of virgin (*i.e.*, un-fished; B_0) population sizes (*i.e.*, B_{MSY} about 0.4-0.6 B_0). A biomass reference point of B_{MSY} equal to about 0.4 B_0 was also used in this assessment.

Management strategy evaluation

On completion of the stock assessment, the performance of different catches and reference points were tested through a series of simulations. The algorithm for the simulations was similar to the Monte Carlo forward projection methods used by Richards *et al.* (1998). Details of the uncertainties are shown in Table 6.3. The algorithm proceeded as follows:

1. The mean and covariance of $N_{1,1940}$, L_{50}, L_{95} were estimated from optimising the base case stock assessment model (*i.e.*, Model 1) to the observed age structures and catch rate.
2. Construct error distributions (see Table 6.3).
3. Draw a random parameter vector from the error distributions estimated in Step 2.
4. Use the random parameters to drive the model and obtain a sample historical trajectory for the stock.
5. Choose a catch to test (*e.g.*, 100 t or $0.75F_{MSY}$).
6. Project the operating model forward 20 years. Recruitment is simulated under a stock-recruitment relationship with lognormal error.
7. The process from Steps 3-6 is repeated 1000 times to obtain a large number of trajectories; each of which reflected the correlations among model parameters estimated.

The expected median outcomes and probabilities indicating risks of over-fishing were summarised in a management strategy evaluation (MSE) (Smith 1994). MSE involves assessing the consequences of a range of fishing strategies and presents the results in a way that lays bare the trade-offs in performance across a range of management objectives. The approach does not define a final fishing strategy or decision. It only provides information on which to base management choices, given a set of management objectives. To fully understand the structure of the MSE, the following key elements and definitions were used:

- The *fishing strategies* were the catches allowed from the fishery each year. The fishing strategies examined included constant MSY (F_{MSY}), 0.75F_{MSY}, 0.5*M*, and set catches ranging from 100 to 300 t.
- The *management strategy* was the decision not to change the catches once the fishing strategies were implemented.
- The *management objectives* considered biological sustainability and commercial/recreational sustainability.
- A number of different *performance measures* or *indicators* were used to gauge each *fishing strategy* against the *management objectives*.
    1. One quantitative measure of biological sustainability was used:
        - The risk over a 20-year period of management that the stock size will fall below the long-term equilibrium population biomass that results from fishing the stock at maximum sustainable yield (B_{MSY}).
    2. Two quantitative measures of commercial/recreational sustainability were used:
        - The median total catch expected over the 20-year period of management.
        - The median catch rate over the 20-year period of management.

Model projections were conducted over a 20 year period from 2004-2023.

Table 6.3. Details of the uncertainties allowed for in the simulations. The italic syntax represents *R* code functions. Graphical display of the error distributions and their justifications are presented in the Results section.

Parameters	Sampling and error distributions
Virgin recruitment (N_{1940})	`mvrnorm` (1000, c(N_{1940}, L_{50}, L_{95}) cov)
Selectivity ($Length_{50}$ and $Length_{95}$), r_{max} and m	The `mvrnorm` function returned a 1000-by-3 matrix of random growth parameters chosen from the multivariate normal distribution with maximum likelihood estimates [N_{1940}, L_{50}, L_{95}], and covariance cov.
Annual natural mortality (M)	`rnorm(n, mean=0.37, sd=0.05)`
	The `rnorm` function returns 1000 by 1 matrix of normal random natural mortality with mean 0.37 and standard deviation of 5%.
Stock-Recruitment (r_{max})	`log(rlnorm(n, mean=4.5, sdlog=0.05))`
	The `log(rlnorm())` function generates 1000 lognormal random variations of r_{max} and standard deviation of 5%.
Predicted recruitment errors ($\varepsilon_{S/R}$)	exp(`rnorm`(1000, 0, 0.25))
	The exponential function returned log-normal errors with a log-mean of zero and log standard deviation for the *S/R* fits for every fishing-year (yrs) recruitment; 1000 variations were produced.
Growth: Mean length at age	`mvrnorm` (1000, c(L_∞, K, t_0), cov)
	The `mvrnorm` function returned a 1000-by-3 matrix of random growth parameters chosen from the multivariate normal distribution with maximum likelihood estimates [L_∞, K, t_0], and covariance cov. This was calculated for both male and female fish.
Weight: Mean weight at age	`mvrnorm` (1000, [a, b], cov)
	The `mvrnorm` function returned a 1000-by-2 matrix of random weight parameters chosen from the multivariate normal distribution with maximum likelihood estimates [a, b], and covariance cov. This was calculated for both male and female fish.

Results

Stock assessment

Results from the stock assessment indicated a significant decline in the exploitable biomass of Torres Strait Spanish mackerel since the assumed commencement of the fishery in 1940, particularly between 1989 and 2001 when the greatest catches were observed (Fig. 6.1).

Biomass levels in 2003 were estimated to be at 26-67% of unfished or virgin biomass levels, with all models demonstrating a similar pattern of decline (Fig. 6.1).

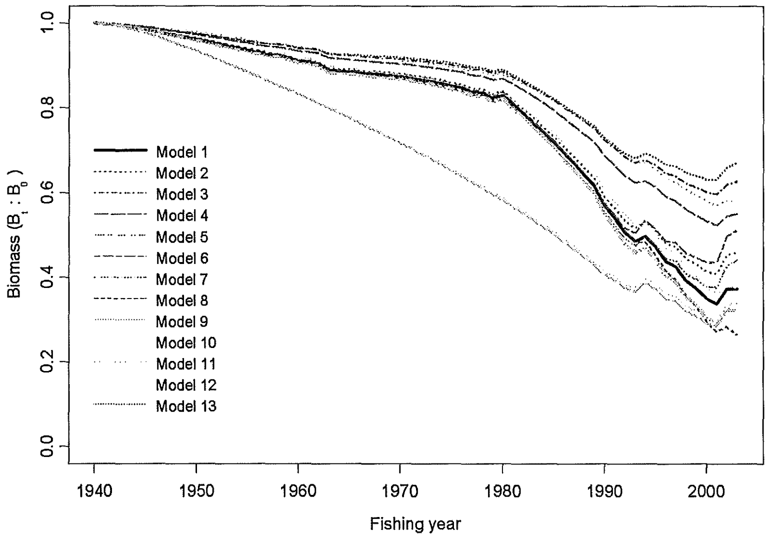

Fig. 6.1. The predicted relative exploitable biomass of Spanish mackerel for all sensitivity model runs, fishing years (1940-2003).

Similar management quantities were also estimated from the different model runs, irrespective of the parameter combinations tested (Table 6.4). Models 1, 8, 9, 11, 12 and 13, predicted the exploitable biomass in 2003 to be below that which would sustain MSY (*i.e.*, $B_{MSY} \sim 0.4B_0$), although the base model (Model 1) predicted the exploitable biomass to be about $0.37B_0$ (Fig. 6.1). Model 1, which included both the age structure and CPUE data, estimated $Y(F_{MSY})$ to be about 169 t (Table 6.4). Based on the more conservative, but recommended reference point of 0.5*M*, this quantity was lowered to 146 t, with the other model runs predicting target yields between 140 t and 221 t (Table 6.4). The estimated total catch in 2003 was 178 t (Table 4.1).

Table 6.4. The equilibrium management quantities for 13 model sensitivities.

Model sensitivity run	$Y(F_{MSY})$ (t)	$Y(0.75F_{MSY})$ (t)	Y(0.5M) (t)
1	169	165	146
2	196	191	156
3	209	201	210
4	173	167	181
5	146	143	140
6	169	165	147
7	187	180	221
8	211	206	129
9	249	243	148
10	264	255	148
11	182	178	157
12	181	176	155
13	162	158	140

Similar model fits were observed for all model runs indicating that the age-structured model was quite robust. Base Model 1, predicted the cumulative age structures reasonably well as demonstrated by the goodness of fit plots for each year (Fig. 6.2). Model 1 also predicted the declining trend in catch rates over time, although underestimated the increasing trend in the latter years (Fig. 6.3) with marginal correlation between parameters N_{1940} and $Length_{50}$ (Table 6.5).

