MINISTRY OF FISHERIES

Te Tautiaki i nga tini a Tangaroa

Pilchard (*Sardinops neopilchardus*) biology and fisheries in New Zealand, and a review of pilchard (*Sardinops, Sardina*) biology, fisheries, and research in the main world fisheries

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EXECUTIVE SUMMARY

The New Zealand pilchard fishery has recently undergone rapid development. This report summarises biological knowledge of the species in New Zealand, describes the commercial fishery, and reviews the overseas literature on pilchard fisheries which may be relevant to New Zealand.

The pilchard may be a single species, *Sardinops sagax*, with geographically separate "forms", it may be five species (the Australasian being *S. neopilchardus*), or it may be three (Japan, west coast of the Americas, South Africa and Australasia). However, the main features of pilchard biology are likely to be similar in each region.

New Zealand pilchard have been taken for food (usually smoked) since the late 1800s. A larger fishery developed in the 1930s and 1940s in the Marlborough Sounds. Around 1970 there was experimental fishing of pilchard for use as live-bait in tuna fishing, but these ventures did not proceed. The most recent fishery developed in 1991, centred on the outer Hauraki Gulf and southeast Northland, landings rising to over 800 t in fishing year 1998–99. From 1996 onwards, catches have come almost entirely from one fisher in east Northland. Lampara netting and purse-seining were both used, with the latter becoming the predominant method. There is little information on the Maori use of pilchards (mohimohi) as a resource. Recreational fishers sometimes take pilchard, more often as bait, and have an interest in their value as gamefish prey.

There is limited biological information on New Zealand pilchards. They spawn in spring and summer over the shelf, are short-lived (to about 7 years), and commercial catches contain about five year-classes. They are susceptible to viral disease: mass mortalities occurred in New Zealand in 1995, and Australia in 1995 and late 1998; imported frozen pilchards may have introduced a pathogen new to both countries.

Studies on pilchard stocks and fisheries elsewhere reveal considerable fluctuations in biomass size, both short-term (individual year-class strengths) and long-term (decadal-scale regime shifts). Several hypotheses have been advanced to explain these; most involve changes in climatic and oceanographic conditions. Population declines may also result from overfishing a naturally shrinking stock. Pilchards occupy a key trophic position in their ecosystem: they have few direct competitors, feed on both micro-zooplankton and phytoplankton, and are a favoured prey of larger fish, seabirds, and marine mammals. When diatoms bloom in nutrient-rich upwellings, pilchards can make direct use of this energy and rapidly increase in numbers.

No reliable biomass or yield estimates are available for pilchards in New Zealand. The quoted values, 6000 t and 9000 t, are early guesstimates, extrapolated from limited observations. If New Zealand pilchard stocks undergo fluctuations similar to those elsewhere, yields are likely to be variable and require a CAY rather than an MCY management strategy, unless the latter is extremely conservative.

Research requirements include an age and growth study, year-class strength (particularly recruit) monitoring, a feeding study, and definition of the reproductive cycle. To estimate biomass, the choice is between aerial surveys, egg and larval surveys, and acoustic surveys. These are more difficult and costly, and will require some initial experimental work.

1. INTRODUCTION

There has been renewed interest in the New Zealand pilchard, *Sardinops neopilchardus* (or mohimohi of Maori) (Figure 1), in recent years. Annual landings were less than 100 t, and usually less than 25 t, from the mid 1940s until the early 1990s. From the fishing year 1991–92, a northern (Hauraki Gulf and East Northland) fishery developed rapidly (though not as quickly as has been noted in large scale fisheries elsewhere; see Figure 4), catches rising to almost 900 t in 1998–99. Although access to the fishery is restricted by a permit moratorium, there is essentially no limitation on catches as several vessels can be worked under a single permit. Some participants in the fishing industry have expressed the belief that a large pilchard stock exists in northern waters, and an intent to raise their catches to several thousand tonnes annually. They consider that the resource is sufficiently large to cater for a commercial fishery while also providing for ecological relationships. Recreational fishers are opposed to the fishery developing on a large scale, on the grounds that (a) over-harvesting (or even heavy harvesting) of pilchards will deplete an important food source of game fish such as billfishes, tunas, kingfish (*Seriola lalandi*), kahawai (*Arripis trutta*), and snapper (*Pagrus auratus*), and (b) purse-seining of pilchards has, in one instance at least, taken a considerable quantity of kingfish as bycatch. Conservationists are concerned that the removal of large quantities of pilchard will damage a balanced coastal ecosystem, and in particular will deplete a valuable food resource relied upon not only by predatory fishes, but marine mammals and seabirds.
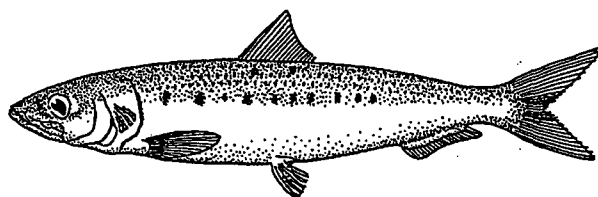

Figure 1: The New Zealand pilchard. Depending upon the classification chosen, either *Sardinops neopilchardus* (Steindachner, 1879) or *Sardinops sagax* (Jenyns, 1842), see text. Within clupeoids the genus *Sardinops* is characterised by fine bony ridges radiating downwards on the operculum, although the closely related *Sardina pilchardus* of the northwest Atlantic also has this feature. The pilchard is most easily recognisable from other small New Zealand pelagic fishes by its colouring: blue-green above, silver flanks and belly, about 10 black spots along the flank with 2 below the dorsal fin, and several lines of much smaller spots extending along the dorsal surface.

NIWA has been commissioned to prepare a report which draws together the currently available information on pilchards in New Zealand, characterises the pilchard fishery as it presently operates, and recommends future research and monitoring of this species and its fishery. The report's main elements are: (1) A literature review of the pilchard in New Zealand; (2) A collation of relevant unpublished New Zealand information on pilchards, with interpretation of a set of otolith ages and length-weight data collected from the developing northern fishery; (3) A review of the commercial fishery, from commercial catch and effort statistics and any associated information; (4) A review of studies on pilchards and pilchard-like fishes, and their fisheries, elsewhere in the world, to identify the features of these fish and fisheries that are important to understand and monitor.

In many parts of the world fishes in the genera *Sardinops* and *Sardina* are known as sardines. The name "pilchard" is in more common usage in New Zealand and is used in this report with reference to species of both genera throughout the world, except where reference is made to *Sardina* when "pilchard (*Sardina*)" is used. The species code of New Zealand pilchard in research and fisheries databases is PIL.

Although most of the present pilchard catch is used as fish-bait, there is certainly the potential to produce a wider range of fisheries products. Josupeit et al. (1999) reported a decline in the supply of pilchards from the Japanese and South American fisheries, but an increasing demand for both pilchards and sardines (the latter may include other genera).

2. LITERATURE REVIEW

2.1 Taxonomy

The New Zealand pilchard has been listed and written about under various specific names: *Alausa melanosticta*, *Amblygaster neopilchardus*, *Arengus neopilchardus*, *Clupea antipodum*, *Clupea neopilchardus*, *Clupea pilchardus*, *Clupea sagax*, *Sardina neopilchardus*, *Sardinia neopilcharda*, *Sardinia neo-pilchardus*, *Sardinops neopilcharda*, *Sardinops neopilchardis*, *Sardinops neopilchardus*, *Sardinopsis neopilchardus* (Paul et al. 1970). Its original description as *Clupea neopilchardus* is attributed to Steindachner (1879) (type locality, Hobson's Bay, Victoria).

Clupeoids have always been difficult to classify. For "pilchards" (or sardines), three alternative systems have been proposed. Until quite recently, two genera and six species were recognised, one species in each of the main current systems of the world's oceans (Figure 2). The monotypic *Sardina pilchardus* occurs in the northeast Atlantic (British Isles to North Africa) and the Mediterranean. Within *Sardinops*, there were five geographically separate species: *S. sagax* (Chile), *S. melanosticta* (Japan), *S. ocellata* (South Africa), *S. caerulea* (California), and *S. neopilchardus* (Australasia). Parrish et al. (1989) retained the two genera, but proposed that the five *Sardinops* species were just geographic forms of *S. sagax*. Subsequently, the work on *Sardinops* by Okazaki et al. (1996) used mitochondrial DNA variation (including the D-loop) in 95 fish from nine localities in the five current systems; they recognised three species: the Japanese *S. melanosticta*, a species combining the South African and Australasian forms, and a species combining the Californian and Chilean form. Bowen & Grant (1997) discussed the taxonomic relationship between the regional forms of *Sardinops*, observing that the complex genetics were in agreement with regional pilchard populations being unstable and (in an evolutionary sense) ephemeral; these populations were considered to have not only varied greatly in size in response to the climate and oceanography of coastal upwelling zones, but to have been periodically extinguished and re-colonised, perhaps from different sources.
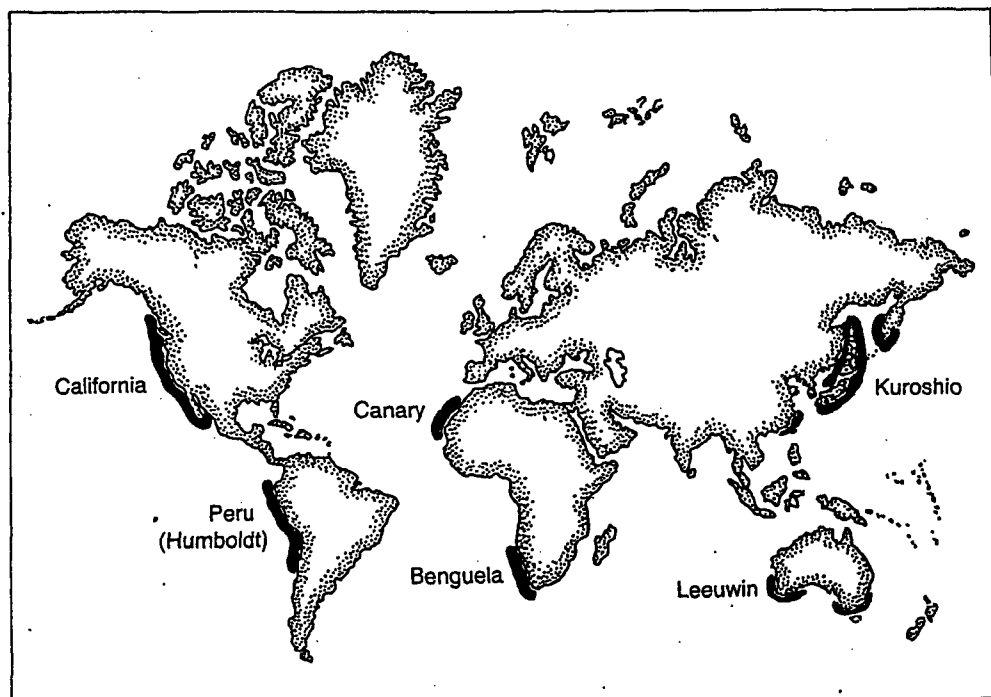

Figure 2: Location of the main pilchard fisheries (solid black), associated with the current systems (labelled) of the world's oceans.

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Consequently, it can be concluded that the various forms of *Sardinops* are very similar, and that this is mostly true for the European pilchard, *Sardina pilchardus*, as well. This close similarity between world pilchard species is our justification for using information from populations elsewhere in the world, and their associated fisheries, to derive an understanding of the pilchard in New Zealand.

2.2 The pilchard In New Zealand

Slack (1969) provisionally estimated the "sustainable yield" for New Zealand pilchard to be about 6000 t, based on an extrapolation from counts of schools in part of the Tasman Bay and Marlborough Sounds region, a mean school size of 3 t, and an exploitation rate of 25%. Robertson (1978) assumed a larger school size of 5 t (and above) to suggest a higher yield of 9000 t based on Slack's counts.

Tunbridge (1969) reported on a survey of pilchards in Tasman Bay, Golden Bay, and Marlborough Sounds carried out in September-October 1964. It incorporated an echo-sounder survey, an aerial survey, and some experimental fishing. The echo-sounder survey was of east-west transects through Golden Bay, around the coast of Tasman Bay, and in Marlborough Sounds, while the aerial survey extended from Kaikoura to Karamea. The position of fish in pelagic fish schools was recorded, but they were not directly identified as pilchards. Experimental night fishing using a floating gillnet took pilchards in the Sounds, but identification of the surveyed schools as pilchards was predominantly based on local fishers' information that the vertically elongated echo traces (Figure 3) were characteristic of that species. An extremely tentative estimate of the biomass in 62 "pilchard schools" across the area surveyed, using procedures derived from Australian work by Rapson (1953), was 293 t (mean 5 t, similar to that noted by Rapson (unpublished) for the Sounds fishery in the 1940s), but it could be higher if some of the "other schools" were also pilchards. Only limited biological information was obtained, and only from samples in the Sounds. The size range was 12–20 cm, with a mode at 13–14 cm. Gonads were "developing", and a summer spawning assumed. Tunbridge (1969) recorded anecdotal information from fishers that suggested pilchards were only "present" in Tasman Bay after September, and implied that his survey was too early for a true biomass estimate. Although unstated, this may have been based on the fishers' recognition of pilchard-type schools on echo traces, and the appearance of pilchard shoals at the surface being preyed upon by gannets. Tunbridge recorded fishers reporting that pilchard abundance varied considerably, both seasonally and between years, in Marlborough Sounds.
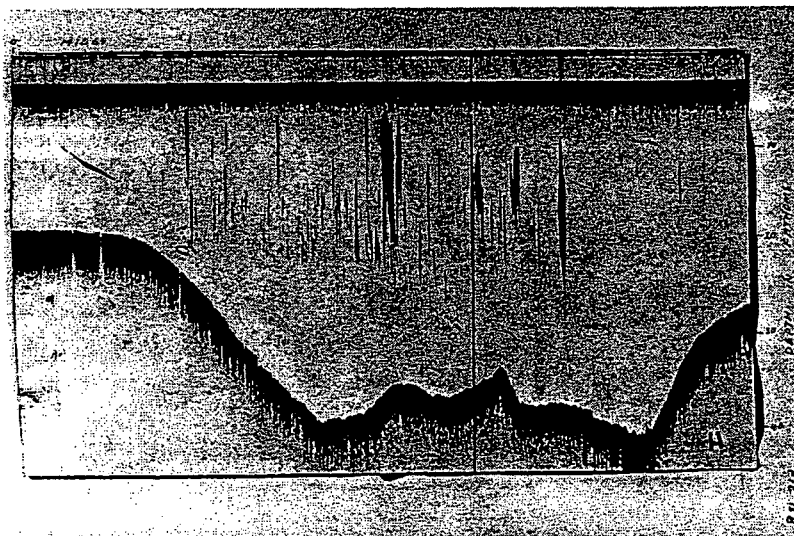

Figure 3: An echo trace of pilchard schools from Maud Island (from Tunbridge 1969).

