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EXECUTIVE SUMMARY

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New Zealand queen scallops (*Zygochlamys delicatula*) are a small pectinid species found on the mid to outer continental shelf of the southeastern coast of the South Island and around the sub-antarctic Islands. They occur in high densities off Otago.

A small trawl fishery for New Zealand queen scallops developed off the Otago coast, Fisheries Management Area 3 (FMA 3) in the 1984–85 fishing year, by vessels from Port Chalmers. In the 1992–93 fishing year, a single vessel from Bluff fished between Slope Point and the Nugget Point in FMA 5. In the 1999–2000 fishing year, five vessels have fished New Zealand queen scallops suggesting renewed interest in this fishery. Reported landings peaked at 711 t in 1985–86 (Fisheries Statistics Unit (FSU) data) and in recent years have been about 100–200 tonnes a year. The competitive Total Allowable Commercial Catch (TACC) of 750 t green weight introduced in the 1990–91 fishing year was probably derived from the peak catch in the mid 1980s and has never been fully caught.

The state of the stock cannot be determined from the data available. The number, relative population size, and distribution of high density patches of New Zealand queen scallops that would support fishing is unknown, as is the impact of fishing on them. Development of the fishery was reportedly constrained by marketing and processing and low returns from the fishery. Renewed interest in the fishery in the 1999–2000 fishing year saw five new permits issued. A moratorium on the issue of new permits was invoked in 2001.

Little is known about the biology of New Zealand queen scallops. There are spawning events in spring and summer, and complete spawning in the autumn. The larval life of New Zealand queen scallops is estimated to be about 40–50 days, suggesting that scallops in the Otago population could recruit from populations up to 300 km upcurrent on the Snares shelf. New Zealand queen scallops are likely to be slow growing because of the low temperatures in the depth range they inhabit. Males reach sexual maturity at about 30 mm in height at age 4 and females at about 40 mm at age 5. They grow to minimum legal size (50 mm in height) in about 8 years and live for more than 10 years.

The close association of bryozoa and New Zealand queen scallops, and the heavy settlement of New Zealand queen scallops on bryozoa, may play an important part in the high densities occurring off the Otago shelf. The incidental removal of bryozoa and may ultimately affect the fishery.

1. INTRODUCTION

1.1 Overview

The New Zealand queen scallop, *Zygochlamys delicatula* (Hutton, 1873), is also known as the southern queen scallop, southern fan scallop and gem scallop. This small pectinid species is distributed on the outer continental shelf along the east coast of the South Island, from Kaikoura to Macquarie Island. A small trawl fishery for New Zealand queen scallops developed off Otago (Fisheries Management Area (FMA) 3) in 1985, (Figure 1) and later (1990) south of Nugget Point in FMA 5. The fishery has remained small with vessel numbers declining to two in the 1997–98 fishing year, one fishing in FMA 3 and the other in FMA 5.

This report describes how the fishery and its management developed, and summarises landings, distribution and abundance surveys, and biological data of New Zealand queen scallops. Most of the information on the abundance, distribution, and biology of New Zealand queen scallops is from unpublished sources. We compare the growth rate of *Zygochlamys delicatula* to other similar pectinid species that support significant commercial fisheries overseas, and discuss recruitment to the Otago population.