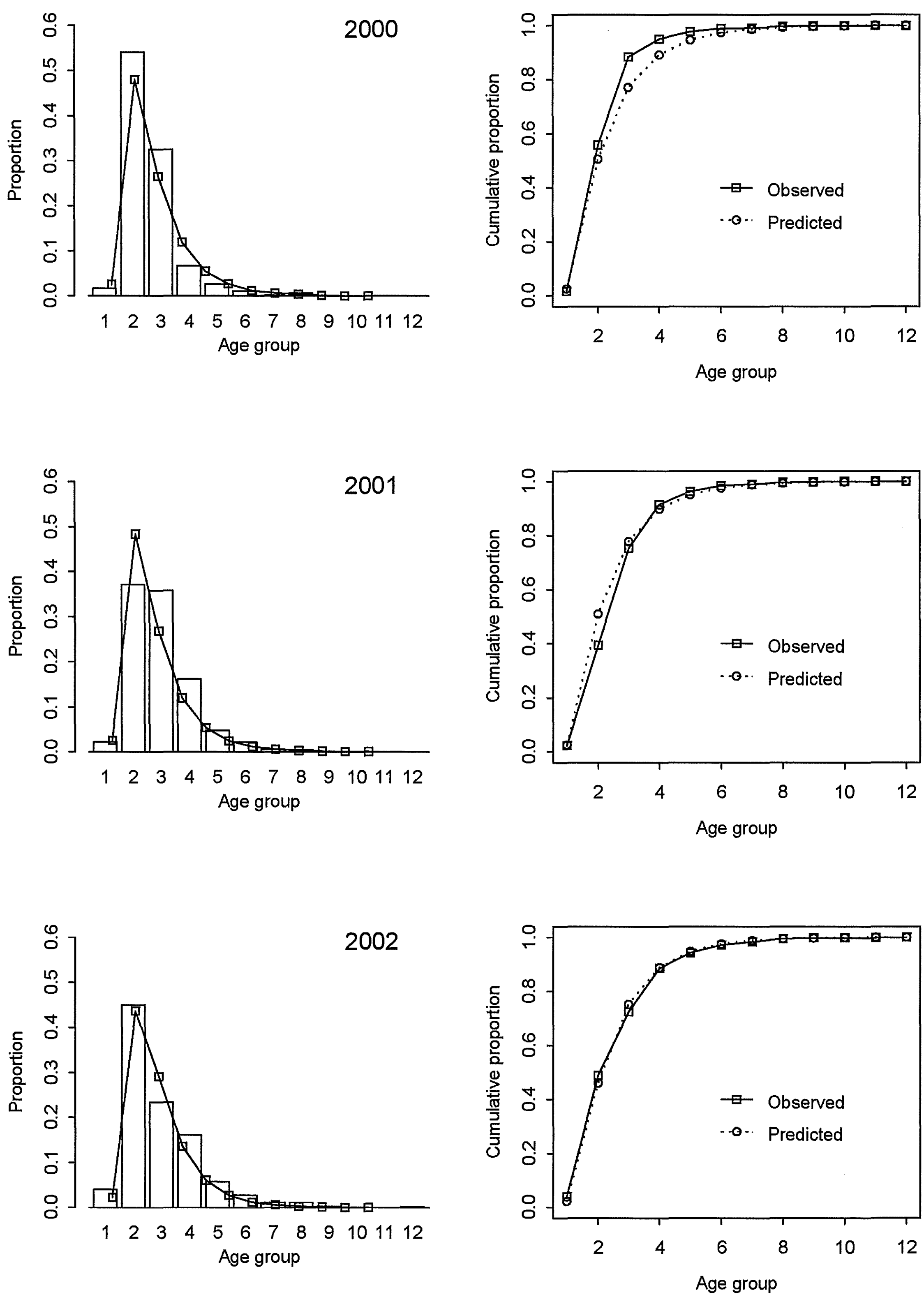

Fig. 6.2. Goodness of fit plots: observed (bars) and predicted (line) and cumulative age structures from Model 1 (age structure and CPUE data).

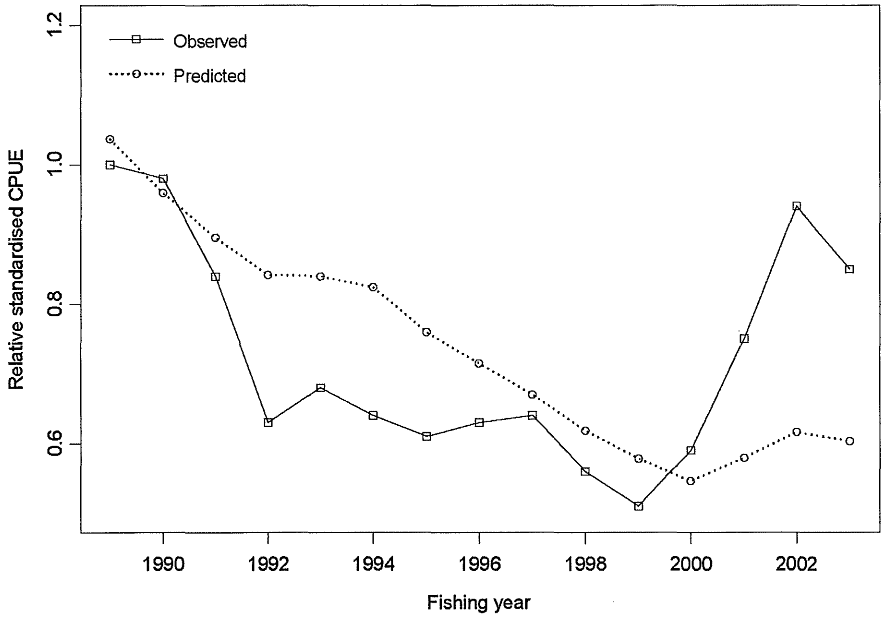

Fig. 6.3. Goodness of fit plot: observed (*i.e.*, standardised; squares) and predicted (circles) catch rates.

Table 6.5. Parameter correlations for model sensitivity runs 1-13.

Model sensitivity run	Parameter correlation		
	N_{1940} : $Length_{50}$	N_{1940} : $Length_{95}$	$Length_{50}$: $Length_{95}$
1	-0.6589	-0.3532	0.6039
2	-0.6460	-0.2876	0.5287
3	0.0005	-0.0008	0.9805
4	0.0024	-0.0020	-1.0093
5	-0.6500	-0.2840	0.4775
6	-0.7112	-0.3771	0.6285
7	0.0013	-0.0011	-1.0078
8	-0.3055	-0.1435	0.9258
9	-0.6854	-0.4431	0.7332
10	0.0007	-0.0005	-1.0150
11	-0.3017	-0.0021	0.5052
12	-0.4009	-0.0803	0.4522
13	-0.6306	-0.3044	0.5409

Management strategy evaluation

The catch projections used in the management strategy evaluation (MSE) were based on Model 1 (tuned to both the age structure and CPUE data). Increasing levels of constant catch had associated increasing levels of over-fishing risk, over both the short- (5 years) and long-term (20 years) (Table 6.6). Based on Model 1, the catch for 2003 of 178 t has about a 46% risk of the exploitable biomass being below B_{MSY}, if this was set at a constant level for the next 20 years (Table 6.6). In contrast, if fishing effort at F_{MSY} was set as a catch strategy for the next 20 years then there would be a 35% risk of the exploitable biomass being below B_{MSY}, while the recommended strategy of 0.5*M* would have only a 9% risk (Table 6.7). Stock increases and associated increased catch rates (CPUE) would also only be expected to occur for total catch strategies less than the catch levels in 2003 (Fig. 6.4, 6.5).

Table 6.6. The performance of five different constant catch tonnages (100-300 t) in relation to the short- (5 years) and long-term (20 years) exploitable biomass of Spanish mackerel. The table summarises over-fishing probabilities (risk) in relation to the biomass reference point that supports maximum sustainable yield (B_{MSY}) and expected median population sizes ($B_{MSY} \approx 0.4B_0$). The results assumed the base case steepness and natural mortality in Model 1 (tuned to both the age structure and CPUE data).