Baker's (1972) account of reproduction, early life history, and growth of pilchard in the Marlborough Sounds and Tasman Bay resulted from a PhD study undertaken in 1966–68. His findings are incorporated in the sections on Reproduction and Growth below. He suspected that the apparent disappearance, or at least reduction in numbers, of pilchards in winter was due to a demersal, non-schooling phase, rather than to their movement out of the area.

Notes on pilchards are included in some accounts of exploratory fishing for baitfish (for tuna fishing) in New Zealand. Webb (1972a) reported on an experimental purse-seine fishing programme for pilchards by the government vessel *W.J.Scott* between October 1969 and May 1970. His records are unfortunately incomplete, but his report contains detail on the net (457 m long, 37 m deep, 13 mm mesh) and its deployment, and on the catch (mainly pilchard, but often mixed with anchovy or kahawai). Sprats (*Sprattus* spp.) and yellow-eyed mullet (*Aldrichetta forsteri*) were also taken, but probably not in any quantity; they are not recorded separately from "pilchard" in the catch records, and apparently combined with them. Length-frequencies obtained from an *ad hoc* sampling procedure are presented, but no clear conclusions drawn, apart from two other general points: (a) schools tended to contain fish of similar size, and (b) there was an apparent difference in the size range between Marlborough Sounds and Tasman Bay possibly attributable to little mixing of fish between the two areas. One sample was very tentatively allocated to age groups based on length modes. Although this fishing programme extended through the most likely season of rapid growth (spring through autumn), no modal progression of age groups was detectable in the length frequencies, possibly because the measured samples were not routinely taken from the same area or were not large enough. This observation also suggests that pilchard school by size range subsets of age groups, which makes the conversion of length modes into ages difficult. Examination of gonad development during the sampling period showed that both sexes matured at 13–14 cm, and spawning took place between November and February.

Webb (1972b) described the bait-fishing component of a more general exploratory fishing programme carried out by a former Japanese tuna longliner off the north and west coasts of the South Island. Bait-fishing was tried along the northwestern coast of Tasman Bay; pilchard schools were seen elsewhere in the bay but the weather was too rough or the fish too "scary". A bouki-ami net (a form of lampara net) was used in association with attractant lights above the water. Catches averaged 180 kg/night, for 77 stations worked during 3 months, pilchards being the main species taken (98%). This was considered poor.

Webb (1972c) described in considerable detail an exploratory tuna pole-fishing venture undertaken in February–March that year off the west coast of New Zealand, which incorporated live bait fishing in Marlborough Sounds. A purse-seine was used, and pilchard and anchovy targeted, but with only moderate success because of a variety of unforeseen practical difficulties in working the net. Pilchards were caught, but no biological information was obtained.

A further brief assessment of baitfish resources in New Zealand was made by Argue & Kearney (1983). A bouki-ami net was fished at several coastal localities from the Bay of Islands to the Bay of Plenty, and in Tasman Bay. Pilchards were often the main species caught, together with jack mackerels. Both were usually above the optimal size for pole-fishing live bait, pilchards being 12–18 cm, rather than the desired 5–12 cm. The catch rate (on baitfish catch standards) was high, although the species composition (too many jack mackerel, not enough anchovy, and with predatory kahawai sometimes a problem) was also less than optimal.

Pole-and-line fishing for tuna did not develop in New Zealand, and small pelagic fishes have subsequently not been harvested for this category of bait.

2.3 Patterns in the world's main pilchard fisheries

There are six regions of the world's oceans with moderate to significant pilchard fisheries (Crawford 1987, Schwartzlose et al. 1999). (1) The northwestern Pacific, around and to the north of Japan and Korea; (2) The northeastern Pacific, from the Gulf of California to British Columbia, generally centred on California; (3) The southeastern Pacific, off Peru and Chile; (4) The northeast Atlantic, off northwest Africa; (5) The southeastern Atlantic, off South Africa and Namibia; (6) Australia, around the southern half of the continent but generally centred on the southwestern and southern coast. In most of these regions, the pilchard fisheries have at times been very large, often being among the dominant local fisheries.

Extensive studies have been undertaken on these large pilchard stocks, particularly in order to explain (and if possible predict) the very considerable fluctuations in pilchard biomass and catches that occur, but a great deal remains to be understood. The main issues are generally defined as the "overfishing problem", the "recruitment problem", and the "regime problem", although they are interrelated (see Section 5.6.1). The latter can perhaps be considered an extension of the recruitment issue, occurring on a scale of several decades. It is usually linked to some kind of major environmental change in the region, and to large-scale variations in the abundance of other small pelagic fishes, often anchovy (*Engraulis*), but also mackerel (*Scomber*) and jack mackerel (*Trachurus*).

The Japanese fishery. In a well-recorded history of catches there have been six peaks: 1633–1660, 1673–1725, 1817–43, 1858–82, 1920–45, and 1975–95. There are irregular intervals between these peaks, and the pattern of each rise and decline is different. The 1920–45 peak (Figure 4) by Japanese vessels was a slow rise to about 1.5 million t in the mid 1930s and a slow decline to about 10 000 t in the 1960s; the next peak was a rapid rise to 4.5 million t in the 1980s and an equally rapid fall in the early 1990s. Soviet and Korean vessels took their peak catches in the same periods. In total, the peak landings in the 1980s were more than 300 times the landings in the 1960s. In the peak years the pilchards were not only more abundant, but were distributed across a much wider geographic range.

The Californian fishery. This fishery developed in the 1920s (Figure 4), peaked at more than 700 000 t in the 1930s, declined steadily during the 1940s, and collapsed in the 1950s. It was closed in the 1970s, but recovered and was re-opened in the 1980s. The stock, which had greatly contracted geographically, expanded again to cover its original range, and the catch rose to over 100 000 t in the late 1990s. An anchovy fishery developed during the 1970s during the period of lowest pilchard abundance, but declined as the latter recovered during the 1980s.

The Canadian fishery. This is a component of the fishery on the west coast of North America, centred on California. It began in 1917 when small quantities of pilchards were canned (Ware, 1999). The large-scale fishery began in 1925 and fifteen reduction plants (meal and oil) were built, which created a high demand for pilchards. The fishery collapsed without warning in 1947, as the result of a combination of unfavourable environmental conditions and overfishing. According to Ware (1999) this was followed by the eventual collapse of the whole North American Pacific fishery, the collapse of local fisheries spreading southwards: British Columbia (1948), Washington and Oregon (1949), and San Francisco Bay (1951).

Overall the North American Pacific stock showed little resilience to fishing during its decline. Although a small fishery persisted in southern California until the early 1970s, Hargreaves et al. (1994) showed that quantities of pilchards did not appear again around Vancouver Island until 1992–93.
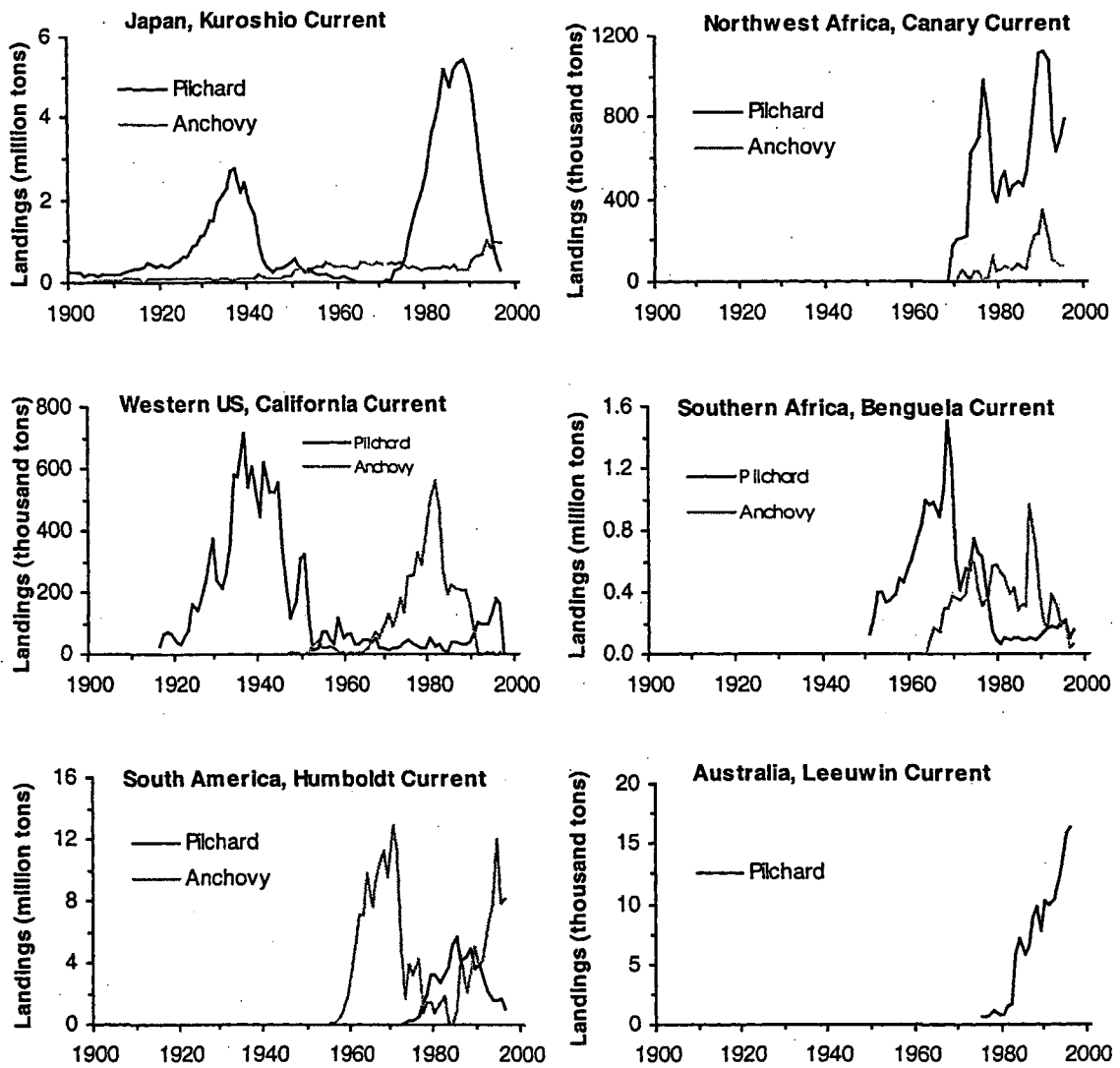
Figure 4: Long-term trends in landings of pilchard and anchovy in the world's major fisheries (source: Schwartlose et al. 1999, FAO yearbook data).

The South American fishery. The Humboldt Current region of Peru and Chile is the most productive in the world for anchovy and pilchard biomass. From 1950 until 1975 (Figure 4), the catch was almost exclusively anchovy, but this suffered a catastrophic collapse from its peak of 13 million tons in 1970, often attributed partially to an El Niño or similar oceanographic event acting in tandem with over exploitation. The biomass and catch of pilchard (and the jack mackerel, *Trachurus symmetricus murphyi*) increased as the anchovy declined. The pilchard catch was about 20 000 t in the early 1970s, rose to between 3 and 5 million tonnes from 1983 to 1990, but dropped back to about 1 million tons in the mid 1990s as the anchovy catch recovered. Catch fluctuations of geographically separate pilchard stocks were not completely in phase, but in general there was an almost complete shift from a pelagic ecosystem dominated by anchovy to one dominated by pilchard, and then back again.

The Northwest African fishery. Catches of pilchard in the Canary fishery peaked at about 1 million tons in the mid 1970s (Figure 4) and declined to about half that by 1980. They remained around 0.5 million t until 1985, and from 1986 steadily increased to about 1.1 million t where they remained from 1989 to 1991, before declining to about 0.7 million t (FAO Yearbook 1995). Anchovy catches from this fishery are an order of magnitude lower than the pilchard catch and show the same

pattern of fluctuations. Some evidence for a regime shift in this area has been described from Moroccan purse-seine vessels, but shifts between pilchard and anchovy cannot be seen in the overall catch history.

The South African fishery. There are two recognised fishery regions off southern Africa: the Namibian coast, and South Africa, and there have been large, often alternating fisheries for pilchard and anchovy in both. In the Namibian fishery the pilchard catch rose fairly steadily from about 1950 to peak at 1.4 million t in 1968 (Figure 4), dropped to about 300 000 t in 1971, recovered to over 400 000 t in 1974, but dropped further to 50 000 t in 1978 and apart from a few years at 90 000–110 000 t has subsequently been between 2400 and 60 000 t. An anchovy fishery developed in the late 1960s when the pilchard fishery underwent its first and largest decline, and has since fluctuated both in step with the pilchard fishery, and reciprocally with it. The South African fishery has gone through a similar progression: a dominant pilchard fishery declining rapidly and being replaced by an anchovy fishery, but with different timing and magnitude. The pilchard catch rose rapidly from about 100 000 t in the 1950s to 400 000 t in the early 1960s, but dropped to about 50 000 t in the late 1960s and has since remained at about that level. The anchovy fishery developed in the mid 1960s, as the pilchard catch fell, climbed erratically to peak at 600 000 t in the late 1980s, but then also fell to less than 50 000 t in the late 1990s.

The Australian fishery. There are two pilchard fisheries in Australia. A fishery for small pelagic fishes centred on southwestern Australia was started in the 1950s (Figure 4), expanded in the 1970s, and then increased rapidly through the 1980s and 1990s, reaching 16 000 t in 1996. It is thus small by world standards. It has been almost completely dominated by pilchards, and during this period there have been no alternations between anchovy and pilchards, as elsewhere. There have been only short-term variations in pilchard biomass, but a sequence of poor recruitment years in the 1970s suggests that longer-term cycles of abundance are possible.

The commercial pilchard fishery in Victorian waters started around 1935 with small catches which increased from 1949 until, in 1997, it was "regarded as Victoria's largest inshore fishery in terms of catch by weight (Neira et al. 1997). Annual catches in Port Phillip Bay and Bass Strait averaged 1770 t and 1000 t between 1990–91 and 1994–95 respectively, representing almost 100% of Victoria's total pilchard catch. Pilchards extend across southern Australia (Stevens et al. 1984) but there is only an intermittent fishery in the Great Australian Bight.