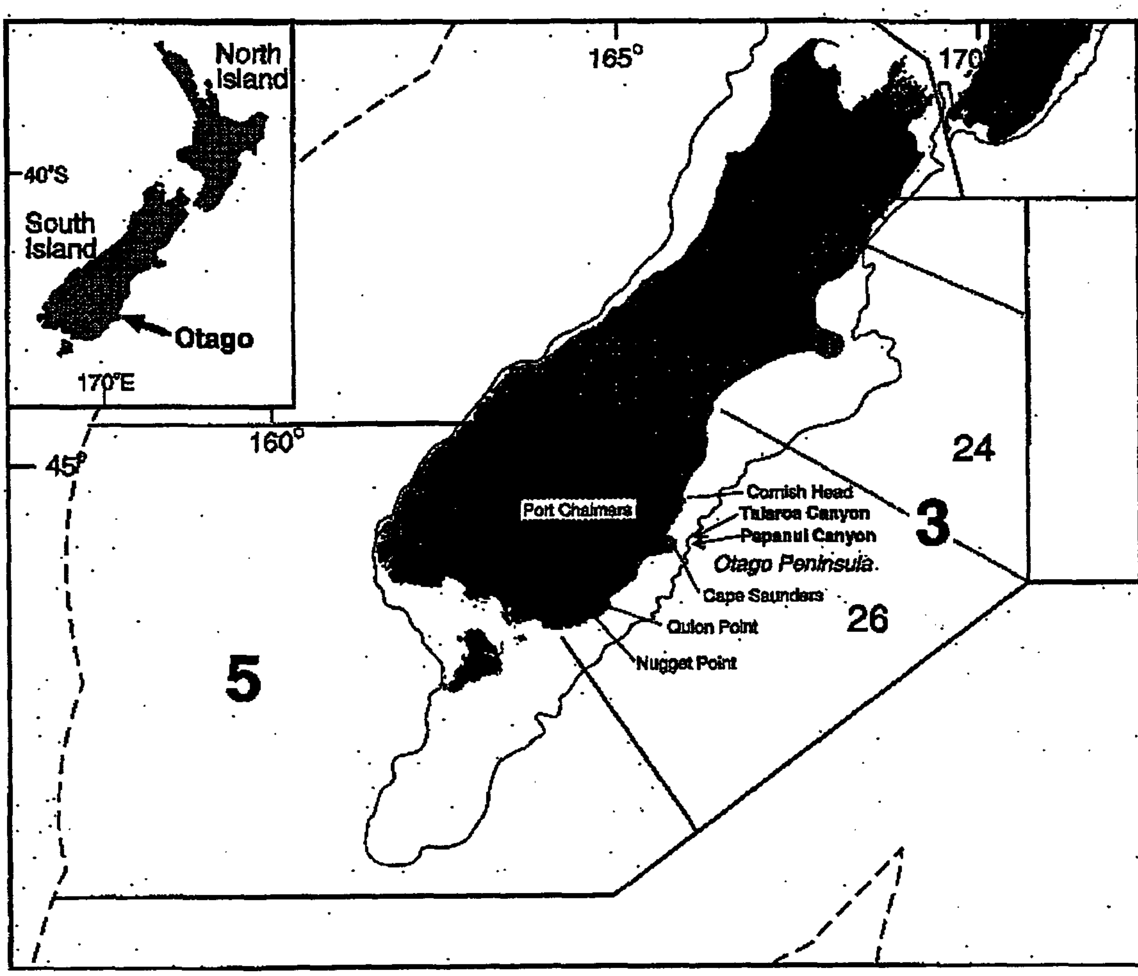

Figure 1: The fishery area for the New Zealand queen scallop (*Zygochlamys delicatula*) and boundaries for Fisheries Management Areas (FMAs), Fishing Return Areas (FRAs), and 200 m contour.

1.2 Description of the fishery

New Zealand queen scallops were first caught as a bycatch of bottom trawling on the continental shelf off Otago in the mid 1970s. A Fisheries Research Division resource survey in 1983 using RV *James Cook* confirmed dense patches of New Zealand queen scallops off Otago. Between 1985 and 1988, experimental fishing by special permit holders led to the development of a commercial fishery.

The number of vessels fishing from Port Chalmers, and total landings of New Zealand queen scallops were highest in the first year (1985–86 fishing year), with almost all of the fishing in FMA 3. Between 1985–86 and 1988–89 there was a steady decline in landings and the number of vessels involved in the fishery. Landings stabilised in FMA 3 between 1988–89 and 1993–94, but declined thereafter. Landings in FMA 5 rose in 1993–94 and have remained steady.