Catch (t)	5yr Probability $B_{t+5}<B_{MSY}$	20yr Probability $B_{t+20}<B_{MSY}$	5yr Biomass ratio B_{t+5}/B_0	20yr Biomass ratio B_{t+20}/B_0
100	0.40	0.25	0.47	0.74
150	0.46	0.38	0.38	0.50
200	0.52	0.53	0.29	0.17
250	0.58	0.66	0.20	0.08
300	0.63	0.77	0.14	0.05

Table 6.7. The performance of three different constant catch strategies (F_{MSY}, $0.75F_{MSY}$, $0.5M$) in relation to the short- (5 years) and long-term (20 years) exploitable biomass of spotted mackerel. The table summarises over-fishing probabilities (risk) in relation to the biomass reference point that supports maximum sustainable yield (B_{MSY}) and expected median population sizes ($B_{MSY} \approx 0.4B_0$). The results assumed the base case steepness and natural mortality in Model 1 (tuned to both the age structure and CPUE data).

Catch rate	5yr Catch (t)	20yr Catch (t)	5yr Probability $B_{t+5}<B_{MSY}$	20yr Probability $B_{t+20}<B_{MSY}$	5yr Biomass ratio B_{t+5}/B_0	20yr Biomass ratio B_{t+20}/B_0
F_{MSY}	168	187	0.50	0.35	0.32	0.39
$0.75F_{MSY}$	153	181	0.41	0.14	0.37	0.48
0.5M	125	159	0.30	0.09	0.47	0.60

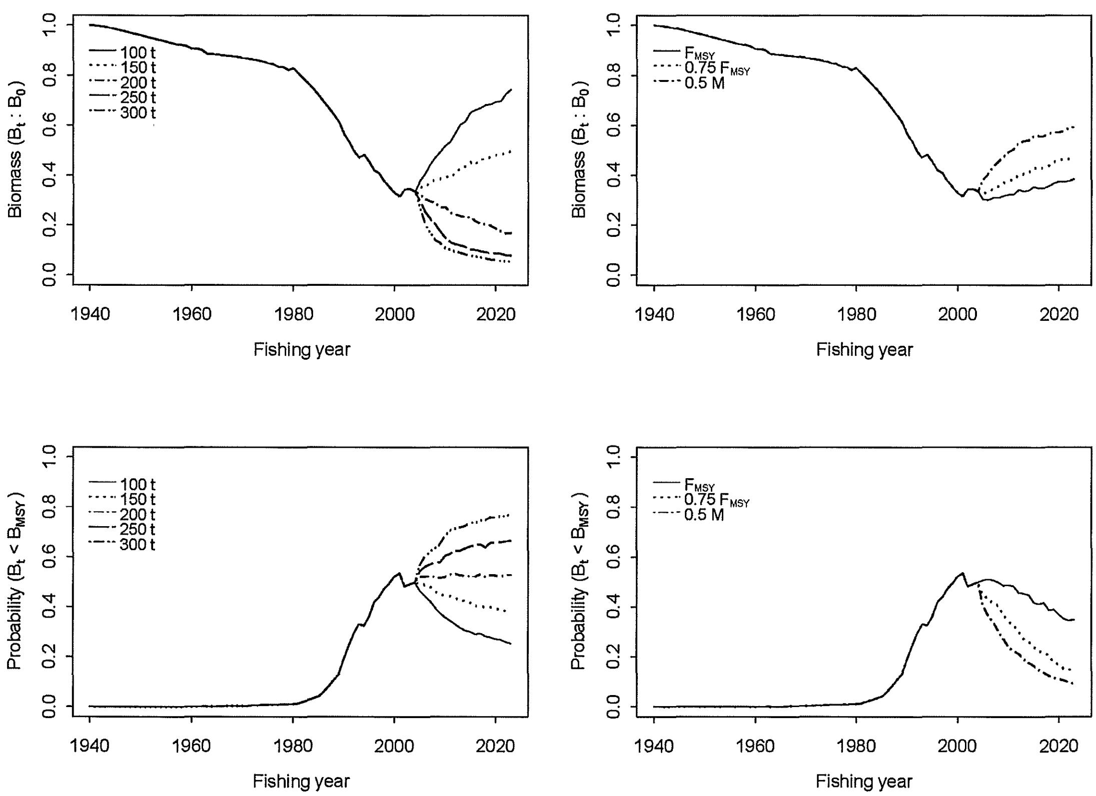

Fig. 6.4. The performance of five different constant catch tonnages (100-300 t) in relation to the short- (5 years) and long-term (20 years) exploitable biomass of Spanish mackerel. The table summarises over-fishing probabilities (risk) in relation to the biomass reference point that supports maximum sustainable yield (B_{MSY}) and expected median population sizes ($B_{MSY} \approx 0.4B_0$). The results assumed the base case steepness and natural mortality in Model 1 (tuned to both the age structure and CPUE data).

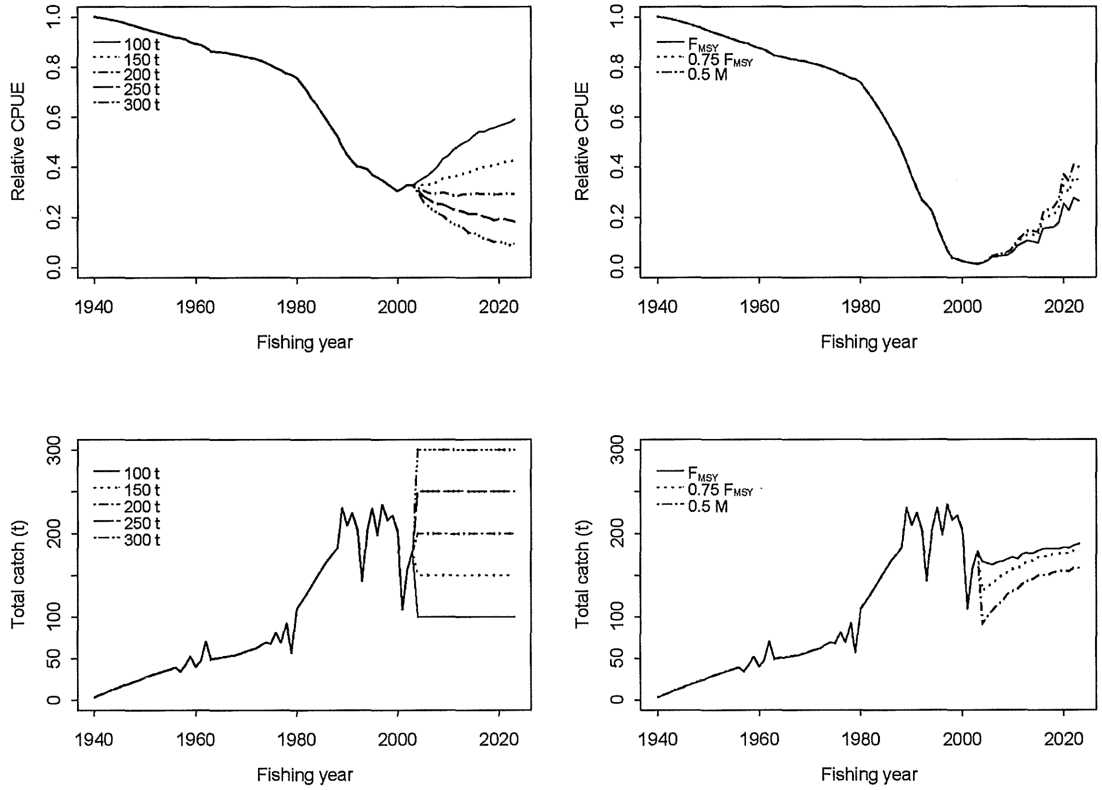

Fig. 6.5. The expected commercial outcomes from allowing constant catch tonnages (100-300 t) or catch strategies (F_{MSY}, $0.75F_{MSY}$, $0.5M$). The plot summarises the expected median proportional change in catch rates and total catch tonnages. The results assumed the base case steepness and natural mortality in Model 1 (tuned to both the age structure and CPUE data).