Patterns in the main fisheries. Two generalisations are possible. (1) The main pilchard fisheries have developed within major eastern boundary current systems with strong upwellings: the California, Humboldt (South America), Benguela (South Africa), Canary (northwest Africa), and Leeuwin (West Australia). The Japanese fishery is closely linked to the powerful Kuroshio Current and its associated oceanographic frontal boundaries. (2) In almost all the main areas there have been regime shifts, where ecosystem changes – which are not well understood – have favoured a pelagic fish community dominated either by pilchard or by anchovy.

3. REVIEW OF THE NEW ZEALAND FISHERY

3.1 The commercial fishery

There has been commercial interest in exploiting New Zealand pilchards since the 1880s, when a small fishery operated in the Marlborough Sounds (Arthur 1883), producing smoked, kipper-like "Picton herring", although there is some confusion about the composition of a product sold under this name because Hutton (1872) mentioned smoked yellow-eyed mullet. After 1900 the Marlborough catches were smaller and less regular, and used mainly for bait, although Phillips (1924) mentioned smoked Picton herring (identified by him as pilchard) being sold in Wellington during winter in the

1920s. Some commercial catches were sometimes made in the Hauraki Gulf. The best-recorded pilchard fishery was that which revived in the Marlborough Sounds in the early 1940s. Good catches were made in the first two years, but quickly declined and the fishery closed in 1950. There have been subsequent small landings reported from several regions, the product sometimes being sold fresh through the local retail trade, but more often frozen as fish-bait or as foodstuff for zoos and marinelands. The present intensive fishery in northern New Zealand began in the early 1990s, primarily to supply the fish-bait market. Recent increases have been made to meet the demand created by importation of product from the Australian fishery, and the subsequent decrease of availability from this source as a result of mass mortality events.

Catches and landings. No formal records are available of pilchard landings or sales before 1930. A note by Phillips (1929) indicates moderate catches being made in the 1880s, with a good day's fishing in 1887 amounting to 1½ tons. Most was smoked and distributed throughout the North Island, to Fiji, and to other Pacific Islands. From 1930 until about 1940, pilchard landings were negligible (Figure 5). In the 1930s, Wellington fishermen procured Italian-style lampara nets and made occasional trips to Marlborough Sounds to catch pilchards. Initially they were taken mainly for use as bait in the Cook Strait line fishery for groper and ling (Webb 1972a), but it seems likely that some of the catch found its way into the local retail trade, particularly when fish-handling and quality improved with experience. The recorded Wellington landings (probably minimum values) for the years 1939 to 1942 were 10, 89, 148, and 95 t.
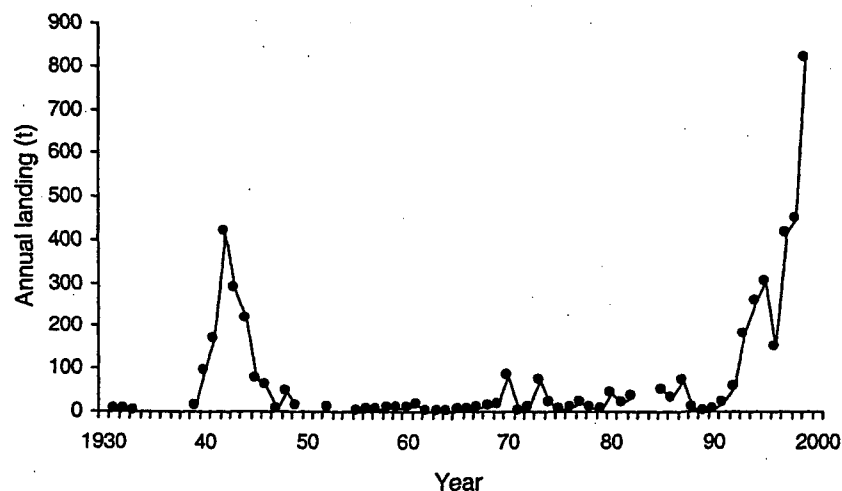

Figure 5:   Total New Zealand catch since 1930 (source: Ministry of Fisheries fish landings database).

In 1942 a cannery was established in Picton. Although it was a commercial venture, it had assistance from the Marine Department as a wartime measure, with the product intended to replace imported canned sardines, and also to supply to overseas troops. Good quality fish were canned, poorer quality fish salted in small barrels. A purse-seine net was used by one Picton-based vessel, and the landings supplemented by lampara net catches of the Wellington line boats, from which they could retain a proportion for bait. Catches were good, at about 270 t, for the first two years, but dropped to 74 t in 1945, and between 5 and 60 t until 1949. In 1950 the purse-seine net was lost, and the fishery closed.

There are several possible reasons for this venture's failure. (1) Overfishing on a limited stock of pilchards within the Marlborough Sounds; there was no fishing in Tasman Bay. (2). A natural fluctuation in pilchard numbers – schools became smaller, difficult to locate, and contained smaller fish (Annual Reports on Fisheries for 1943 and 1944). The 1940s were rather cool years; it is possible that recruitment was low, and that surface schooling was adversely affected. (3) A closed season was imposed from 1945 (Webb 1972a). (4) Renewed post-war importation of canned fish reduced the

demand and price for local product. It is possible that unsold stockpiles developed; during the 1950s canned "Picton herring" or "Picton bloater" were sold cheaply as bait through the Wellington region.

From the late 1940s to the 1980s reported landings were again negligible, although some small catches were undoubtedly made and either not reported or recorded in a "mixed" or "other species" category. Vessels working in the Cook Strait line fishery, targeting gropers, bluenose, and ling, would first catch a supply of pilchards in the Marlborough Sounds for bait, using small lampara nets.

Some experimental fishing for pilchards and other small pelagic fishes was undertaken by the New Zealand Government's exploratory fishing vessel *W.J.Scott* in 1970 (Anon. 1970), but despite moderate catches a commercial fishery did not eventuate. At the time, there were no processing facilities that could handle an intermittent supply of large catches, and there was the added difficulty that the catches often comprised a mixture of species (pilchards, garfish, sprats, and anchovy), which complicated processing and handling. A proposal for a cannery resulted in the introduction in November 1989, of regulations allowing fishery closures based on maximum catches of "20 t of pilchards, or 20 t of garfish, or 20 t of sprats or anchovy or both", in QMAs 2, 7, and 8 (Figure 6).

The present northern (east Northland to Bay of Plenty) fishery for pilchards commenced in 1991. Catches increased to reach almost 900 t in the 1998–99 fishing year, but dropped in 1995–96 when a natural mortality of pilchards occurred (Hine 1995, Smith et al. 1996, Jones et al. 1997). Since then there has been a steady increase in the catch in QMA 1. Catches reported from other areas of New Zealand continued to be small, less than 7 t, and usually less than 4 t annually (Table 1).
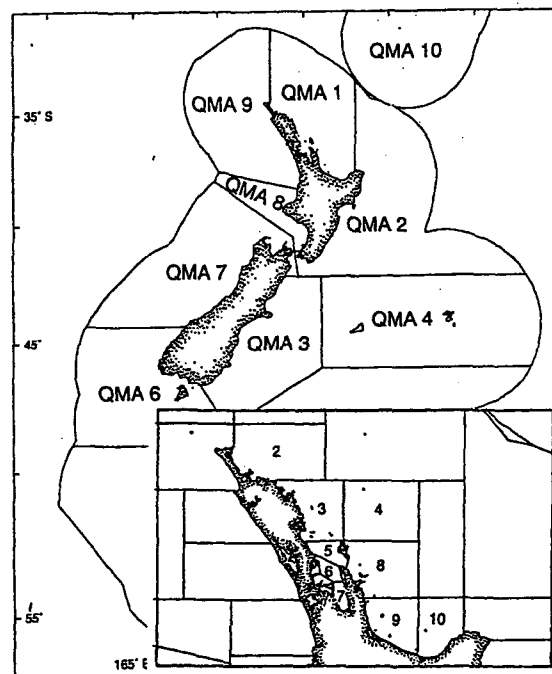
Figure 6: Standard New Zealand quota management areas. Inset: statistical areas in the northern pilchard fishery.

In the northern fishery, first (1990–91 and 1991–92 fishing year) catches were made in the outer Hauraki Gulf, statistical areas 4 and 5 (see Figure 6). Area 5 remained the main area fished in the Gulf to 1994–95, but in 1992–93 the fishery extended northwards into statistical area 3 off southern east Northland. From 1994–95 this became the main fishing ground (Figure 7, see Table 1). This shift of grounds is more likely to be the result of the movement of vessels, based at different ports, into and out of the fishery, than to any change in the real or perceived distribution pattern of pilchards.
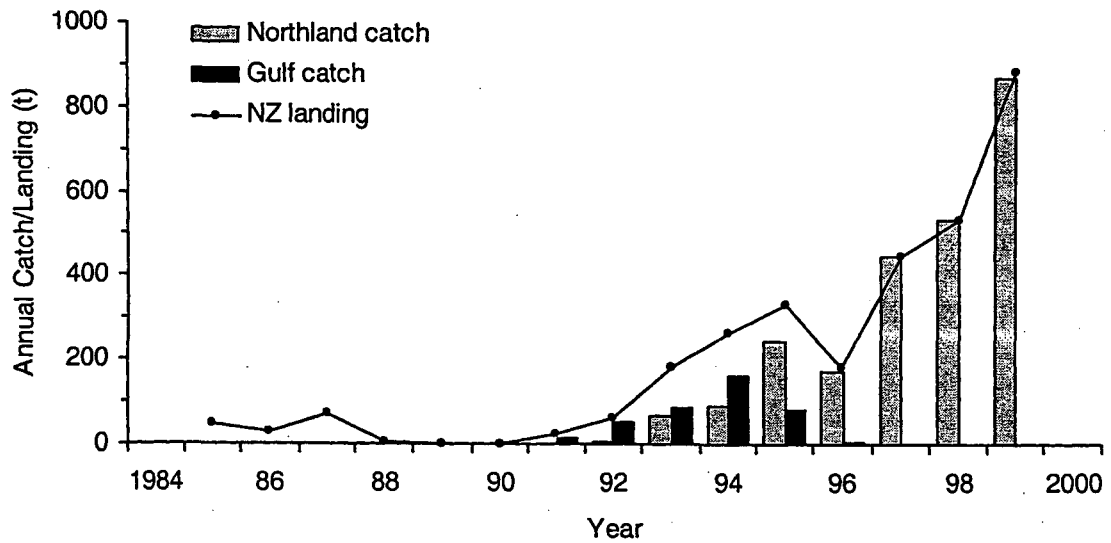
Figure 7: Annual catch of pilchard in QMA 1 from 1985 (source: MFish catch and effort database).

Table 1: Pilchard catches (t) by statistical fishing area, region, and fishing year, 1989–90 to 1998–99. Based on CELR (estimated) data.

Region/								Fishing year			
Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total
Northland											
1		< 1		< 1				< 1	< 1	53	53
2				14	< 1				50	5	69
3			5	53	93	242	170	395	524	816	2297
Total		< 1	5	67	93	242	170	445	529	868	2419
Hauraki Gulf											
4		1	40		3	11					55
5	1	14	14	83	143	69	3				325
6		< 1		< 1	6	< 1					6
7	< 1	< 1	< 1	3	10	1	< 1	< 1	1	< 1	16
Total	1	14	53	86	161	81	3	< 1	1	< 1	402
Bay of Plenty											
8			< 1	< 1	< 1		2				3
9				< 1	< 1	1	2			< 1	2
10							1				1
Total			< 1	< 1	< 1	1	5			< 1	6
Cook Strait											
16						< 1					< 1
17	1	2				4	2	1	1	1	12
18						3					3
Total	1	2				7	2	1	1	1	15
Tasman Bay											
38	0	7	2	5	4						18
Other				21	3		1			10	35
Total	2	22	60	180	261	331	180	447	530	880	2894

Notes:
1. Fishing year 1990 is 1 October 1989 to 30 September 1990; similarly with subsequent years.
2. Estimated catches can be less than recorded landings for non-target species, but most of the pilchard catch reported here was targeted.
3. Incomplete values from fishing year 2000 show almost all the catches being made in statistical area 3.

Fishing operations and fishing effort. Two fishing methods are employed: purse-seining and lampara netting. Both methods catch fish by surrounding them from the sides and underneath, thereby preventing their escape into deeper water below. During the developmental phase of this fishery in the 1990s, vessel type, fishing gear, and fishing procedures varied between the few vessels involved, and gear and procedures evolved towards greater efficiency on each vessel as the skippers gained experience.

Lampara netting. The lampara net originated in the Mediterranean and was used for small pelagic fishes; its name is said to be derived from the Italian "lampo" because the nets are usually deployed with lights which attract the fish (von Brandt 1964). A lampara net is an encircling net, somewhat similar to a purse seine, but smaller. It has no purse line to close the bottom of the net, but because the ground-rope is much shorter than the float-line a partial floor is formed when the net is closed, particularly at the central bunt (Figure 8). As with a purse-seine, the net is set around a fish school, the two wing ends brought together at the boat, and the net is hauled aboard. The encircled school moves to and is retained in the bunt, and then taken out by dipnet.
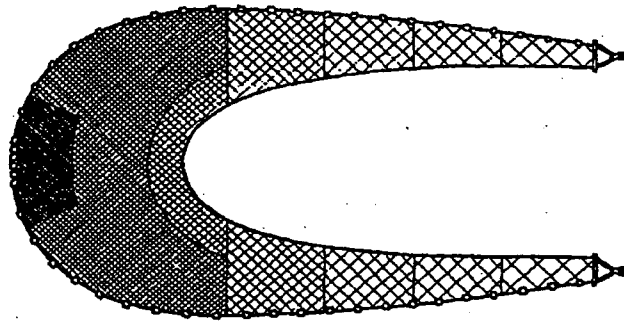
Figure 8: Design of the lampara net (after Dieuzeide & Novalla 1953).

Purse-seining. The main feature of the purse-seine is a purse line at the bottom of the net, which allows it to be closed to retain the encircled fish. Net sizes vary but can be about 600 m in length by about 70 m depth. Since about 1993 the mesh size of purse-seines used in the pilchard fishery has been ¾ inch (20 mm). Regulations stipulating minimum net mesh size were removed by MFish to eliminate the problem of "gilling" that occurred with the original mesh size of 1 inch (25 mm).