1.3 Literature review

Published information on New Zealand queen scallops consists of four popular articles in *Catch, Professional Fisherman*, and *Seafood New Zealand.* Street & Michael (1985) summarised the results of an exploratory survey off the Otago Peninsula in 1983 and discussed the potential for a new fishery. Lloyd (1987) described a day trawling for New Zealand queen scallops off Otago and mechanical sorting of the catch, and discussed processing and the potential to develop a new fishery. Sanders (1994) gave an overview of the history of the New Zealand queen scallop fishery, processing and research carried out by the Ministry of Agriculture and Fisheries (MAF) and the fishing industry. Street (1996) compared the Otago New Zealand queen scallop fishery with overseas fisheries based on similar species. He gave an update on the fishery including processing and marketing, and discussed management and research needs.

Joan McKay (University of Otago) provided data from an incomplete draft thesis on the relative density, distribution, and population size structure of New Zealand queen scallops from samples caught by dredging between 1976 and 1979. She also investigated changes in reproductive condition and spawning. MFish carried out a resource survey off the Otago coast in 1983 (author's unpub. data) based on McKay's data. This report provides a summary of the relevant information from these studies.

Creswell (1993) briefly summarised some of McKay's' and our unpublished data, provided summaries of landings data from fishing returns between 1987–88 and 1992–93 fishing years, and described the management of the New Zealand queen scallop fishery. In this report, we present all the available information on the history of the New Zealand queen scallop fishery and its management, and updated landings, catch and effort data to March 1997.

We have checked the literature for information on other similar pectinid species: *Argopecten gibbus* (Miller et al. 1981, Costello et al. 1973, Roe et al. 1971); *Argopecten irradians* (Barber & Blake 1983, Castagna & Duggan 1971, Sastry 1963); *Chlamys opercularis* (Le Pennec 1982, Brand et al. 1980, Taylor & Venn. 1978, Aravindakshan 1955); *Chlamys islandica* (Barney et al. 1982, Gruffydd 1976, Wiborg 1963); and *Chlamys varia* (Shafee & Lucas 1980, Rodhouse & Burnell 1978). However, the life histories and productivity of these species differ significantly from *Zygochlamys delicatula* and the information is used here for comparative purposes only.

2. REVIEW OF THE FISHERY

2.1 Data sources

Landings, catch and effort data for the 1985–86 to 1987–88 fishing years were recorded by the Fisheries Statistics Unit (FSU). We have been unable to locate these data. Fishers probably filled out an obsolete Commercial Fisherman's Dredge Return. Landings and catch and effort data for the 1988–89 fishing year onwards have been reported on catch effort landing returns (CELR) and catch landing returns (CLR). These data are available on the Ministry of Fisheries Catch-Effort Database.

Fishing area codes are not standardised. Both FMAs and Fishing Return Areas (FRAs) are used. For simplicity we have used only FMAs in this report as the fishery is managed by FMAs. We have combined all landings, catch and effort data from Fishing Return Areas (FRA) 22, 24, and 26 in the summaries for FMA 3 (Figure 1). Data summaries for FMA 5 include data from FRA 25, 29, and 30. We assumed all data coded under QSC are correct and excluded any data that could not be validated. We ignored data coded as SCA (*Pectin novazealandiae*) from FMAs 3 and 5 and FRAs 24, 26, and 27; data for New Zealand queen scallops (QSC) from outside FRAs 24, 26, and 27, and FMAs 3 and 5, and spurious data that may have been miscoded or punched. Landing information may therefore be incomplete.

Effort data are available for the key vessels, but not recorded by three of the vessels. Processed weight was defined as green weight multiplied by 1.0, but this is possibly landed weight data. Landed green weights and processed weights often differed.