Discussion

The Torres Strait Spanish mackerel fishery is most likely being harvested near or exceeding maximum sustainable levels, with biomass levels at 26-67% of unfished or virgin biomass levels. The base model assessment results (*i.e.*, Model 1) indicated that the 2003 biomass of Torres Strait Spanish mackerel was near the over-fishing limit reference point of B_{MSY} (*i.e.*, 40% B_0). Biomasses between 1989 and 2001 declined considerably as a result of increasing total catches, where catches for 12 of the past 15 years were above the estimated MSY limit reference point of 169 t. Model projections indicated that management strategies may need to be implemented to ensure total catches decline slightly from those in 2003 to ensure the likelihood of the stock size increasing within acceptable levels of risk to avoid being over-fished. The results, however, need to be tempered with the significant uncertainty associated with the various data and model assumptions. Moreover, some model results suggested increasing biomass levels and corresponding catch rates in 2002 when total catches were lower than $Y(F_{MSY})$; supporting the relative robust nature of the stock when catches are at acceptable levels.

The model results across the sensitivity analyses suggested that catches in the 1990s were most likely too high to promote higher or stable biomasses in the future (*i.e.*, catches exceeded MSY). Furthermore, the model projections suggested that catches greater than 150 t have a high risk of reducing the population in relation to MSY, and that the 2003 total catch of about 178 t has a moderate risk in relation to MSY. The projection results show lower risks and higher catch rates at lower catches; although this depends on what is an acceptable level of risk and catch rate.

The nominal 2003 total catch of 178 t for the Torres Strait Spanish mackerel fishery was above the recommended target reference point of 0.5*M* for 10 of the 13 model sensitivity runs; suggesting that management of the fishery may need to consider more prudent actions in accordance with the precautionary approach to ensure the long-term sustainability of the fishery. Similar mackerel fisheries overseas have been exploited down to low levels leading to recruitment over-fishing and stock decline (FAO 1996, Hoyle 2002). Consequently, the selection of candidate reference points for setting appropriate catch strategies for the fishery should consider the impacts and management of all sectors, and not rely solely on the regulation of any one sector. Moreover, data and model uncertainty should not be used as a basis for management inaction, but instead as dictated by the precautionary approach, provide a greater prompt for management intervention (Begg *et al.* 2005).

7. Monitoring

The Torres Strait Spanish mackerel fishery is monitored by AFMA through the use of compulsory commercial fishery logbooks, Islander docket books, and previously as part of the DPI&F LTMP. The AFMA operated logbooks and docket books provide an inventory of catch and coarse levels of effort, while the DPI&F LTMP collected biological information from commercial catches of mackerel fishers operating in Bramble Cay from 2000 to 2002 (see Chapters 1 and 2). In 2004, AFMA trialled a voluntary fisher logbook designed to record length and sex of Spanish mackerel caught in the non-Islander commercial sector. In 2005, a CRC Torres Strait research project (reported here) adopted the DPI&F LTMP protocols to collect information on age, length and sex of Spanish mackerel caught in the commercial non-Islander sector from Bramble Cay in October. Problems exist with consistency in data recording, quality and continuity for most of the monitoring programs for Spanish mackerel in Torres Strait, leading to significant uncertainty in the assessment (see Chapters 3, 4 and 5). Currently, there is no routine monitoring of the Spanish mackerel fishery in Torres Strait, besides the compulsory logbooks, albeit that annual biological samples, particularly age data, are required as key input for the age-structured model used to assess the status of the fishery (see Chapter 6). We adopt a randomisation approach from Sumpton and O'Neill (2004) to determine a possible monitoring strategy for Spanish mackerel in Torres Strait, and discuss alternate sampling strategies that could be used to derive a cost-effective and optimal monitoring program to collect biological data required for future assessments of the fishery.

Sampling strategies

Randomisation analysis

A randomisation analysis was used to construct length frequency distributions of Spanish mackerel sampled from fish length data collected in 2000-2002 (DPI&F LTMP), 2004 (AFMA voluntary fisher logbooks) and 2005 (CRC Torres Strait project) following the approach of Sumpton and O'Neill (2004) (Table 7.1). The data were structured to examine a stratified sampling program by four regions (Bramble Cay, Central, Eastern and Southern Torres Strait) based on the distribution of daily commercial catches (Table 7.2). The Northern and Western Torres Strait regions were excluded from the analysis because of limited sample numbers. Only data from the commercial non-Islander sector were used in the analysis.

Table 7.1. The total number of Spanish mackerel length frequencies collected by the DPI&F LTMP (2000-2002), AFMA voluntary fisher logbooks (2004) and CRC Torres Strait research project (2005).

Year	Source	Total number of fish measured
2000	DPI&F LTMP	900
2001	DPI&F LTMP	909
2002	DPI&F LTMP	612
2004	AFMA voluntary logbooks	1789
2005	CRC Torres Strait project	719

Table 7.2. The total number of Spanish mackerel daily catches and individual fish reported in the AFMA compulsory logbooks (1989-2003). Also shown is the median number of fish landed per catch.

Region	Total number of catches	Total number of fish	Median number of fish
Bramble Cay	5784	455548	79
Central Torres Strait	3507	50498	10
Eastern Torres Strait	6023	284996	42
Northern Torres Strait	55	419	7
Southern Torres Strait	1069	27357	20
Western Torres Strait	144	2341	16

The analysis followed a series of steps to construct the actual length frequency distributions and those determined by specific monitoring sampling protocols. Results from the analysis compared the actual and simulated length frequency distributions to assess the accuracy of monitoring Spanish mackerel from the different regions in Torres Strait. We assumed that accurately monitoring the length frequency distributions would in turn provide an accurate representation of the corresponding age structures. A total of 10 to 90 daily catches of Spanish mackerel (in numbers of fish by fisher) from the AFMA compulsory logbooks were randomly sampled from each stratum and used to dictate the number of fish lengths to be randomly sampled from the year-specific length frequency data. These steps were repeated 1000 times to provide an indication of variation in the data and potential sampling strategies. For further details see Sumpton and O'Neill (2004).

Reduced error (*i.e.*, least squares) and greater monitoring accuracy were found in estimating the length frequencies of Spanish mackerel when more catches were sampled (Fig. 7.1). About 30 to 40 catches from each region and year were needed to be sampled for the simulated data to approximate the actual observed length distributions. Therefore, about 2400 or more Spanish mackerel would need to be sampled each year from Bramble Cay to provide sufficient data to represent the underlying length and age structures of the exploitable component of the population; representing a two- to four-fold increase in sampling intensity depending on the strategy applied.