Most vessels in the pilchard fishery have been ex-trawlers of about 20 m (60–70 ft) in length, working with the assistance of one or more skiffs. The fisher with longest history in FMA 1 now uses a custom-built vessel and tender. Vessels search suitable areas during daylight hours, looking either for surface schools, or for sub-surface aggregations ("haystacks") using sonar (Figure 9). If a sufficiently large surface school is located, the purse-seine is deployed around it in the usual manner. In an alternative procedure used after nightfall, the vessel is positioned over a sub-surface aggregation. A powerful underwater light source is lowered to just above the aggregation and over a period of some hours is slowly raised to the surface, bringing the fish up with it. The light is transferred to a skiff, which moves away from the main vessel allowing it to then deploy the purse seine around the school. The concentrated fish are dip-netted or pumped aboard the vessel into a refrigerated brine slurry, then boxed and frozen either aboard the vessel or when brought ashore. The time between capture and freezing is kept as short as possible to ensure a quality product.

Figure 9: Aspects of pilchard fishing. Clockwise from top left: "haystack" on sounder; operation of the skiff; hauling the purse seine; the catch comes on board; catch dipnetted into the brine; the packing area; the packing operation. *Photos: Ministry of Fisheries.*

Lampara netting and purse-seining both began in 1991 (Figure 10). Lampara netting continued until early 1995, with only two subsequent periods of fishing in 1997 and 1999; purse-seining began more slowly, but became the dominant method in 1993. As very few vessels are involved in the fishery (only 1 to 3 making a significant landing in any one year), this pattern is entirely dependent on the movement of individual vessels into and out of the fishery.

There is no consistent seasonality in reported landings. In the first few years there were pulses of fishing, but at different times of the year. In 1993–95, and to a lesser extent in subsequent years, there were lower landings in early summer (November to January). This could have been caused by a decline in demand for bait when coastal longliners take a break over the holiday period, with the more consistent – and rising – landings in later years resulting from a diversification of markets.
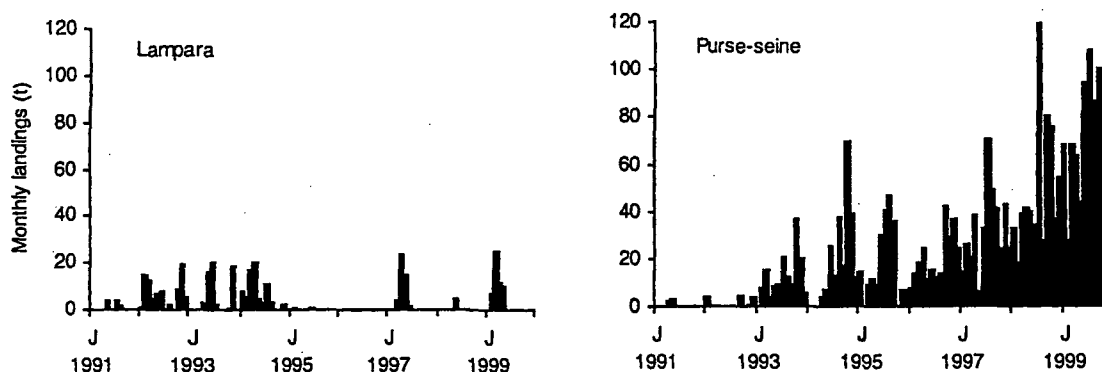

Figure 10: Pilchard catch in east Northland and the Hauraki Gulf (combined) by year, month, and gear type (lampara & purse seine) since 1991. J is January (source: MFish catch and effort database).

Bycatch. Little is known about bycatch in the pilchard fishery as it operates currently. Some data were collected in 1993 (Dave Allen, unpublished data) to investigate the effect of varying mesh size on meshing rates. This study showed that a number of species can be encircled during the pilchard fishing operation, including anchovy (*Engraulis australis*) (ANC), jack mackerel (*Trachurus* sp.) (JMA), kingfish (*Seriola lalandi*) (KIN), barracouta (*Thyrsites atun*) (BAR), blue mackerel (*Scomber australasicus*) (EMA), blue maomao (*Scorpis violaceus*) (BMA), koheru (*Decapterus koheru*) (KOH), frostfish (*Lepidopus caudatus*) (FRO), garfish (*Hyporhamphus ihi*) (GAR), squid (*Nototodarus* sp.) (SQU), and flying fish (Exocoetidae) (FLY). Catch rates of these bycatch species were very low compared with those of pilchard, ranging from 0.003% by weight for trevally, to 8.19% by weight for anchovy:

| | | | No. | | | | | *BAR | *BMA | *FRO | *SQU |
Vessel	Start	Finish	shots	PIL	ANC	JMA	KIN	EMA	KOH	GAR	FLY
											Percentage of species in aggregated catch, by weight
1	25/5/93	16/12/93	30	88.8	8.19	0.14	2.57	0.15	0.07	0.03	0.010
2	29/10/92	25/10/93	53	85.1	0.64	7.12	0.18	3.67	3.15	0.11	0.003

* Upper species for vessel 1, lower species for vessel 2

Management. Before September 2000 there was no catch limit in the pilchard fishery and it was not managed under the quota management system (QMS). In December 1992 a permit moratorium was introduced for non-QMS species. Before the moratorium there were more than 30 permit holders authorised to fish pilchards in QMA 1 (see Figure 6), but only a few were exercising their permitted fishing rights. After the moratorium was implemented, changes to the criteria for issuing permit authorisations resulted in a reduction to six permit holders in QMA 1, one permit holder in QMA 2, QMA 8, and QMA 9, and two permit holders in QMA 7.

MFish staff observed pilchard-fishing procedures during the 1992–93 fishing year and, from 1 October 1994, the minimum net mesh sizes specified for commercial pilchard fishing (previously 25 mm) were reduced to minimise the waste caused by enmeshing smaller fish.

In June 2000 a target commercial catch limit (CCL) of 813 t was proposed for PIL 1, defined as QMA 1. This was based on the average catch over the three fishing years 1997–98 (447 t), 1998–99 (791 t), and 1999–2000 (1202 t). The latter value was extrapolated from a total of 601 t for the first six months of the fishing year (to 31 March 2000). In September 2000 a CCL of 2000 t was set for PIL 1.

3.2 Traditional Maori fishing

The importance of pilchard to Maori is difficult to determine. Existence of a specific name (mohimohi) indicates that it was recognised as an individual species, although its omission from a "brief account of the principal kinds [of New Zealand fish]" by Taylor (1885) (a list with descriptions based on Maori names), suggests that it may not have been an important resource. There is little information on the specific use to which pilchard were put. A catch of pilchard being taken by Maori was observed by Mair (1903) at a village some 3 miles up the Piako River. He recorded a number of fish species taken using a fixed, funnel-shaped net, including: yellow-eyed mullet, snapper, mullet (probably *Mugil cephalus*), kahawai, hundreds of what were described as red cod but were probably ahuru (*Auchenoceros punctatus*), an unknown species described as rock cod, "very large quantities of a kind of white-bait", and "about 60 lb. or 70 lb. weight of pilchard or mohimohi (*Clupea sagax*) [*S. neopilchardus*]". There was no comment on how the catch was used.

There is no mention of pilchard having importance to Maori in the Waitangi Tribunal (1988a) Muriwhenua fishing report, apart from its inclusion in a list of the modern resource and its potential. Similarly, there is no reference to pilchard having been taken traditionally in documentation for the Ngai Tahu claim (Waitangi Tribunal 1988b), or in other historical records (Taylor 1855, Poata 1919, Best 1929), nor is there evidence from archeological sites (Waitangi Tribunal 1988a; Leach & Boocock, 1993). Generally, uncertainty and the lack of numerical information precludes any estimation of the amount of fish taken in the traditional Maori fishery.

3.3 Recreational fishery

Anecdotal information and personal observations indicate that pilchards can easily be taken using lures from wharves. This activity attracts some recreational effort, around Wellington Harbour at least. However, only three records of pilchard catches have been captured by national recreational fishing surveys. They were recorded during the 1996 national survey and remain the only information currently available on the recreational catch. Their details are

Date	Area of capture	Number caught
26 December 1995	Pelorus, Kenepuru, Mahau Sounds	1
2 January 1996	Whangarei Harbour & entrance	1
7 February 1996	Tarawera River–Cape Runaway	60

Phillipps (1924) described the capture of pilchards at the Wellington wharves by sailors lowering wire netting cages into the water, scattering breadcrumbs and other small food particles on the surface, and lifting the cage to trap the pilchards which had gathered. "Local amateur fishermen" were reported to have copied this procedure.

Recreational fishers mostly regard pilchards (purchased in frozen packs) as bait, though they have an interest in maintaining a healthy pilchard stock in the ocean as natural prey for the gamefish (snapper to billfish) they target.

4. RESEARCH

4.1 Distribution

Pilchards are widely distributed around New Zealand. They now appear to be least common off southeastern New Zealand, although Graham (1956) recorded large quantities in the Otago region during the early decades of the 20th Century, but inferred that they were not regularly abundant there. Robertson (1973) reported on ichthyoplankton sampling around much of New Zealand in 1969–72 which failed to reveal any evidence of pilchards between Banks Peninsula and Dusky Sound.

Little is known of the distribution of juvenile (0+ and 1+) fish in New Zealand. In southeastern Australia, these age groups appear to occur, at least during summer months, in shallow and sheltered water (Blackburn 1949, Hoedt et al. 1995, Neira et al. 1999). In southwestern Australia, however, juvenile pilchards occur in shallow inshore areas but only rarely in enclosed bays or estuaries, despite the large number of such systems in the region (references given by Neira et al. 1999)

As *Sardinops neopilchardus*, the species was formerly considered to be shared only with Australia, but more recent studies suggest that this is unlikely (see Section 2.1 above). The Australian population was judged by Okazaki et al. (1996) to be more closely related to the South African than the Chilean population; the New Zealand population was unfortunately not sampled, but is likely to have a close affinity with that of Australia. The precise relationship between Australian and New Zealand pilchards is not known, but some differences are likely at the population, perhaps even sub-specific, level. Within Australia, the situation is not clear. Despite strong genetic uniformity, there is evidence from recent morphological, electrophoretic, and otolith studies (trace elements and oxygen isotopes) that there are several identifiable stocks and sub-stocks of adults along the West Australian to South Australian coastline, although there is undoubtedly a genetic link through the dispersal of larvae and juveniles (Fowler et al. 1997, Gaughan et al. 2001).

4.2 Stock structure

No information is available on the stock structure of pilchards in New Zealand.

4.3 Fish size

Baker (1972) compiled length frequency distributions for 660 pilchards (318 males, 342 females) taken in Golden and Tasman Bays and the Marlborough Sounds between January 1966 and February 1968. They ranged in size from 47 to 204 mm standard length, 50 to 220 mm fork length (FL).

Pilchard samples collected in the outer Hauraki Gulf by the Ministry of Fisheries between December 1992 and April 1993 showed maximum sizes of 230 mm and 240 mm (FL) for males and females respectively. Length frequency distributions (Figure 11) suggest a bimodal structure. Large fish are better represented in the female distribution.
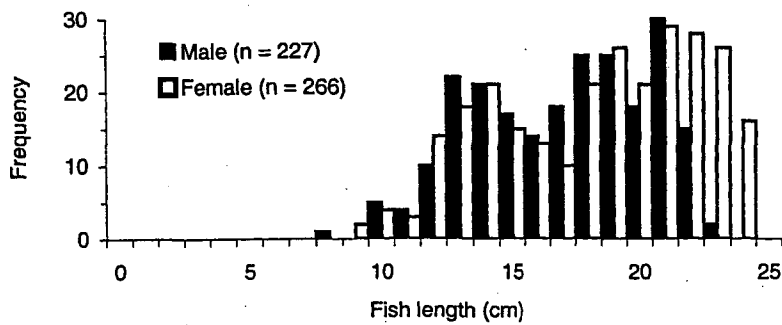
Figure 11: Length (fork length) frequency distributions of male and female pilchards (source: unpublished MFish data collected in the outer Hauraki Gulf in 1993).

Trawl surveys of demersal fish optimised for one or more species (in Hauraki Gulf, snapper) do not reliably sample schooling pelagic fishes such as pilchard. The larger sizes, in particular, are probably able to avoid the net. However, pilchards have been measured during these surveys, and their size frequencies are shown in Figures 12 and 13. The combined data for all surveys, subdivided by region (Figure 12), show that the smallest fish occur in the shallow Firth of Thames, although some larger
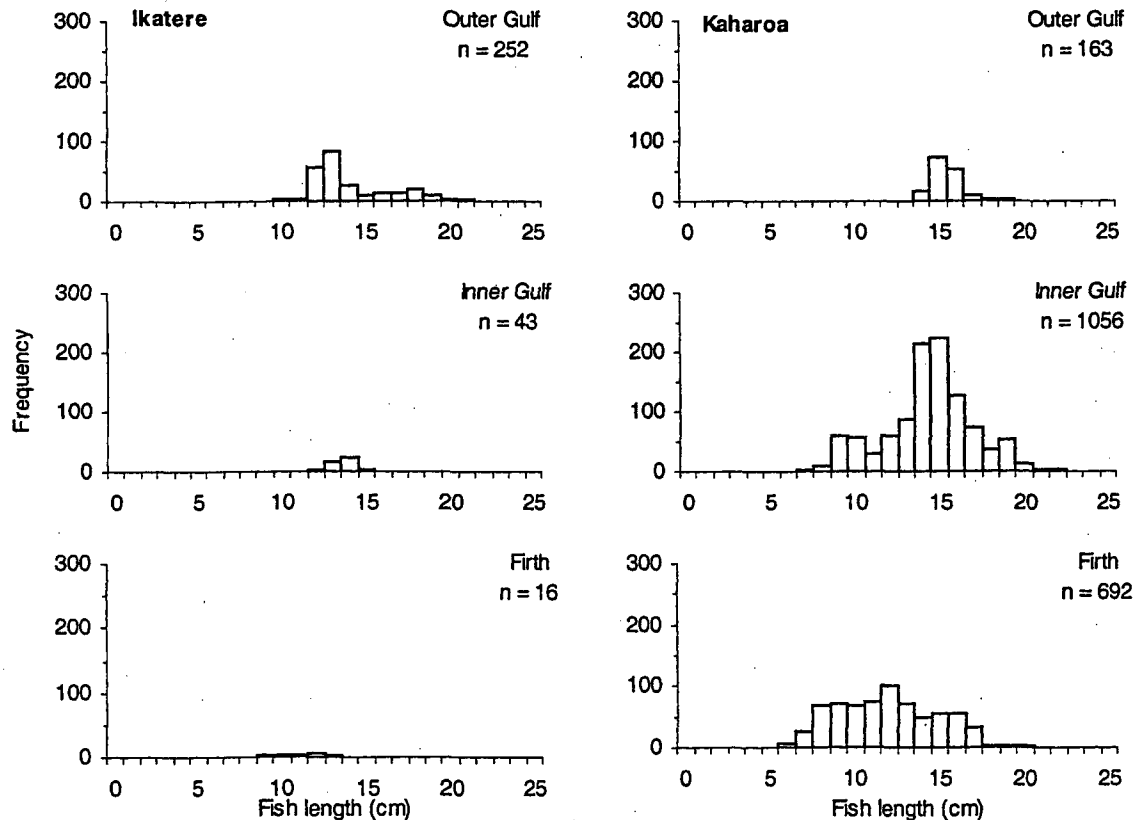
Figure 12: Size range of pilchards taken during trawl surveys in the Hauraki Gulf, 1964–66 (R.V. _Ikatere_) and 1982–97 (R.V. _Kaharoa_), by region.

fish are also present. In the inner Gulf, south of a line between Capes Rodney and Colville, the main mode is of slightly larger fish. In the outer Gulf, north of this line, the mode is similar but there are fewer small fish. Pilchard were not observed to spawn near the Firth during the egg and larval surveys

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reported by Crossland (1981), but the Firth is a nursery area for many species of fish which spawn both there and elsewhere (NIWA, unpublished data).