Creswell (1993) reported the main fishing method as bottom trawl, with some dredging. Many CELR returns for dredging give effort width (gear spread) as 12–25 m and bottom trawling width as 12–50 m. Most fishing methods coded as dredging are likely to be bottom trawling.

2.2 The fishery

2.2.1 History of the fishery

Experimental fishing for New Zealand queen scallops on the continental shelf off Otago began in 1985 under a Ministry of Agriculture and Fisheries Special Permit. Between 1985 and 1988, an increase in the number of permit holders led to the establishment of a commercial fishery.

2.2.2 Management

Initially the fishery for New Zealand queen scallops developed in FMA3, with vessels fishing out of Port Chalmers, Dunedin. The size of the fishery was restricted between 1985 and 1988 by limits on the number of special permits. Although 58 permits were issued over this period, the number of vessels fishing (10) was highest in the first year (19856–86 fishing year), declining to three vessels by the 1988–1989 fishing year. Concerns were raised about the sustainability of the resource in FMA 3 if the large number of permits were used. The fishery was gazetted as a restricted fishery under Section 65 of the Fisheries Act (1983) in September 1988. During 1988 and 1989, no new permits were granted. Most fishing permits were reportedly not used over this time because of low returns from the fishery. In December 1990 entry restrictions into the fishery were lifted and the New Zealand queen scallop fishery became an "Open Fishery". A competitive annual catch limit (TACC) was set at 750 t green weight (in FMA 3 only) and a minimum size regulation of 50 mm in shell height (axis of the umbo to the ventral margin) was introduced. No information is available on how this limit was set. The Fisheries Amendment Act (No. 3) was introduced in 1992. Fishers who did not land New Zealand queen scallops between 1 October 1990 and 30 September 1992 had their permits revoked and a moratorium was placed on the issue of new permits until New Zealand queen scallops are bought into the Quota Management System. Currently fishing for New Zealand queen scallops in FMAs 3 and 4 is managed pursuant to the South-East Area Commercial Fishing Regulations of the Fisheries Act 1983 and in FMAs 5 and 6 pursuant to the Southland and Sub-Antarctic Area Commercial Fishing Regulations of the Fisheries Act (Creswell 1993). In FMAs 4, 5, and 6 New Zealand queen scallops are a 'Part A' species and targeting them is prohibited unless authorised. Four new permits were issued in the 1999–2000 fishing year, but a moratorium on the issue of new permits was invoked in 2001.

2.2.3 Fishing methods

Specialised fishing gear has been developed to fish New Zealand queen scallops. The depth (110–170 m), strong currents, and large volumes of epifauna and shell were major problems that had to be addressed in the development of an efficient catching method. Both dredges and trawls were tested during exploratory fishing in 1985–88. Dredges tended to saturate too quickly with shell and epifauna and caught few queen scallops. Trawls caught large numbers of scallops, but also caught too much other material (shell, epifauna, and fish bycatch). The main problem was sorting the enormous volume of the catch. Trawling has since been developed as the method used by all commercial fishers. Initially, trawls used trawl doors developed in the U.S. calico scallop fishery and imported from the U.S. (Sanders 1994). These trawls were towed from a single warp and had a door spread of about 6 m (Lloyd 1987). The ground rope was modified to minimise the catch of shell and epifauna. The trawl was towed at about 2 knots for 1.5 hours. The effectiveness of the initial trawl was increased by the development of new design doors, bobbins on the ground rope, and adding a 'veranda' extension of the headline 1.5 m above and forward of the ground rope. Trawl door spread was increased to 7.5 m. The trawl mesh size was 52 mm and predominantly caught large live New Zealand queen scallops (B. Fairweather, Superior Oysters Ltd, Invercargill, pers. comm.).

Trawl catches are mechanically sorted to remove undersized scallops and shell and epifauna. The catch is emptied into a hopper that feeds a rotary sorter comprising of steel bars orientated length–wise down the revolving cylinder. As the catch is moved from one end to the other, shells, epifauna, and substrate components pass through the grill. Larger items are hand culched before the scallops are packed in bags (Street 1996). The catch is chilled or blast frozen.