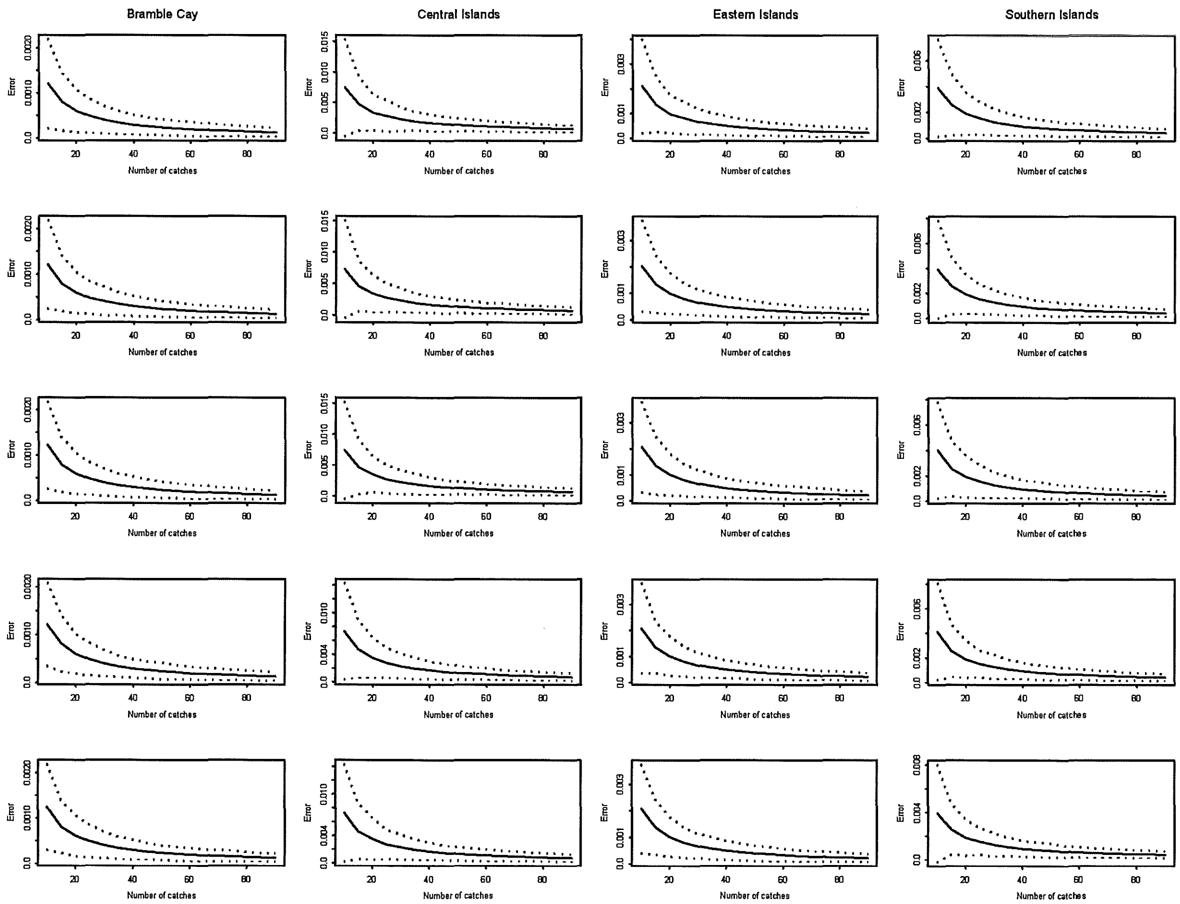

Fig. 7.1. Estimated error (*i.e.*, average least squares) from monitoring numbers of different catches within each region (2000-2002, 2004, 2005). Dotted lines represent 95% confidence intervals. Different years in sequential order for each region.

Voluntary fisher logbooks

In 2004, AFMA trialled a voluntary fisher logbook designed to record length and sex of Spanish mackerel caught in the non-Islander commercial sector. Two commercial non-Islander operators trialled the logbooks from September to November, recording information on Spanish mackerel landed for each morning and afternoon fishing session of each day. Depending on numbers, either the entire catch for each session was measured or only part of the catch when significant numbers were landed. Logbook entry was designed to fit in with the daily fishing operations, hence the separation into morning and afternoon sessions. Overall, the voluntary logbook proved to be an efficient and cost-effective method of obtaining sex-specific length frequency data that could be used to evaluate resource status. Although only two fishers trialled the logbooks, they could be expanded to the entire fleet and fishing season which would ensure the required numbers of catches and fish are sampled as indicated from the randomisation analysis (Fig. 7.1). A similar logbook has been trialled in the Islander sector on Murray Island where the number of selected demersal reef fish species sold through the Council freezer are recorded (Williams, unpublished data). This system could also be expanded to include the other main fishing islands in the eastern and central Torres Strait, as well as recording information on length and sex of species landed, including Spanish mackerel. The main trade-offs with this data acquisition method is that no otoliths or other biological material are collected, and concerns with representative sampling of the catches, particularly when sub-sampling of large catches is required.

Voluntary fisher collections

An alternate, but potentially complimentary sampling strategy is through the use of voluntary fisher collections where head and gonad samples from individual Spanish mackerel landed are frozen onboard. These samples can then be processed for age, sex, maturity and fecundity data at a later time in an appropriate laboratory. Head and jaw measurements can also be converted to fish lengths based on the following equations of Mackie *et al.* (2003) derived for Spanish mackerel sampled from the Kimberley region in Western Australia:

$$FL = -205.3115 + 7.5891HL - 0.008HL^2 \quad (7.1)$$

$$FL = -204.8015 + 13.115JL - 0.0249JL^2 \quad (7.2)$$

where, FL = fork length (mm); HL = head length (mm); and JL = jaw length (mm). The HL relationship was derived from Spanish mackerel 476 mm to 1480 mm FL and 1.1 kg to 25.0 kg. The JL relationship was derived from Spanish mackerel 550 mm to 1480 mm FL and 1.1 kg to 25.0 kg. Mackie *et al.* (2003) suggest that the head length relationship is preferable to that for jaw length as statistically it performed slightly better and is easier to measure and less influenced by individual shape and protrusion of the jaw. Although data generated by such means is less accurate than that obtained from whole, fresh samples, it presents a viable alternative for sampling Spanish mackerel (Mackie *et al.* 2005). A pilot study, however, should be conducted on Torres Strait Spanish mackerel to determine region-specific head – fish length relationships if voluntary fisher collections are deemed a suitable monitoring strategy.

A similar strategy has been suggested for monitoring the Western Australian Spanish mackerel fishery because of limited funding and large distances over which the fishery operates restricting future research trips (Mackie *et al.* 2005); an analogous situation to monitoring the Torres Strait fishery. Although a voluntary fisher collection program is a potentially cost-effective and useful monitoring strategy in the Torres Strait, there was reluctance from fishers to implement the approach because of concerns with limited freezer space, particularly at the start of a fishing trip. Such logistical issues, however, may be overcome by collecting samples at the end of a trip when freezer requirements are clearer and commensurate payment of sample collections to cover any potential loss in sales through storage issues. As for the voluntary logbooks, representative sampling of catches is also an issue.

Observers

In 2005, a CRC Torres Strait research project (T1.14) adopted the DPI&F LTMP protocols to collect information on age, length and sex of Spanish mackerel caught in the commercial non-Islander sector from Bramble Cay in October and November (25 October – 3 November). An observer onboard a primary vessel monitored the catches of as many commercial vessels as possible for 10 fishing days. All Spanish mackerel obtained on the primary vessel were measured, weighed, sexed, gonads staged for maturity and otoliths removed. For further details on DPI&F LTMP sampling protocols see DPI&F (2005). The length and age distributions observed from the landed catches of Spanish mackerel in 2005 were similar to those from previous years (Fig. 7.2 and see Figures 2.7 and 2.8).