In individual Gulf surveys between 1982 and 1997, which are similar in design and area covered, the size range of pilchards taken has varied considerably between years (Figure 13). The largest sample, in 1982, covered a wide length range with length modes – possibly representing year-classes – at about 9, 15, and 19 cm. Subsequent samples each contained fewer length modes. Few fish were caught in the late 1980s. In 1992, a mode of small fish (9 cm) was caught, and in 1993, 1994, and 1997 the main size mode was at 14–16 cm. While it is possible that this variation results entirely from inadequate sampling by the trawl net, it may also reflect some real variation in year-class strength. Of particular interest is the difference between the broad size distribution in 1982 and the narrower size range in the 1990s, almost certainly representing fewer age groups.
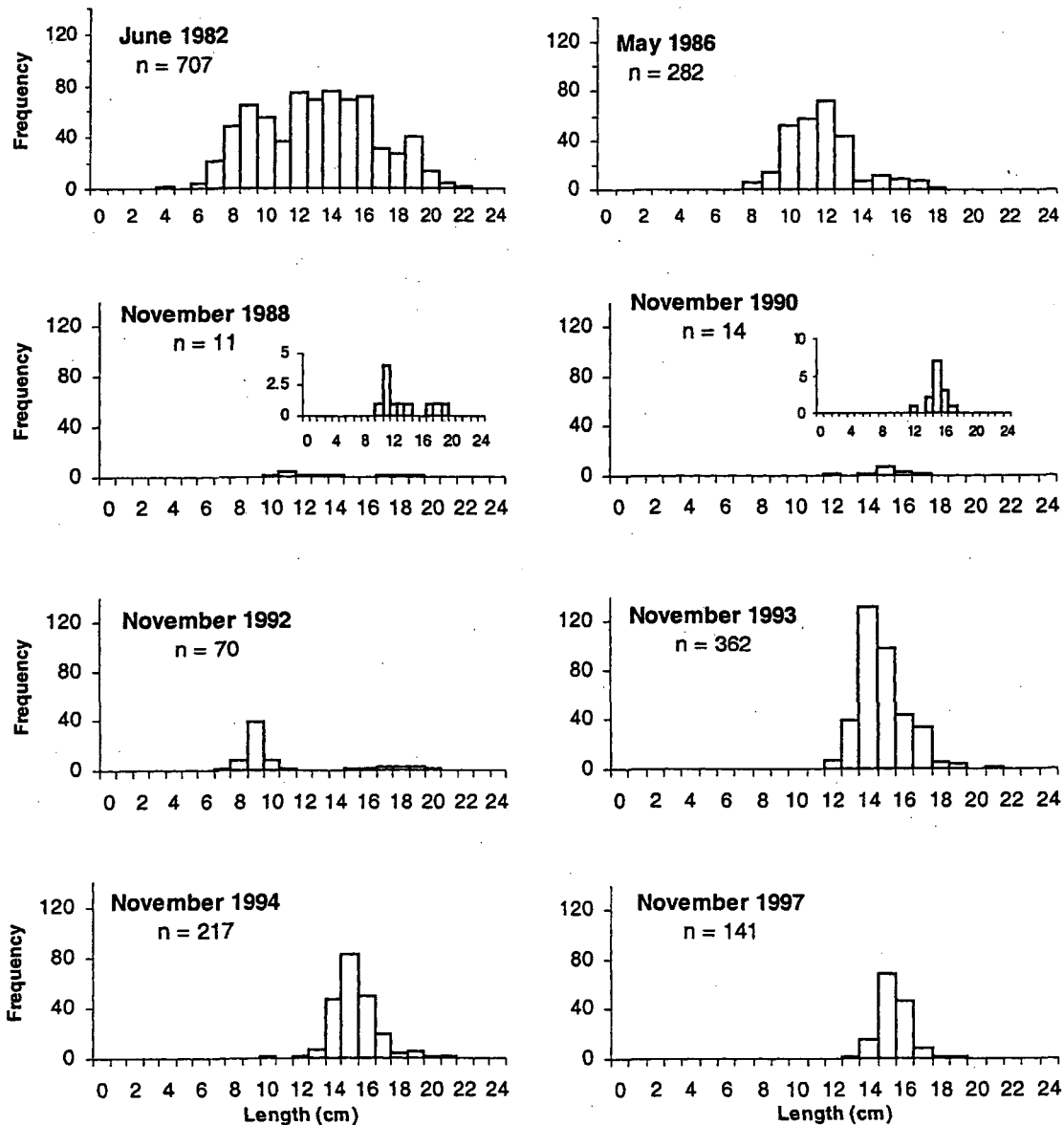

Figure 13: Length frequency distributions of pilchards taken by R.V. *Kaharoa* during trawl surveys in the Hauraki Gulf, 1982–97, by year (source: MFish trawl survey data).

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4.4 Age and growth

The most comprehensive account of the age and growth of New Zealand pilchard is that of Baker (1972). He followed the growth of 0-year fish by modal length frequencies, finding that the length (standard length) at 12 months was 55–60 mm. He used scales to determine subsequent ages, defined scale ring formation as occurring in spring (with mature fish forming a second ring shortly afterwards), and used back-calculated lengths to define growth. The first ring (formed at 18 months) was at a mean standard length of 94 mm, with successive rings at 122, 138, 151, 163, and 173 mm. A few larger fish, to 200 mm, were believed to have reached up to 9 years.

Robertson (1976) found the scales of six large pilchards difficult to interpret, and read whole otoliths in reflected light, counting the narrow dark (hyaline) zones. The sample comprised fish with three rings (at about 20 cm total length, 18 cm fork length), and four rings (at 20–26 cm total length, 18–24 cm fork length). This indicated a growth rate faster than that described by Baker, but similar to unspecified age data accepted for South African pilchards at that time. It is also comparable with recent New Zealand otolith reading (see Figure 15), although both remain 'ring counts' rather than true ages.

Some work on pilchard ageing was undertaken in 1992–93 (Ministry of Fisheries, unpublished data). The samples were collected from commercial catches of a purse-seiner in the outer Hauraki Gulf between December 1992 and April 1993, 10 kg boxes of pilchards being selected at random from the packaged catch and returned to the laboratory for sampling. Length, weight, and sex were recorded. Otoliths were removed dry and stored in paper envelopes. For age reading, the otoliths were immersed in a high refraction oil in a small black dish, and the distal (lateral) surface viewed whole in reflected light using a stereo microscope at various magnifications. The dark (hyaline) rings were counted. Two readers made independent counts of rings, and noted the marginal increment as 'line', 'narrow', or 'wide', but these observations were not compared and adjusted to a single reading, or converted to ages using a nominal birthday.

Ring counts were recorded from the otoliths of 781 pilchards (Figure 14). Because these are not true ages some caution is necessary in interpreting the mortality rate implied by the catch curve. There are some differences between the two readers, which is a feature of pilchard otolith-based ageing studies elsewhere (e.g., Fletcher & Blight (1996) found only 43% of agreement between readers). The greatest variation was at ring counts 4 and 5. However, the results clearly show the samples to be of short-lived fish, with the most individuals between 2 and 4 years old. Maximum "age" (ring count) appears to be somewhere about 7 years, although there was only one fish in this category.

Growth parameters were estimated for the two readers using the von Bertalanffy equation, which was fitted to the age data using an iterative procedure in Microsoft Excel to minimise the squared differences between the predicted and observed values of length at "age" (ring count):

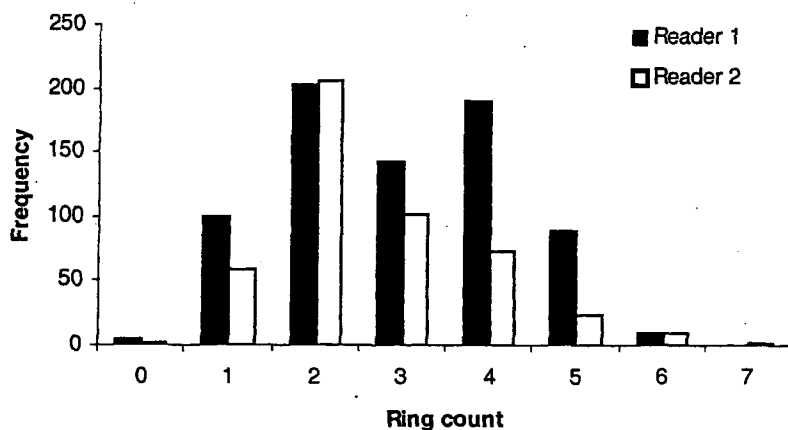| Growth parameter	Reader 1	Reader 2
L_∞	246	241
t_0	-0.23	-0.12
K	0.37	0.45

Figure 14: Frequency distribution of ring counts from pilchard otoliths (both sexes combined) by two readers (source: unpublished MFish data).

There is little difference between the two readers based on a comparison of growth parameters and growth curves (Figure 15). The individuals with zero ring counts ("age" 0) may represent the upper portion of that distribution, with gear selectivity resulting in fish smaller than about 55 mm being lost from the sampling.
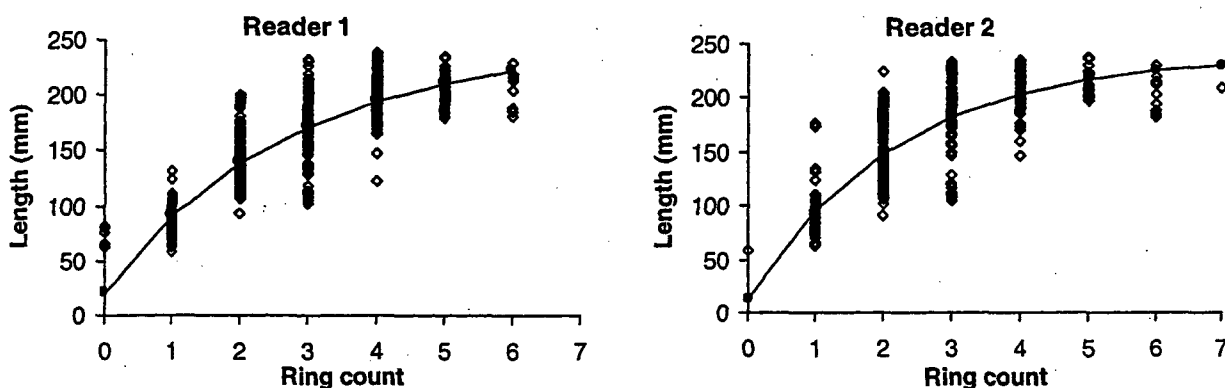

Figure 15: "Age" (ring count)–length relationships for pilchards (both sexes combined) by two readers; curve represents predicted length, open symbols observed length (source: unpublished MFish data).

There has been considerable work on the age and growth of pilchards, particularly where major fisheries exist. Some recent examples which deal with adult growth are: Japan (Dudarev & Bednykh 1980, Wada & Kashiwai 1991, Hiyama et al. 1995), California (Felix-Uraga 1992, Barnes & Foreman 1994, Butler et al. 1996), South America (Cardenas 1989), South Africa (Thomas 1983a, 1983b, 1984, 1985, Waldron 1998), and Australia (Fletcher 1991, 1995, Fletcher & Blight 1996). There are contradictions and obscurities in much of this work, and no standard ageing protocols appear to have been developed. There has been relatively more work done on the ageing, growth rate, and survival of juvenile fish in studies directed at determining whether recruitment variation drove the large fluctuations in pilchard stocks.

Scale annuli and then otolith rings have been used to age pilchard in Australia, as elsewhere (Fletcher 1990, Fletcher & Blight 1996). However, scales were judged problematic for several reasons, particularly loss and regeneration. Otoliths also proved difficult to interpret, having accessory rings,

and an obscure pattern of marginal increments when they were read without knowing month of capture (though a clear pattern of annual ring formation was apparent when the latter was known). Agreement between readers was poor. Fletcher (1991, 1995) demonstrated that West Australian pilchards could be aged with a reasonable degree of accuracy from otolith weights alone, in a procedure that was objective, rapid, and repeatable, although it did require arbitrary cut-off values to separate age groups because the weight modes overlapped. This ageing method, via an otolith weight/age class key, has been used during the 1990s for routine stock assessments, although an apparent and as-yet unresolved anomaly became apparent as the time series developed, with mean fish weight and mean otolith weight trending in opposite directions, possibly because of a change in the growth rate of the pilchards over time (Cochrane 1999).

The interpretation of otoliths has changed over time in South Africa; early studies counted all rings, later studies recognised accessory rings (Thomas 1983, 1984), but the reliability of these in turn has come under question (Fletcher & Blight 1996, Kerstan 1995, 1996, 1997, unpublished ICES documents).

In summary, studies in several parts of the world indicate that ageing pilchards by otolith reading is not straightforward. There is often poor agreement between readers interpreting annuli, there are false rings, difficulties in interpreting the marginal state, and interannual changes in growth. Fletcher's procedure of using otolith weights to assign ages is certainly worth investigating, but requires testing (comparing otolith weights, otolith ring counts, and length frequency modes) in the New Zealand population of pilchard.

4.5 Length-weight relationships

Using length (standard length, mm), and weight (g), Baker (1972) determined the relationship from 660 fish as $W = 3.7*10^{-6} L^{3.3}$, with little difference between sexes.

The length-weight relationships for males and females in the age sample taken by MFish in 1992–93 in the outer Hauraki Gulf also show little difference between sexes (Figure 16) with $W = 2.2*10^{-6} L^{3.3}$ for males ($n = 227$) and $W = 2.2*10^{-6} L^{3.3}$ for females ($n = 266$).
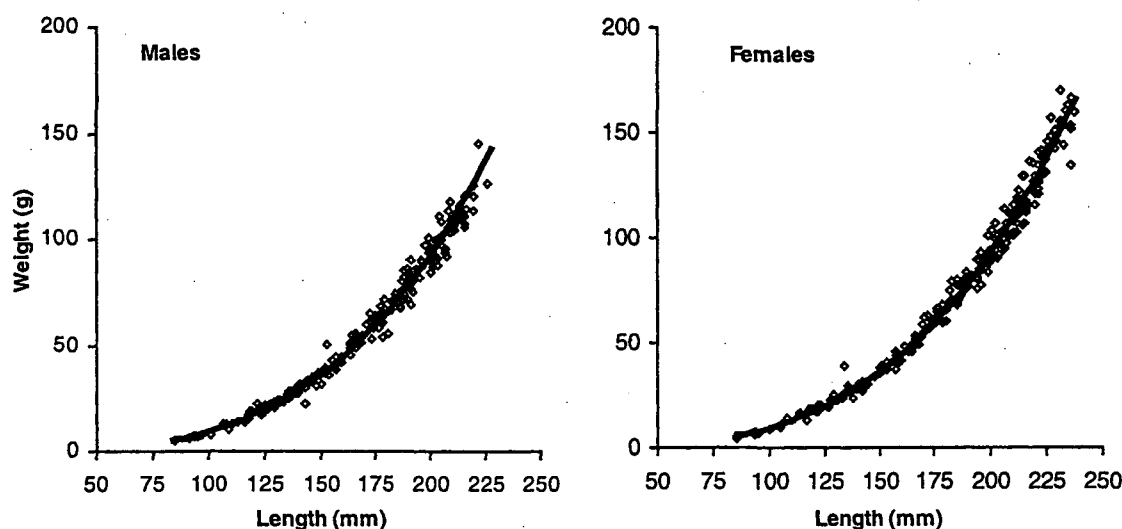

Figure 16: Length-weight relationship of male and female pilchards; observed (open symbol) and predicted (trend line) weight (source: unpublished MFish data).

4.6 Reproduction

In Tasman Bay and the Sounds, the smallest mature male was 115 mm standard length, the smallest mature female 118 mm (Baker 1972). At 120–124 mm 65% of both sexes were mature, and at 135–139 mm almost all males were mature, as were all females. Over two spawning seasons, maximum gonad weight (gonadosomatic index) of both sexes occurred in January of both years. Maximum fecundity (medium and large ova) was 110 400 eggs, comparable with the estimates reported from South Africa (Davies 1956) and California (Clark 1934). Regular plankton sampling in Tasman Bay and the Sounds took eggs from December to February (peaking in January) in the first year, November to February (peaking in December) the second year. Optimal surface water temperatures were considered to be about 16 °C. Larvae were recorded during summer and autumn of both years, but inadequate numbers were taken for any conclusion on distribution patterns. The developmental stages of eggs and larvae were comprehensively described by Baker (1972).

Baker (1972) thus found a late spring through summer spawning season in central New Zealand, and he cited observations by other authors (Sherrin 1886, Thomson 1892, Graham 1939) that inferred a similar spawning season in southern waters – this was further supported by Sutherland (1885) who described spawning near George Sound in Fiordland as being complete in early December. Baker (1972) reported that some planktonic eggs had been found in the Hauraki Gulf and Bay of Islands at other seasons including winter, which seemed to confirm the suggestion of Blackburn (1960) – based on temperature-related Australian studies – that spawning would be year-round in northern New Zealand, spring-summer in southern regions.

Robertson (1973) incorporated information from earlier accounts of pilchard spawning with results from his 1969–72 ichthyoplankton sampling around New Zealand to describe spawning areas and seasons off Fiordland, in Tasman Bay, the Gisborne-East Cape region, and eastern Northland. He agreed with Baker (1972) that the spawning season occurs in late spring-summer in central and southern New Zealand, and potentially all year round in northern waters. Localised heavy pilchard spawning was recorded in the Bay of Plenty in April (Robertson 1975).

Crossland (1981) described pilchard eggs and larvae in his account of the inner and central Hauraki Gulf's ichthyoplankton. He considered the main spawning season to be October and November, extending into December, with a sea surface temperature at 16–18°C. He encountered abundant eggs during only one of 13 sampling cruises over two seasons, representing a spawning event just east of Tiritiri Matangi and Kawau Islands. Larvae were generally found a little distance to the north in the central Gulf, with a distribution pattern that suggested the main spawning areas were further north still, probably near Little Barrier Island.

In his subsequent study of the outer Hauraki Gulf and east Northland's ichthyoplankton, Crossland (1982) found pilchard eggs and larvae where predicted in the outer Gulf, near Little Barrier Island, as well as in Bream Bay. Pilchard eggs were found to be common along much of the east Northland coast in October 1977. Larvae were found at all stations at the same time, particularly around and north of Bream Head, and from the Bay of Islands to Tom Bowling Bay; they were the most abundant species taken. Crossland considered that spawning had occurred at a sea surface temperature of 14–15°C, lower than the 16–18°C previously described for Hauraki Gulf and Tasman Bay, and to have been earlier (October, perhaps September).

An analysis of sex ratios from the unpublished MFish data collected in 1993 (Table 2) shows a predominance of females (over 60%) in December and January of 1992–93, with equal proportions (50%) in March and April. The February sample size is too low for the result to be reliable.

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Table 2: Monthly distribution of sex ratios of pilchards collected in 1992–93 in the outer Hauraki Gulf (source: unpublished MFish data).

Year	Month	Proportion of males	Proportion of females	Number sampled
1992	Dec	0.35	0.65	97
1993	Jan	0.37	0.63	134
	Feb	0.64	0.36	11
	Mar	0.48	0.52	338
	Apr	0.5	0.5	88

An examination of gonad stages in the same dataset (Table 3) shows few of either sex in resting condition during January – many are spent or in late-stage developing condition. By March–April the proportions are different, with high proportions of both sexes in resting condition, although there are still high proportions spent in both sexes in both months. Frequencies for February are too low to provide reliable results.

Table 3: Monthly proportions and frequency distribution of gonad stages by sex, for pilchards collected in 1993 in the outer Hauraki Gulf (none were staged in December 1992) (source: unpublished MFish data).

		Gonad stage				
		1	2	3	4	5
Monthly proportions						
Males	Jan	0.06	0.28	0.2	0.04	0.42
	Feb	0.86				0.14
	Mar	0.44	0.24	0.14		0.19
	Apr	0.47	0.09	0.14	0.07	0.23
Females	Jan	0.04	0.2	0.43	0.01	0.31
	Feb	0.25				0.75
	Mar	0.34	0.3	0.15	0.01	0.2
	Apr	0.36	0.05	0.23	0.02	0.34
Monthly frequencies						
Males	Jan	3	14	10	2	21
	Feb	6				1
	Mar	63	34	20		27
	Apr	20	4	6	3	10
Females	Jan	3	17	36	1	26
	Feb	1				3
	Mar	51	44	22	1	30
	Apr	16	2	10	1	15

The results of these analyses suggest the main spawning activity occurs during December and January, based on the predominance of females and the low proportions of resting fish. Although there are still spent fish during March and April, indicating recent spawning, the lower proportions of still developing fish indicate a decrease in spawning activity. This may also be reflected in the similar proportions of males and females in the samples; many fish species school by sex during their spawning season but mix more evenly at other times of the year, but the extent to which New Zealand pilchard do this is unknown.

4.7 Feeding

The feeding pattern generally assumed for pilchards, in common with most other clupeoids, has been that the larvae and small juveniles feed mainly on zooplankton, particularly copepods, and the adults filter-feed on phytoplankton, usually large chain-forming diatoms (e.g., Hardy 1959, in the review by Blaxter & Hunter 1982). In such cases, the change from predation to filter-feeding appears to be both gradual and incomplete. In *Sardinops*, consistent filter-feeding may not occur until a length of 80–100 mm (citations in Blaxter & Hunter 1982). The change has been described as most complete where diatoms are abundant in highly productive upwelling systems, which is where large stocks of pilchard tend to build up. The inference has generally been that direct utilisation of primary production (filter feeding on diatoms) is of considerable benefit to pilchards. Where upwelling is weak or inconsistent, zooplankton may remain the dominant food source. For example, Kawasaki & Kumagai (1984) recorded considerable variability in the proportions of copepods and diatoms eaten by *Sardinops melanosticta* off Japan. In a review of clupeoid diet patterns, James (1988) questioned this generally accepted transition from zooplankton to phytoplankton on several grounds. He considered the sampling methodology of many studies to be flawed, for example ignoring diurnal or seasonal patterns, and inappropriately assessing the value of gut content components. He noted that in several instances different authors came to opposing conclusions from further analyses of the same, or augmented, data, and stated that there was great variability in the described composition of a species diet, both within and between studies. His conclusion was that clupeids were flexible and opportunistic in their feeding behaviour, able to forage efficiently across a wide range of prey size, so enhancing their ability to survive in unstable upwelling regions.

Many studies record, however, that the feeding pattern of *Sardinops* differs from that of anchovies, which co-exist but undergo population fluctuations generally reciprocal to those of pilchards. *Sardinops* feeds on microzooplankton and phytoplankton (in highly variable proportions), whereas *Engraulis* feeds predominantly on larger zooplankton (van der Lingen 1994). The availability to planktivores of a larger fraction of the energy produced by phytoplankton than to members of higher trophic levels (Lazzaro 1987, Sanderson & Wassersug 1990) is even more pronounced in phytoplanktivores, given their position nearer the base of the trophic pyramid. This may account for the development of huge populations which support the high levels of catch in world pilchard fisheries, which are generally larger than those based on anchovy (see Figure 4).

There is little information on the food and feeding patterns of pilchard in New Zealand. Graham (1956) recorded copepods and larval crustaceans as the main food of pilchards off Otago, and also noted the presence of diatoms.

4.8 Predator-prey relationships

Anecdotal information suggests that pilchards are taken as prey by a wide range of species, but support from the literature is sparse. In New Zealand, pilchards have been described as an important element in the diet of gannets (Wodzicki & Moreland 1966, Wingham 1985, 1989, Robertson 1992). Kahawai feed on pilchards (Baker 1972) as most predatory fishes almost certainly do. Pilchards (*Sardinops* and *Sardina*) have proved to be an important food for John dory (*Zeus faber*) in the regions where the latter's feeding habits have been studied (Godfriaux 1970, Velasco & Olaso 1998, Silva 1999).

Robertson (1992) extrapolated from calculations of the mean daily food intake of gannets, and estimates of the New Zealand gannet population size in 1980–81, to derive an estimated annual consumption of 2880 t of pilchards, the most important prey species. (The other main species were anchovy at 2020 t and saury at 2140 t.) He cautiously speculated that reduction of the populations of barracouta, kahawai, gemfish, and skipjack and albacore tuna from commercial fishing may have

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allowed the small pelagic prey species (pilchard, anchovy, jack mackerel, saury, and squid) to increase in abundance and contribute to the observed increase in the New Zealand gannet population during recent decades. The predator-prey relationship in marine ecosystems is complex, however, and not well understood. More recently, Bunce & Norman (2000) reported that gannets in southern Australia switched – apparently successfully – to other prey species, particularly barracouta, following the natural mass mortality of pilchards in 1998 (see also Section 4.12). However, Dann et al. (2000) attributed an increased mortality of blue penguins in Bass Strait, and a reduction in their breeding success, to the mass mortality of pilchards there in 1995. The situation in New Zealand is unclear. Taylor (1997) hypothesised that the unusually large number of gannets washed ashore on west Auckland and Northland beaches from August to October 1995 was due either to a period of strong south-westerly winds or to the pilchard mortality event then in progress. Ingrid Visser, Whangarei (pers. comm.) noted large numbers of malnourished and dying blue penguins on the east Northland coast when the pilchard die-off was occurring there in 1995. However, the mortality pattern of blue penguins, particularly fledglings, is complex and variable on the north-east coast (Powlesland 1984).

Beckley & van der Lingen (1999) reviewed the role of pilchard as a prey species in South African waters. Based on the results of other workers they recorded 3 shark species whose diets were dominated by pilchards: great white sharks (*Carcharodon carcharias*), copper shark (*Carcharinus brachyurus*), and blacktip shark (*Carcharinus limbatus*); 11 fish species: barracouta (*Thyristes atun*), geelbek (*Atractoscion aequidens*), dusky shark (*Carcharinus obscurus*), skipjack tuna (*Katsuwonus pelamis*), garrick (*Lichia amia*), elf (*Pomatomus saltatrix*), Atlantic bonito (*Sarda sarda*), yellowtail kingfish (*Seriola lalandii*), hammerhead shark (*Sphyrna zygaena*), and tunas (*Thunnus* spp.); 3 seabird species: Cape gannet (*Morus capensis*), Cape cormorant (*Phalacrocorax capensis*), African penguin (*Spheniscus demersus*); and 1 seal species: Cape fur seal (*Arctocephalus pusillus pusillus*); for which pilchard provide an important component of the diet; and noted that two fish genera: hakes (*Merluccius* spp.) and skates (*Raja* spp.) and 5 cetacean species: Bryde's whale (*Balaenoptera edeni*), Heaviside's dolphin (*Cephalorhynchus heavisidii*), common dolphin (*Delphinus delphis*), dusky dolphin (*Lagenorhynchus obscurus*), and bottlenose dolphin (*Tursiops truncatus*) occasionally feed on pilchards.

4.9 Ecology

In the main eastern boundary current systems of the world, the fish fauna is dominated by just a few species, including four types of small pelagic fish: pilchard, anchovy, mackerel, and jack mackerel (Bakun & Parrish 1980, Parrish et al. 1989).

It has been suggested that pilchards occupy a pivotal position for energy transfer in the food web they occupy (Cole & McGlade 1998). They feed on many species, and are in turn preyed on by many others, but there are few fish species of similar size that share their position on the food web. This model has been termed the 'wasp-waist' (J. Rice pers. comm. in Bakun 1996, Cury et al. 2000), which describes the pilchard's position as a narrow channel of energy flow between primary production and various molluscan, teleost, avian, and mammalian groups (Cole & McGlade 1998, Ward & Jones 1998, Gaughan et al. 2000).

Bakun (1996) extended this model to include the regime shifts mentioned above, so that the midtrophic level of a wasp-waist system is usually dominated by one of the phytoplanktivores (pilchard, anchovy, or, in some cases, menhaden species, e.g., *Brevoortia tyrannus*) at any particular time. The trophic dynamics of these systems are mostly dominated by the extreme variations in population size typical of these mid-trophic-level species, which strongly impact on the trophic levels both above and below. Weak links in their life cycles offer potential "reflex points" for environmental

variability "to exert direct control on their population dynamics, and thus on the trophic dynamics of the entire ecosystem" (Bakun 1996).