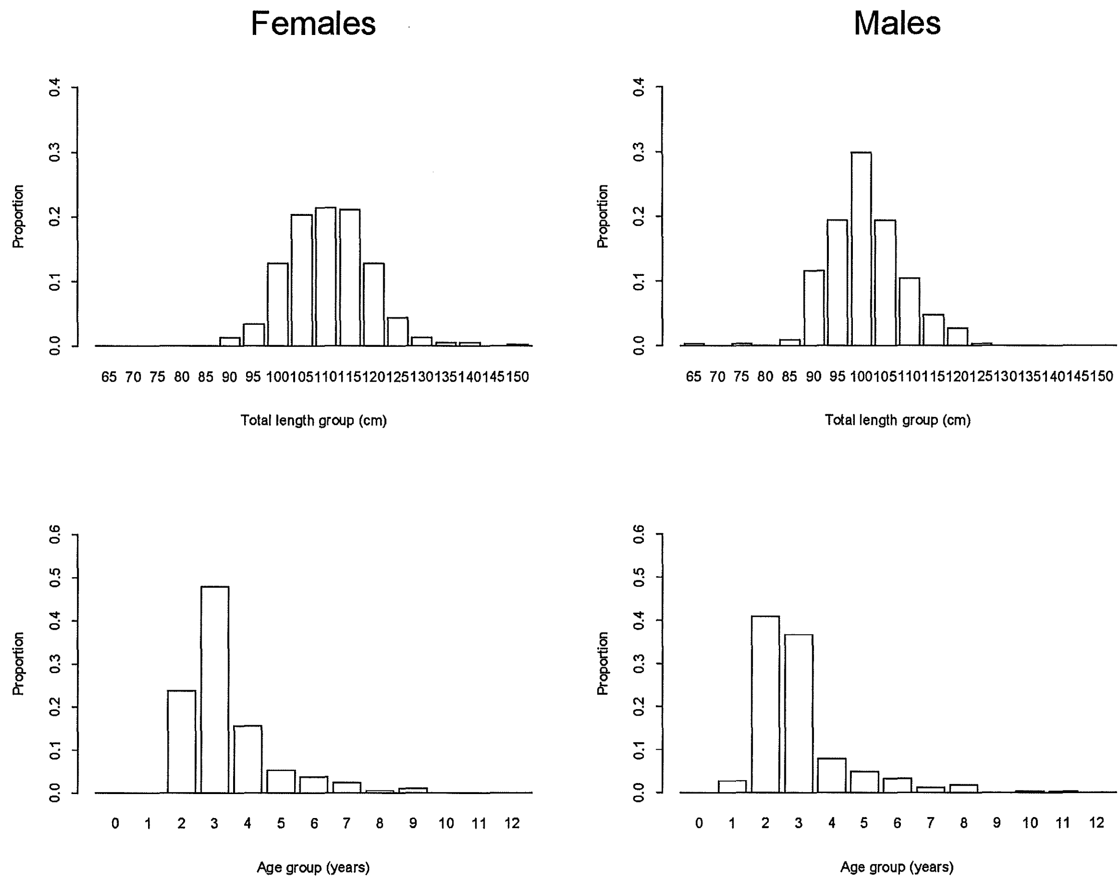

Fig. 7.2. Sex-specific length (n=719) and age (n=710) frequency distributions of Spanish mackerel collected in 2005 from Bramble Cay as part of CRC Torres Strait research project following the protocols of DPI&F LTMP.

Although observer programs are relatively expensive compared to other monitoring methods they may provide the most suitable and representative data required for assessing the status of the fishery. Besides collecting necessary otolith and gonad samples required for constructing sex-specific age structures, observers can validate the sampling methods and data entries conducted in voluntary fisher logbooks and collections to ensure data consistency and representative sampling of catches. Observers can also opportunistically sample catches from a range of fishers, collect more detailed catch and effort statistics, document by-catch and discard practices and importantly liaise with fishers on a range of issues. The trade-off with observers is the potential loss of temporal and spatial coverage and the expense of operating in remote places such as Bramble Cay and the eastern Torres Strait, particularly if the target numbers of 2400 fish are to be achieved.

Discussion

Future assessments of the Torres Strait Spanish mackerel fishery will only be enhanced by the continuation of a dedicated monitoring program to collect reliable catch, effort and biological data at appropriate spatial and temporal scales. Notably, the cost-effectiveness and success of any monitoring program in the Torres Strait will depend on the good-will and acceptance of industry and Islanders alike, particularly considering the relatively low value of the fishery, the number of operators, and the remoteness of the region which leads to costly monitoring programs. Because of these considerations and other logistical issues a combination of approaches should be adopted for monitoring the Spanish mackerel fishery in Torres Strait.

A combination of voluntary fisher and Islander logbooks, as well as periodic observer trips would most likely provide an adequate sampling strategy to ensure that the minimum biological and catch data required for future assessments are collected. Although the randomisation analysis indicated that 30 to 40 catches from each region may need to be sampled to provide meaningful information on the status of the fishery, the current lack of biological data for Torres Strait Spanish mackerel limited the analyses that could be undertaken to more fully design an optimal monitoring strategy such as the one for east coast Spanish mackerel which used random effects modelling, power analysis and randomisation analysis (see Sumpton and O'Neill 2004). The comprehensive analytical approach to the design of a monitoring program for the east coast fishery suggested that sampling needed to be structured according to the different regions and sectors operating in the fishery, and that a minimum of 60 catches and 250 fish per sector and region were required to detect a 5 cm difference in fish length with 95% confidence (Sumpton and O'Neill 2004). Following the outcomes of their analyses, it may be prudent to structure a potential monitoring program in the Torres Strait around the major regions and sectors of the fishery. Hence, it is desirable to monitor Bramble Cay and the eastern Torres Strait in particular, as well as the non-Islander and Islander commercial sectors to ensure the samples collected are representative of the total catch. Furthermore, it is imperative to sample a small number of fish from a large number of catches rather than sampling large numbers of fish from only a few catches (Sumpton and O'Neill 2004). Sampling only one sector, region or catch may result in biases in the data collected that are not representative of the total catch and underlying exploitable population, upon which the assessment and subsequent management advice is based.

This assessment for the Torres Strait Spanish mackerel fishery (Chapter 6) uses an age-based population model that requires inputs on commercial and Islander total catches, as well as, representative catch age structures. The uncertainty associated with this assessment and subsequent reference points and management advice derived from the related analysis and models is a function of the quality and extent of the input data (Begg *et al.* 2005). Research and monitoring programs, therefore, should be directed towards providing the necessary data required for model parameters and reference point estimation. These programs should attempt to provide more detailed and reliable information through a dedicated data collection framework, so that greater certainty in model predictions and subsequent management advice can be achieved (Cadrin *et al.* 2004). Various forms of monitoring and opportunistic research provided the necessary data used in this age-structured assessment of Torres Strait Spanish mackerel, but principally from the DPI&F LTMP. The continuation of a dedicated and routine long term monitoring program is essential if further data- or model-based assessments are to be conducted for this fishery. Information collected from such a program is critical for evaluating trends in the underlying population upon which the harvests are based and required for future assessment models to evaluate the status of the fishery. Collecting biological information on the sampled catch on an annual basis provides information about the dynamics of the exploited population on the major fishing grounds over time, and helps detect changes in the biology of the species not discernible from data recorded in commercial logbooks (DPI&F 2005). This approach ensures that comparable information is gathered each year in a consistent manner and changes in the underlying population and fishery upon which it depends can be readily detected.

8. Discussion

This stock assessment is the most comprehensive attempt to evaluate the status of the Torres Strait Spanish mackerel fishery. The assessment used all available biological and fisheries data to provide an indication of the current level of exploitation and sustainability of the fishery. At a time when the status of the Torres Strait Spanish mackerel fishery is uncertain and undergoing extensive revision of its current management arrangements, results from this project provide stakeholders with an understanding of the status of the fishery to enable future management decisions to be derived from a more informed basis. The project encapsulates our current understanding of the biology and fishery characteristics of Spanish mackerel in Torres Strait, thereby, facilitating a comprehensive interpretation, analysis and assessment of the fishery.

The assessment facilitated critical evaluation of the important levels of risks associated with, and yields that can be taken from the fishery, and highlighted the areas of research and data collections that are limited, uncertain and require future work for improving our understanding of the status of the fishery. The assessment used known and derived fundamental biological relationships on growth, maturity, natural mortality, stock-recruitment and reproductive output of Spanish mackerel (see Chapter 2), which in many cases were highly uncertain, being proxies derived from data for other mackerel species and/or other regions. Indeed, the only biological data available for Torres Strait Spanish mackerel to parameterise the model were collected from the DPI&F LTMP between 2000 and 2002, and more recently the dedicated CRC Torres Strait research project in 2005. A comprehensive investigation into the population dynamics of Torres Strait Spanish mackerel, however, is needed to validate and broaden the biological patterns derived from the LTMP data collections which were based on an annual two week sampling event during the main spawning period in October from Bramble Cay. Moreover, a dedicated and routine monitoring program is required to develop a time-series of biological data needed to improve this assessment, particularly the ongoing collection of age data for input to the age-structured population model (see Chapters 6 and 7).