Kawasaki & Omori (1995) presented a possible model for fluctuations in the Japanese pilchard population. They suggested four phases. The "coastal phase" is characterised by small numbers of large, high-quality fish; the "oceanic phase" is the opposite extreme with "enormous numbers of small, low-quality fish" and represents the maximum population level at the height of a pilchard "bloom". Following the bloom is the "falling phase", which is density dependent and characterised by "ineffective offshore spawning and recruitment failure resulting from low-quality parents". The opposite extreme in this case is the "rising phase", which is density independent, occurs as a result of changes in global climatic patterns leading to intensified upwelling and oceanic turbulence, and is characterised by increased primary productivity. Within this system the pilchard can survive as small coastal remnant populations, then, under favourable conditions (increased temperature, or higher density or quality of preferred prey) undergo a population explosion, which either generates just a few strong year classes, or can build to a solid biomass of many year classes, that roll over sustainably until the system becomes resource-limiting and the falling phase occurs with its huge reduction in biomass. Figure 4 shows that the rising phase of one mid-trophic-level, wasp-waist species can begin before the dominant species enters its falling phase.

There are probably several factors which, in combination, give rise to strong year-classes of pilchards. One that has been associated with high survival of late stage larvae in the California Current is the presence of offshore mesoscale eddies (Logerwell & Smith 2001). Once strong year-classes have been generated, other factors become involved in the population's rise to temporary dominance in the small-pelagic ecosystem.

4.10 Fishing mortality (F)

A number of values for F are available from the literature. MacCall (1979) used simulations to estimate the maximum constant fishing pressure that the Californian fishery could sustain as 0.25. Salazar et al. (1984) estimated values from 0.18 to 0.25 for the pilchard fishery in northern Chile, with the highest values corresponding to the oldest age groups. Nevarez-Martinez et al. (1999) proposed a value of F less than 0.25 for the Gulf of California Pacific sardine stock.

Ware (1999) reported that the California fishery was exploited at an average rate of 5–15% (mean 10%) of the biomass available to it, and suggested that the Canadian harvest should be at the lower end of this range.

4.11 Movement and behaviour

Baker (1972) reported pilchards to be present as visible surface schools in the Marlborough Sounds and Tasman Bay from October to March. During the winter months many subsurface schools of fish were detected by echo-sounder, but the relative abundance of pilchards among sprats, anchovies, and perhaps juvenile jack mackerels could not be determined. He attributed the paucity of published reports of the presence of pilchards in winter months throughout their New Zealand range, to their adoption of a demersal phase during this time.

4.12 Natural mass mortalities

Pilchards (*Sardinops neopilchardus*) are among the clupeoid fishes which suffer periodic epizootic mass mortalities and strandings (Hine 1995, Smith et al. 1996, Jones et al. 1997). A large-scale event

occurred in Australia from March to September 1995, across the entire range of the species there, and in New Zealand from June to September of the same year. Jones et al. (1997) commented "... to our knowledge this is the largest mortality event ever recorded in any fish species in terms of both numbers affected and geographic range." It was concluded that a hitherto undetected herpesvirus was closely involved and most probably the causative agent (Smith et al. 1996, Whittington et al. 1997, Hyatt et al. 1997, Jones et al. 1997).

Reviews of the available information concluded that the origin of the herpesvirus involved in both countries may never be known, but possibilities for its appearance in Australia included transport on migratory birds, in ballast water, or imported baitfish, and that it may have arrived in New Zealand via imported frozen pilchard bait from Australia (an alternative possibility is via gannets). The spread of the disease in both countries was extremely rapid, usually greater than pilchard swimming speed or the likely movement of currents, and the involvement of a vector such as marine mammals or seabirds (e.g., gannets) was suspected. Murray et al. (2000) have developed models to determine key parameters in the spread of the Australian herpesvirus epidemics, with the objective of being able to predict the response, if any, of an epidemic to management actions and other changes in the environment.

Mortalities were restricted to fish above the size of maturity (11–12 cm), but the link between the disease and reproductive state (perhaps a suppressed immune function) is only speculative (Jones et al. 1997, Fletcher et al. 1997). In New Zealand, only adult pilchards (over 9 cm long) were affected, and the possibility that the disease was associated with toxic algae (adult fish are reputed to feed more intensively on algae than are juveniles, but see Section 4.7) was considered and discounted; if toxic algae were involved, species other than pilchards would almost certainly have been affected (Smith 1995). However, the death of a relatively small number of pilchards in Wellington Harbour in 1993 was attributed to suffocation (gill clogging) by a microalga (Jones & Rhodes 1994).

A smaller mortality event, apparently due to the same or similar herpesvirus, occurred in Australia in 1999 but this time it did not reach New Zealand. The origin of the virus was unknown, though there was strong speculation it was linked to the importation of frozen pilchard as foodstuff for sea-cage fish farms (Gaughan et. al. 2000).

Smaller mortalities and/or strandings have occurred in Australia (Copas 1982) and New Zealand (Sutherland 1885, Thomson 1892, Phillips 1929, Graham 1956, Smith et al. 1995) in previous years, but it is not known how many were disease-related — some almost certainly were not. The stranding/mortality reported by Sutherland (1885), that "tons of them [pilchards] are on the beach in Freshwater Basin [near Milford Sound]" may have been caused by the fish entering freshwater. An event at Picton in the 1920s was described by Phillips (1929) as disease-related, though without explanation, and resulted in pilchards actively "jumping to land".

Although very large numbers of pilchards were killed by the 1995 event in New Zealand, it is not known what proportion of the population was lost. Estimates for Western Australia by Fletcher et al. (1997) indicate a total mortality of 8000–10 000 t across all zones, which equated to an overall decline in the spawning biomass of about 10–15% (Gaughan et al. 2000). The 'best' estimate of mean mortality by Gaughan et al. (2000) for Western Australia during the second event in 1999 was, based on counts of pilchards on beaches and the sea surface in the two areas considered to be most representative, about 70%, although it was lower (about 25%) for a bootstrapped 95% confidence level. Daily egg production method surveys were used in South Australia for the second event (Ward & McLeay 1999), which suggested that 60% of that stock was killed. Gaughan et al. (2000) concluded that the Western and South Australian stocks "should be considered to be depressed and, at best, in a period of regrowth if the combined effects of the variables able to influence recruitment strength have been favourable". It appears that the New Zealand stock has recovered, but the speed and extent of this recovery cannot be quantified.

4.13 Pilchards and New Zealand oceanographic conditions

An area of high abundance of pilchard in New Zealand is the northeast coast (North Cape to the Hauraki Gulf). In this region, current-driven upwellings caused by the East Auckland Current, and wind-driven upwellings under northwesterly conditions (particularly during *El Niño*), occur along the shelf edge and transfer nutrients from the sea-floor of the upper slope up and onto the shelf (Zeldis et al. 1998, 2000). This environment seems similar to that of the main global pilchard fisheries, but there may be important differences, such as the strength and seasonality of these upwellings, which prevent direct comparison of the abundance, seasonality, and sustainability of New Zealand pilchard stocks with those elsewhere.

The importance of these upwellings to the abundance of New Zealand pilchards has not been studied but is probably related to the availability of food, with different prey items being preferred by different pilchard life-history stages and therefore required at different times throughout the year. Pilchard spawning is known to occur in the areas of the outer Hauraki Gulf investigated by NIWA (Zeldis et al. 1998, 2000), and further north (Crossland 1982) where upwelling is known but not well studied. Diatoms, an important prey item of adult pilchards, were the largest phytoplankton group recorded across the shelf during spring 1996 in the outer Hauraki Gulf (Chang 2000). See also Sections 4.3, 4.7, and 4.9.

4.14 Size and number of pilchard schools

School size and the number of schools were important factors in early attempts to guess the abundance of pilchards in New Zealand (Slack 1969, Robertson 1978). Some estimates of pilchard school size are available from the MFish aerial sightings database (*aer_sight*), which contains records of sightings of pelagic-fish schools by pilots flying small aircraft and assisting with purse-seine fishing operations (Taylor 1999). Because this database does not include purse-seine vessels targeting pilchards, they have only been recorded incidentally, and there is less information available on this species than the main purse-seine target species, skipjack tuna (*Katsuwonus pelamis*), kahawai, blue mackerel (*Scomber australasicus*), and jack mackerel.

However, there are enough data to determine a rough estimate of the size of pilchard schools, although these estimates must be treated with some caution. The original estimates made by pilots are not subject to the same cross-checking as species that are targeted, where the accuracy of a pilot's estimates of school size can be checked by comparing it with the tonnage of schools caught by the vessels. This cross-checking also applies to species composition of the school. In this way pilots initially develop their estimating procedure, and then maintain its accuracy, a skill which is fundamental to successful operation of the fleet. Because pilchards are not fished, pilots do not receive feedback on school size and species composition from the vessel, and their estimation procedure can only be based on approximations to other species.

Size range of pilchard schools from the database were summarised by quota management area (QMA) and pilot. The minimum and maximum school size in a sighting are given in Table 4, together with the total number of schools and sightings recorded. Each sighting comprises a number of schools, so that the values presented are means of school size. Assuming that pilots can translate the knowledge they have of the target species to estimating size and composition of pilchard schools with some acceptable level of accuracy, we can summarise the data as follows:

- Most schools are in the 5–30 t range.
- An appreciable number are in the 25–50 t range.
- Sometimes larger pilchard schools are seen.

Table 4: Data on pilchard (*Sardinops sagax*) school size. "Minimum size", "maximum size", and "number of schools" are mean estimates for all sightings by pilot in each quota management area (QMA) and "number of sightings" is the total number of sightings of pilchards recorded in the aerial sightings database by each pilot recording pilchard sightings, for each QMA since 1976. A sighting can be made up of any number of schools (source: Aerial sightings database).

QMA	Pilot	Minimum size (t)	Maximum size (t)	Number of schools	Number of sightings
1	2	30	50	2	1
1	6	10	11	2	2
1	9	101	103	19	3
2	9	11	17	26	2
7	8	6	28	17 021	128
7	10	8	34	51	4
7	18	5	16	193	9
7	22	24	49	2 621	8
8	8	5	10	10	1

The number of pilchard schools recorded in the aerial sightings data is sometimes very high. Figure 17 is a frequency distribution from the records of pilots 8 and 22, mostly of observations in the Golden-Tasman Bay area between 1989 and 1995. Individual sightings range from a single school to one where 1000 schools were estimated. There is no way that the error in these estimates can be determined, nor can the accuracy of the species identification be tested, but it seems that there are times when pilchards are seen at the surface in high numbers.
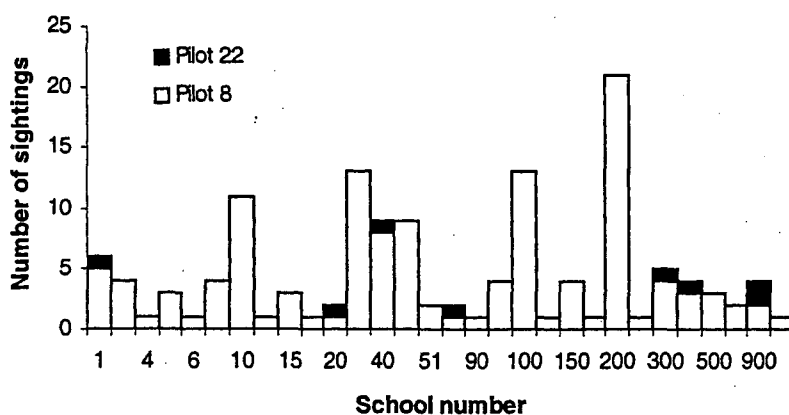

Figure 17: Distribution of the frequency that aerial sightings of pilchard schools are made up of particular numbers of schools. The scale of the X axis is not regular; its last three labels are 800, 900, and 1000 schools (source: Aerial sightings database).

5. STOCK ASSESSMENT

5.1 Previous yield estimates

The yields of 6000 and 9000 t for the New Zealand pilchard fishery proposed by Slack (1969) and Robertson (1978) respectively (Section 4.2) are based on extrapolations from a relatively small area of known high abundance. Slack's original estimate was extrapolated from counts over about one quarter of the total area of Tasman Bay and the Marlborough Sounds, by multiplying to the total area of sea in this region under the assumption that pilchard schools were distributed evenly throughout the total area. There is no way to determine the accuracy of this assumption.

Other values used in these yield estimates are reasonable. Values of F presented in the literature (0.18–0.25), are similar to the exploitation rate of 25%. Later estimates of school size, based on aerial sightings data (see Section 4.14), are greater than those used in this estimation procedure, and Tunbridge's (1969) school sizes from echo traces did indicate some large schools present in the Tasman Bay area.

5.2 Acoustic and egg and larval surveys

Because of the mobility of pelagic fish stocks both vertically within the water column, and geographically between areas, an almost complete lack of information on the factors causing their presence at the sea surface, and the tendency for catch rates to remain high when abundance is low (i.e., "hyperstability" (Cochrane 1999)), stock assessments incorporating abundance indices from catch per unit effort (CPUE) are likely to be unreliable. Abundance indices from fishery-independent sources are highly desirable.

Early attempts during the 1980s at setting a Total Allowable Catch (TAC) for anchovy and pilchard stocks in the South African fishery were based on indices of abundance from CPUE trends (Barange et al. 1999). However, variations in availability were a serious limitation to explaining distribution and migratory patterns, and to determining the age structure of the population (Hampton, 1987). More recent research by Hampton (1992) has shown that the pelagic fishery failed to sample older fish of both species and that CPUE values from the commercial fishery were not proportional to abundance. In 1983 a programme of fishery-independent acoustic surveys was initiated, and since 1995 these survey results have been used as a basis for setting TACs.

Two procedures are available which can determine the biomass of pilchards at a particular point in time: (1) egg and larval surveys – either estimating the biomass (or relative biomass) directly from the areal extent of eggs and larvae, or calculating the biomass using a number of reproductive parameters and the 'Daily Egg Production Model' (DEPM); (2) acoustic surveys – calculating the biomass from the sum of echoes received from identifiable pilchard schools. One or both of these approaches has been used to measure and monitor the biomass of stocks contributing to the larger pilchard fisheries of the world.

Acoustic surveys are used in New Zealand for a number of QMS species and NIWA has developed considerable experience in the field. To date however, there has been little attention paid to pelagic species, except for two experimental surveys of pelagic fish in Hawke Bay 1980: (Francis 1985), which mentions pilchards but does not quantify them, and a survey of jack mackerel in Taranaki Bight in 1984 (MFish unpublished data).