The estimated total catches, responsible for the apparent population trends and status of the fishery, were also uncertain. The total catches were comprised of landings from the non-Islander and Islander sectors and based on major assumptions about the historical trends in catches and fishing practices (see Chapters 3 and 4). The assessment included estimated historical catches prior to the compulsory logbook system implemented in 1989, as well as the uncertain and poorly estimated Islander catches; albeit that these catches were significantly lower than those of the commercial non-Islander sector. Although greater certainty is given towards the accuracy of recent catches with the implementation of the compulsory logbooks, inconsistencies in data quality and recording may compromise their accuracy and credibility. One concern relates to the recording of fish weights in the logbooks and their subsequent use in this assessment. Traditionally, Spanish mackerel have been filleted in the fishery and reported in numbers of fish and resultant cartons of frozen product. Average daily carton weight has also been reported throughout the logbook's inception, although it's reporting tends to be highly variable among operators. Data on individual fish weights or aggregated catches upon which this assessment is based, therefore, is limited. Consequently, to support revisions to current management arrangements that may involve the setting of total allowable catches, we recommend that catch estimates obtained from compulsory logbook and docket book data be validated against commercial unloading data to assess the reliability of total catches from the fishery, particularly for the major operators that have persisted throughout the recent history of the fishery.

The assessment was also based on a time series of only three years of ageing data and 15 years of standardised catch rate data (see Chapters 2 and 4). For robust assessments to be conducted in the future, it is critical that a routine and structured monitoring program be developed to collect the age and supplementary biological data needed to further assess the status of the fishery. There is also a need for better measures of fishing effort in the logbooks to provide a more reliable indicator of catch rates, and in turn, stock abundance. Fishers should be encouraged to record search and fishing times, and days when zero catches occur to minimise the effect of hyperstable catch rates (Begg *et al.* 2005). More accurate and representative data of fishing effort will reduce the uncertainty and hyperstability issues associated with the catch rate time series. Furthermore, to address EPBC sustainability requirements fishers should also identify and record number of by-catch species caught, including under-size Spanish mackerel (Lilly 2000b); albeit those levels in this fishery are relatively low.

Historically, the Torres Strait Spanish mackerel fishery was assumed to be part of a larger migratory stock where concerns existed over the impacts of adjacent and/or illegal fishing, both within and outside the TSPZ, on the stock as a whole (O'Brien 1995). These concerns still persist today, particularly with respect to potential Taiwanese and Indonesian gillnet operations whose impacts and level of catches are unknown. Similarly, the impacts of catches of Spanish mackerel from Papua New Guinea and outside the Protected Zone are poorly known. Although in this assessment we assumed a single stock of Spanish mackerel in Torres Strait based on more recent parasitological, otolith chemistry and mtDNA studies (Lester *et al.* 2001, Moore *et al.* 2003, Ovenden 2004, Buckworth *et al.* 2005), there still remains considerable uncertainty regarding the actual stock boundaries and relatedness of fish in the Torres Strait to those in the Gulf of Carpentaria and off the Queensland north east coast (Sumpton and O'Neill 2004). The stock structure of Spanish mackerel in Torres Strait, therefore, is uncertain and it is unknown what impacts catches from outside the Protected Zone may have on the long-term sustainability of the fishery.

A major facet of this assessment is that it has highlighted the various sources of uncertainty that exist in the data and model assumptions which may confound our interpretation of the status of the fishery. However, this should not be used as a basis for management inaction, and indeed the precautionary approach dictates that management should be more prudent given greater uncertainty (FAO 1995a, b). Results from this assessment indicated that the Torres Strait Spanish mackerel fishery is most likely being harvested near or exceeding maximum sustainable levels, with biomass levels at 26-67% of unfished or virgin biomass levels. Model projections also indicated that management strategies may need to be implemented to ensure total catches decline from those levels in 2003 to ensure the likelihood of the stock size increasing within acceptable levels of risk to avoid being over-fished. Notably, the potential meta-population stock structure of Spanish mackerel, highly aggregated schooling and voracious feeding behaviour, and predictable seasonal occurrence allows ease of targeting and makes the stock susceptible to over-fishing, localised depletion and stock collapse (Tobin and Mapleston 2004).

The analyses and modeling conducted in this assessment facilitated critical review of the Torres Strait Spanish mackerel fishery; thereby, making more effective use of the available catch data and past biological research on the species. The management strategy evaluation and model projections quantified the trade-offs between particular management strategies in relation to a series of reference points that will assist in setting target management objectives for the fishery. Outcomes from the assessment do not define a final reference point, management strategy or the future status of the fishery, but rather provide expected outcomes that may be used by decision makers to help select appropriate fishing strategies to achieve target objectives (Begg *et al.* 2005). This project has demonstrated the importance of dedicated data collections and structured monitoring programs if this assessment is to be improved for future evaluation of the status of the fishery and ramifications of alternate management strategies.

9. Research and monitoring recommendations

In summary, we provide the following recommendations for future research and monitoring of the Torres Strait Spanish mackerel fishery to improve and develop this stock assessment:

- Need to develop a long term monitoring program that provides a comprehensive and structured approach to the collection of appropriate age-structured data for Spanish mackerel from both the commercial and traditional non-Islander and Islander sectors. [***Urgent & Critical***]

- Need for improved reporting in the compulsory commercial logbooks and Islander docket books. Reporting of catch in both numbers and weight for both individual fish and cartons needs to be more consistent and comprehensive. Fishers need to be encouraged to fill out logbooks in their entirety. Logbook data should be compared to unload/buyer dockets for validation and data checking. [***Urgent & Critical***]

- Need for a better measure of effort in the commercial logbooks and Islander docket books to provide a more reliable indicator of CPUE, and in turn, stock abundance. Fishers should be encouraged to record search and fishing times, number of fishers, and days when zero catches occurred to minimise the effect of hyperstable catch rates when these data are used in catch rate analyses and assessment models. [***Urgent & Critical***]

- Need to assess the historical commercial logbooks to reconcile differences between the AFMA and DPI&F databases. [***Important & Critical***]

- Need for a comprehensive investigation into the population dynamics of Torres Strait Spanish mackerel, including growth, maturity, fecundity and spawning. Samples need to be collected throughout the year from a range of areas to validate biological patterns derived from LTMP data collections which are based on a limited sampling period in October from Bramble Cay. [***Important***]

- Need to confirm the single stock assumption for Torres Strait Spanish mackerel. This assumption is currently based on a single collection from Bramble Cay. A more comprehensive sampling program is required to validate the single stock assumption and clarify stock boundaries, particularly those in the Gulf of Carpentaria, the east coast of Queensland and the Gulf of Papua. This sampling program could be integrated with that for a broader population dynamics study. [***Important***]

- Need to assess the historical and current impact of neighbouring fisheries, particularly the Indonesian, Taiwanese and PNG gillnet and longline fisheries, on the Torres Strait Spanish mackerel fishery. [***Important***]

- Need for a periodic review and update of the assessment as determined by the requirements of AFMA. Operational management objectives, performance measures and decision rules need to be defined for future management strategy evaluation. [***Critical***]

- Need for a systematic and transparent stock assessment review process. This process should include the formation of a steering committee involving the representation of all relevant stakeholders, an independent peer-review of the assessment, and all related reports and presentations to have a clear and concise statement of the review process that the assessment has undergone. The formation of a Resource Assessment Group could direct this process. [***Critical***]

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Appendix 1: Age length distribution keys

Table 1. Sex-specific age length distributions (actual number aged) for data collected in DPI&F LTMP (2000-2002). Data pooled across years and months (October-November).

TL	Females												Males											
(cm)	0	1	2	3	4	5	6	7	8	9	10	Total	0	1	2	3	4	5	6	7	8	9	10	Total
70												0		1										1
71												0												0
72												0												0
73												0												0
74												0												0
75												0												0
76												0												0
77												0		1										1
78												0												0
79												0												0
80												0		1										1
81												0												0
82		2										2		1										1
83		1										1												0
84												0		3										3
85												0		1	1									2
86												0		2	1									3
87												0		1	4									5
88				1								1		3	5									8
89		1										1		1	7									8
90			3									3		2	16									18
91		1	2									3		3	18	1								22
92		1	5									6		2	26									28
93			15									15		5	31	3								39
94		1	17	1								19		3	44	2								49
95		2	14	1								17		3	52	4								59
96		2	27	2								31		1	46	8								55
97												0												0
98		2	30		2							34			52	17								69
99			35									35		1	42	12	2	1						58
100			41	7								48		1	43	17	6	2						69
101			31	5	2							38			37	25	3							65
102			45	8								53			35	29	11							75
103			51	9	1							61		1	23	34	4							62
104			48	24	2							74		4	20	33	6							63
105			46	18	2							66			17	18	11		1	1				48
106			31	16	4							51		1	10	19	4	1						35
107			19	24	2							45			8	21	14	3						46
108		1	16	32	6	1						56		1	4	17	11	1	1	1				36
109			15	40	7							62			5	17	11	4						37
110			6	48	6							60			1	3	11	3	1					19
111		1	6	32	7							46			3	5	7	5			1			21
112			7	32	11							50	1			11	5	4	1					22
113			6	31	11	2						50				2	3	3	2					10
114												0												0
115			2	21	18							41				3	2	3		1				9
116			3	21	15	2	2					43				1		1	1					3
117			1	16	8	5	1					31				1	3	1	1		1			7
118			1	13	12	1						27			1	1		2		1				5
119				9	13	2	3					27				1	1	2		1				5
120			1	7	12	3			1			24				1	1	4		1				7
121				7	8	3		1				19						3	1		1	1		6
122			1	3	8	5	2					19						1	2					3
123				2	3	3	3					11					2			1	1			4
124			1	1	2	3	2	1				10									1			1
125				5	3	3	3		2			16												0
126					3	1	1					5									1		1	2
127				1	3	3	5		1			13												0
128					2	1	3					6										1		1
129						2						2											1	1
130					2	3	5		1			11												0
131					1	4		1				6					1					1		2
132												0												0
133					3	1				1		5						1	1					2
134				1		1	1		1			4												0
135				1				1				2												0
136					1	1	1	1				4												0
137						2	1	1			1	5												0
138						1						1												0
139									1			1												0
140								1				1												0
141												0												0
142						1						1												0
143												0												0
144						1	1		1			3												0
145												0												0
146												0												0
147												0												0
148												0												0
149												0												0
150												0												0
151						1			1	1		3												0
152												0												0
153												0												0
154									1			1												0
155												0												0
156												0												0
157												0												0
158												0												0
159												0												0
160												0												0
161												0												0
162												0												0
163												0												0
164									1			1												0
Total	0	15	526	439	180	56	34	7	11	2	1	1271	1	43	552	306	119	45	12	7	6	3	2	1096

Table 2. Sex-specific age length distributions (proportions) for data collected in DPI&F LTMP (2000-2002). Data pooled across years and months (October-November).

TL	Females												Males											
(cm)	0	1	2	3	4	5	6	7	8	9	10	Total	0	1	2	3	4	5	6	7	8	9	10	Tot
70														1.00										1.
71																								
72																								
73																								
74																								
75																								
76																								
77														1.00										1.
78																								
79																								
80														1.00										1.
81																								
82		1.00										1.00		1.00										1.
83		1.00										1.00												
84														1.00										1.
85														0.50	0.50									1.
86														0.67	0.33									1.
87														0.20	0.80									1.
88				1.00								1.00		0.38	0.63									1.
89		1.00										1.00		0.13	0.88									1.
90			1.00									1.00		0.11	0.89									1.
91		0.33	0.67									1.00		0.14	0.82	0.05								1.
92		0.17	0.83									1.00		0.07	0.93									1.
93			1.00									1.00		0.13	0.79	0.08								1.
94		0.05	0.89	0.05								1.00		0.06	0.90	0.04								1.
95		0.12	0.82	0.06								1.00		0.05	0.88	0.07								1.
96		0.06	0.87	0.06								1.00		0.02	0.84	0.15								1.
97																								
98		0.06	0.88		0.06							1.00			0.75	0.25								1.
99			1.00									1.00		0.02	0.72	0.21	0.03	0.02						1.
100			0.85	0.15								1.00		0.01	0.62	0.25	0.09	0.03						1.
101			0.82	0.13	0.05							1.00			0.57	0.38	0.05							1.
102			0.85	0.15								1.00			0.47	0.39	0.15							1.
103			0.84	0.15	0.02							1.00		0.02	0.37	0.55	0.06							1.
104			0.65	0.32	0.03							1.00		0.06	0.32	0.52	0.10							1.
105			0.70	0.27	0.03							1.00			0.35	0.38	0.23		0.02	0.02				1.
106			0.61	0.31	0.08							1.00		0.03	0.29	0.54	0.11	0.03						1.
107			0.42	0.53	0.04							1.00			0.17	0.46	0.30	0.07						1.
108		0.02	0.29	0.57	0.11	0.02						1.00		0.03	0.11	0.47	0.31	0.03	0.03	0.03				1.
109			0.24	0.65	0.11							1.00			0.14	0.46	0.30	0.11						1.
110			0.10	0.80	0.10							1.00			0.05	0.16	0.58	0.16	0.05					1.
111		0.02	0.13	0.70	0.15							1.00			0.14	0.24	0.33	0.24			0.05			1.
112			0.14	0.64	0.22							1.00	0.05			0.50	0.23	0.18	0.05					1.
113			0.12	0.62	0.22	0.04						1.00				0.20	0.30	0.30	0.20					1.
114																								
115			0.05	0.51	0.44							1.00				0.33	0.22	0.33		0.11				1.
116			0.07	0.49	0.35	0.05	0.05					1.00				0.33		0.33	0.33					1.
117			0.03	0.52	0.26	0.16	0.03					1.00				0.14	0.43	0.14	0.14		0.14			1.
118			0.04	0.48	0.44	0.04						1.00			0.20	0.20		0.40		0.20				1.
119				0.33	0.48	0.07	0.11					1.00				0.20	0.20	0.40		0.20				1.
120			0.04	0.29	0.50	0.13			0.04			1.00				0.14	0.14	0.57		0.14				1.
121				0.37	0.42	0.16		0.05				1.00						0.50	0.17		0.17	0.17		1.
122			0.05	0.16	0.42	0.26	0.11					1.00						0.33	0.67					1.
123				0.18	0.27	0.27	0.27					1.00					0.50			0.25	0.25			1.
124			0.10	0.10	0.20	0.30	0.20	0.10				1.00									1.00			1.
125				0.31	0.19	0.19	0.19		0.13			1.00												
126				0.00	0.60	0.20	0.20					1.00									0.50		0.50	1.
127				0.08	0.23	0.23	0.38		0.08			1.00												
128					0.33	0.17	0.50					1.00										1.00		1.
129						1.00						1.00											1.00	1.
130					0.18	0.27	0.45		0.09			1.00												
131					0.17	0.67		0.17				1.00					0.50					0.50		1.
132																								
133					0.60	0.20				0.20		1.00						0.50	0.50					1.
134				0.25		0.25	0.25		0.25			1.00												
135				0.50				0.50				1.00												
136					0.25	0.25	0.25	0.25				1.00												
137						0.40	0.20	0.20			0.20	1.00												
138						1.00						1.00												
139									1.00			1.00												
140								1.00				1.00												
141																								
142						1.00						1.00												
143																								
144						0.33	0.33		0.33			1.00												
145																								
146																								
147																								
148																								
149																								
150																								
151						0.33			0.33	0.33		1.00												
152																								
153																								
154									1.00			1.00												
155																								
156																								
157																								
158																								
159																								
160																								
161																								
162																								
163																								
164									1.00			1.00												
Total	0.000	0.012	0.414	0.345	0.142	0.044	0.027	0.006	0.009	0.002	0.001	1.000	0.001	0.039	0.504	0.279	0.109	0.041	0.011	0.006	0.005	0.003	0.002	1.00

Appendix 2: Intellectual property

No patentable or marketable products or processes have arisen from this research. All results will be published in scientific and non-technical literature. The raw data from compulsory fishing logbooks remains the intellectual property of the Australian Fisheries Management Authority. Islander catch data remains the intellectual property of the respective Island Council. Raw catch data provided by individual fishers to project staff remains the intellectual property of the fishers. Intellectual property accruing from the analysis and interpretation of raw data vests jointly with the Cooperative Research Centre for the Great Barrier Reef World Heritage Area and the Principal Investigator.

Appendix 3: Staff

Principal Investigator:	Gavin Begg
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