A tradeoff exists between the use of DEPM and acoustic surveys (Cochrane 1999). Where acoustic surveys should provide a more precise estimate of abundance, it is likely to be biased, usually negatively, thus providing an under-estimate. In contrast, DEPM estimates should be unbiased, but

their precision is low. In South Africa the two methods are used together for anchovy (and possibly for pilchard as well, although it is unclear from the literature), and the data modelled to estimate the value of key parameters and variables (Butterworth et al. 1993).

These surveys are costly and time consuming. An important consideration is the frequency with which they should be performed. Although a single survey would certainly provide a good basis for future work (see Cochrane 1999), these methods provide only a snapshot, and the high variability likely to exist in the New Zealand pilchard stock will require regular monitoring if reliable abundance indices are to be developed. As a prerequisite, spawning seasons and areas would first need to be identified.

5.3 Biomass estimates

Estimates of current and reference biomass are not available.

5.4 Estimates of Maximum Constant Yield (MCY)

MCY for pilchards cannot be determined. Biomass estimates are not available, and there are no appropriate data from the fishery which would enable the method $MCY = cY_{av}$ to be employed. The fishery is under development and has only a short catch history, and because pilchards are a schooling species, and/or attracted into an aggregation for capture, there is no reliable information on changes in effective fishing effort, or on mortality over the history of the fishery. Even in the longer term, this method of determining MCY is likely to be unreliable.

5.5 Estimates of Current Annual Yield (CAY)

At present CAY cannot be determined.

5.6 Factors modifying yield estimates

5.6.1 Fluctuations in population size

The "regime problem" and "recruitment problem" (see Section 2.3) are interrelated. Despite considerable research over recent decades in many parts of the world, uncertainty remains over their cause and nature. The very large fluctuations in the population size of clupeoid stocks are probably the greatest for any group of fishes. These fluctuations are generally considered to be environmentally driven, but there are also claims (e.g., Beverton 1990) that they result from excessive fishing pressure on naturally declining stocks, "excessive" in the sense that these schooling fishes can still be easily targeted, with modern techniques of location and capture, at relatively low stock sizes.

Among the environmental (i.e., natural) causes proposed for changes in population size (from one or more year-class failures up to long-term alternations between dominant species – usually pilchard and anchovy – in the ecosystem) are the following.

- **Temperature.** It has been suggested that pilchard populations are more successful at higher temperatures, anchovy at lower (Cole 1999).

- **Food.** The favoured prey items of pilchard (phytoplankton, microzooplankton) are smaller than those favoured by anchovy. An environmentally driven change in the species or size composition of the prey community may influence the relative survival of pilchard and anchovy.

- **Episodic mortality.** The sudden loss of a substantial part of a stock to disease, environmental catastrophe (e.g., an altered pattern of upwelling, or a change in the direction and strength of coastal currents), or some similar event, may not only produce one or more poor year-classes, but create a niche into which an alternate species can move and become dominant. Heavy predation by larger fish which become suddenly or locally abundant (though over a moderately large area) may have a similar effect.

- **Strong year-class effects.** One or more particularly strong year-classes of pilchard may enable that species to become dominant, perhaps through predation on the egg and larval stages of the other.

- **Quality of the spawning stock.** It has been suggested by Kawasaki & Omori (1995) that a cycle of abundance commences with the production of high-quality eggs from a relatively small adult stock, and these eggs and larvae have a high survival rate (adult quality and spawning success both linked to an environmental factor, and density-independent). This progressively produces a larger stock of fish, until a point is reached when the very abundant adults produce low-quality eggs with poor survival (density-dependent).

Some of these potential causes are gradual, and there would be a threshold position at which one species would gain ascendancy, either suddenly or gradually, over the other. Others are abrupt or episodic, and the shift from one ecosystem state to another, or the replacement of the dominant species in the ecosystem, would occur rapidly. Many of these events are interdependent, and/or correlated, and identifying the primary cause for a change in population size has proved to be exceedingly difficult. For example, the decline in the Japanese stock of pilchards in the early 1990s resulted from recruitment failure of four successive year-classes; these appeared not to be caused by a failure of spawning success, or of egg and larval survival to the first-feeding stage, but to some unknown event, or environmental condition, in the Kuroshio Current during the period from post-larval life to age 1 (Watanabe et al. 1995). There is an extensive and rapidly growing literature on the topic of clupeoid recruitment patterns, shifts in climatic, oceanographic, and ecosystem regimes, and major fishery fluctuations, the most recent including Fukushima & Ogawa (1988), Lluch-Belda et al. (1989), Kawasaki (1991), Butler (1991), Smith et al. (1992), Kawasaki & Omori (1995), Lo et al. (1995), Watanabe et al. (1995), Cole (1999), Schwartzlose et al. (1999), and Yasuda et al. (1999).

This present account does not attempt to draw any general conclusions from these studies, or to assess the most likely cause(s) of population fluctuations which have in the past, or might in the future, occur in New Zealand. It does, however, draw attention to them.

6. MANAGEMENT IMPLICATIONS

Pilchard stocks typically vary greatly in size (biomass), and sometimes also in their distribution. As a stock increases, it tends to extend over a broader geographic area. There are two consequences for biomass estimates. (1) Biomass estimates based on such procedures as acoustic surveys and the daily egg production method can produce a measure of the stock's size only at that point in time, a "snapshot". (2) Potential differences in geographic distribution of the stock being assessed at different times must be taken into account; repeat surveys must be of the stock, and not necessarily of the same geographic region.

For robust assessments, regular monitoring is required. Catch trends alone, and even CPUE, are likely to be only broadly indicative of changes in stock size, given the specific targeting nature of the gear (purse-seine and lampara nets) used in the fishery. Catches and CPUE will remain high even as the biomass declines.

Monitoring incoming recruitment, from age 1 onwards, may be moderately successful in predicting the state of the stock in the short-term. There is a very low probability of being able to predict a stable and safe longer-term yield. There is greater likelihood of successful management of the pilchard fishery under a CAY regime, rather than an MCY regime, although some form of CAY management will require more frequent monitoring of the stock. An alternative would be to adopt a very conservative MCY.

Schwartzlose et al. (1999) pointed out that for species with a very widely fluctuating biomass it is important to maintain the "abundant phase" of the cycle for as long as possible. They suggested that heavy fishing has the potential to decrease the magnitude and duration of the peaks of abundance, and to depress and prolong the troughs. Their worst-case scenario is for a continued high level of fishing to prevent recovery, even of a theoretically productive species such as pilchard, and greatly extend the period of low abundance.

This conclusion reinforces that of Beverton (1990), who noted that for fisheries of small pelagic species like herring, mackerel, anchovy, and pilchard, "there is a tendency for the most severe decline to be followed by the slowest recovery". The Californian pilchard stock, for example, declined steeply to less than 0.4% of its peak in the mid 1960s, and remained at this level for 20 years before there was evidence (from larval surveys) of recovery (MacCall & Prager 1988). Further north, closer to the extreme of the pilchard's geographical range, the overall decline in the North American stock impacted even more strongly on the fishery. Its greatest affect (in terms of time) was on the Canadian (British Columbian) fishery, which showed no evidence of recovery for almost 50 years after its decline in 1947 (Ware 1999).

The cautionary implications of these studies are clear — overfishing (probably in association with natural declines) can have long-lasting effects on the abundance of pilchards. Recovery has certainly occurred in the fisheries that have been investigated, but it can be very slow, particularly in areas closest to the limit of the pilchard's range.

Extrapolating from these overseas fisheries to New Zealand is not straightforward. The statements of Beverton (1990) and Schwartzlose et al. (1999) are based on trends in large stocks within large ecosystems, and not necessarily on the smaller, coastal populations that the New Zealand pilchard may prove to be. However, any fisher considering investing in a pilchard fishery, and any fisheries manager faced with the task of setting a sustainable yield, should keep in mind the landing trends illustrated in Figure 4.

In a broader context, it is difficult to unravel the impact of fishing on pilchards from their other, "natural" characteristics, particularly their high level of natural mortality and susceptibility to environmental changes. There is considerable interaction between all these, which can cause declines in abundance to accelerate. It is probably appropriate, therefore, to regard pilchard stocks as "unstable". Fishing contributes to this instability, but is not usually the principal cause.

In well-managed fisheries for perhaps most fish species, there is an initial fishing-down phase followed by a relatively stable fishery which can take a sustainable level of surplus production from the stock. In pilchard fisheries, however, catches necessarily track the natural and often large changes in biomass, and what may appear to be the normal "fishing-down" phase of a fish stock may be the "falling phase" of a natural cycle in pilchard abundance as postulated by Kawasaki & Omori (1995). In such a case, there will not be a single, sustainable level of surplus production. In years when pilchard are abundant there will be a high potential yield. As abundance declines, the yield must also decline, and it must be reduced rapidly enough to avoid driving the stock below the level from which recovery will be very slow.

Consequently, setting a reasonable level of exploitation is more difficult than usual. Because pilchard stocks are unstable and somewhat unpredictable, there is a need to be cautious until fishery indicators

are developed that enable management (and catches) to follow the natural fluctuations. Development of the fishery should be encouraged to ensure that surplus production is utilised, but the risk of overfishing leading to a diminished stock with a potentially long recovery time also needs to be recognised.

7. RESEARCH RECOMMENDATIONS

Almost all the research on pilchards undertaken elsewhere has been based on large stocks, within large pelagic ecosystems, which undergo moderate short-term and significant long-term variability. Although this should be kept in mind when developing hypotheses for research projects in New Zealand, it must also be recognised that the situation here may be rather different. The pilchard stock off northeastern New Zealand does seem likely to be influenced by upwellings and other features of the East Auckland Current, but it may otherwise be more limited by coastal marine processes.

- **Reproductive cycle.** As a precursor to developing any stock assessment procedure based on egg and larval surveys, information is required on the spawning season, and main spawning grounds, of pilchard in northeastern New Zealand.

- **Biomass estimation by the Daily Egg Production Method (DEPM).** This approach generates estimates which have a relatively low precision but are unbiased. They are considered to have been useful in assessment of the Western Australian pilchard stocks, but they require good knowledge of the spawning area and season, and very careful statistical design.

- **Biomass estimation by egg and larval surveys of spawning grounds.** This approach relates the area of spawning to the size of the spawning stock, and has mainly been used in the Californian fishery. It requires good knowledge of the reproductive cycle, fecundity, sex ratios etc., and the distribution of spawning grounds, is probably better at measuring relative rather than absolute abundance, and because of its relatively high cost is likely to be most effective for large fisheries.

- **Biomass estimation by acoustic surveys.** This procedure has been used in conjunction with the DEPM in the South African fishery. It tends to give a more precise estimate of abundance than the DEPM, but one that is typically biased towards an under-estimate. Consequently, it is appropriately used together with another method. NIWA has considerable expertise in undertaking acoustic surveys of middle depth and deepwater fish stocks, and it would be theoretically possible to use acoustics for pilchard assessment. Some experimental work would first be required on target strength, and the issue of distinguishing pilchard schools from other small pelagic fishes would need to be resolved.

- **Age estimation by otolith weight.** This procedure has proved successful in Australia, and could be useful in New Zealand to (a) determine whether the age structure of the pilchard population (or population) was uniform over the entire area of the fishery, and (b) monitor the relative strength of year-classes recruiting into the fishery. It requires an initial validation study which compares modes in otolith weights with the result of counting otolith rings, and preferably also follows the progression of otolith weight modes through an annual cycle. If the growth pattern of pilchard is suspected to vary across the geographical range of the stock being commercially exploited, this should be examined during an initial ageing study, and if necessary more than one otolith weight/age key established.

- **Physiological condition from lipid content.** A key point in the work by Kawasaki & Omori (1995) is the difference in condition between individuals in the large, widely distributed population at the peak of the population cycle (the "bloom"), and those in the small, remnant coastal population. This condition is characterised by the lipid content of the fish, and could be

quite easily monitored. The first objective of this work would be to determine whether lipid content could be used to as an indicator of the population cycle the New Zealand pilchard was in (in theory, lipid-rich = expanding, poor = contracting).

- **Escapement mortality.** When relatively small purse-seine vessels capture schools that are larger than anticipated, some of the school may have to be released from the net. It is not known to what extent this occurs in New Zealand, and whether this leads to measurable levels of mortality. Pilchards are particularly fragile, and there could be considerable mortality from net damage. It is therefore recommended that school-release be monitored and/or reported.

- **Feeding study.** Although this may not seem particularly relevant to fisheries management, it has more than just an academic element. There are many unknowns in the feeding regime of pilchards, but a growing consensus that in highly productive regions of the ocean, where a large stock of pilchards exists or is developing, adult pilchards switch to filter-feeding on microalgae, particularly diatoms. In less productive (or variable) areas, pilchard tend to remain feeding on microzooplankton, particularly copepods. Knowing whether adult New Zealand pilchards were feeding predominantly on zooplankton or diatoms could, in association with other factors, give some indication of whether they were a relatively limited stock sustained by the coastal plankton, or a large and/or increasing stock utilising the higher productivity of upwellings along the edge of the rather narrow northeastern shelf. Such a feeding study would probably be most appropriately undertaken by an Honours or Masters student at the University of Auckland, if support was given by the Ministry of Fisheries and by commercial pilchard fishers. It could be integrated with more basic research on the rather variable oceanography and productivity of New Zealand's north-eastern shelf and upper slope waters currently being undertaken by NIWA.

- **Year-class strength monitoring.** In many, probably most (and certainly the largest), pilchard fisheries, stock size is very strongly influenced by recruitment. In association with a study on ageing, the relative abundance of year-classes in the commercial catch, and also those about to enter it, should be monitored. This would involve regular and appropriate sampling of the catch, either at sea, or upon landing if an appropriate sampling protocol of the cartoned product can be established. This work might also require some at-sea work on commercial vessels (with the cooperation of the industry), to determine whether it is possible – in some standardised way – to sample the smaller fish (1+ and 2+ pre-recruits) which are not normally targeted by fishers.

- **Viral mortalities.** A contingency plan should remain in place to monitor any future mass mortality and collect samples for forensic analysis. Any geographic links with usage of imported pilchards (as bait) should be recorded. Although estimates should, if possible, be made of the geographical extent of the mortality, it will be difficult to assess its magnitude, and in particular, its impact on pilchard biomass. In Western Australia it has been recommended that a new biomass assessment should follow any major mortality event, and if it does prove feasible to undertake biomass estimates of the New Zealand stock, similar post-event biomass surveys should be considered here.

8. ACKNOWLEDGMENTS

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