CELR data show a significant portion of the catch is reportedly taken by dredging. These data are probably the result of errors in data entry, as fishing since the early 1990s has been by bottom trawling (B. Fairweather, pers. comm.).

2.2.4 Landings

Initial interest in the fishery was high with 711 t (green weight) landed in the first year (1985–86 fishing year) from FMA 3 under special permit (Fisheries Statistics Unit (FSU), unpub. data.). Reported difficulties in marketing New Zealand queen scallops between 1985 and 1989 resulted in a steady decline in landings and the number of vessels involved in the fishery. Most of the New Zealand queen scallop catch was landed in FMA3 until the 1993–94 fishing year. Landings stabilised in FMA 3 between 1988–89 and 1993–94, but declined thereafter. Landings in FMA 5 began to increase in 1993–94 and have remained about 150 t per year.

We were unable to locate catch data from 1985 to September 1989 on FSU tapes or as written summaries and returns. The Ministry of Fisheries holds landings data for the fishing years 1 October 1989 onwards from CELR and CLR returns. A summary of the best available landings data provided by the Ministry of Fisheries is shown in Table 1.

Table 1: Number of vessels and reported New Zealand queen scallop landings in tonnes (t) green weight (LGW) by fishing year (1 October–30 September) 1985–2000 in FMA 3, FMA 5, and all FMAs combined. NA, no data available. Individual vessel data of exploratory fishing by commercial vessels with special permits, 1985-1988 are not available.

Fishing Year	No. of vessels	FMA3 LWG (t)	No. of vessels	FMA5 LWG (t)	No. of vessels	All FMAs LWG (t)
1985–86	NA	NA	NA	NA	10	711
1986–87	NA	NA	NA	NA	NA	NA
1987–88	NA	NA	NA	NA	NA	NA
1988–89[1]	3	34	1	1	3	35
1989–90	6	288	0	0	6	288
1990–91	5	238	1	23	5	261
1991–92	4	194	0	0	4	194
1992–93	4	105	0	0	4	105
1993–94	3	134	0	0	4	134
1994–95	2	147	0	0	2	147
1995–96	2	154	1	1	3	155
1996–97	2	118	1	6	2	125
1997–98	2	208	1	6	2	214
1998–99	5	82	0	0	5	82
1999–2000[2]	2	177	0	0	2	177

1. Estimated catch and reported landings for the 1988–89 fishing year cover only the period from 3 August 1989 to 30 September 1989.
2. Estimated catch and reported landings for the 1999–2000 fishing year cover only the period from 1 October 1999 to 14 May 2000, but the data is assumed to cover the full fishing year.

The Ministry of Fisheries cannot substantiate the total catch for the 1985–86 fishing year. The 1985–86 catch (FSU records) may have been the basis of the 750 t TACC set in 1990, restricting catch to about the peak landings. Total landings data from the 1988–89 to 1999–2000 fishing years show a second peak at over 250 t in 1989–90 and 1990–91, and the number of vessels increased to 6. Landings data (Table 1) and catch effort data (Table 2) differ markedly and are not useful in monitoring the sustainability of the fishery.

The highest monthly landings (up to 50 t green weight) of New Zealand queen scallops are taken between September and February when sea conditions are favourable and market demand highest (Creswell, 1993). New Zealand queen scallops caught from FMA 3 are landed in Port Chalmers and those caught from FMA 5 in Bluff. The average trip duration is 4 days and average catch about 5 t landed green weight per trip.

2.2.5 Reported catches

Reported catch is shown in Table 2. Catch and effort increased in FMA 5 over the 1992–93 fishing year and probably coincides with the closure of the Foveaux Strait oyster fishery that year. Fishing effort (number of vessel days) peaked over the period the Foveaux Strait oyster fishery was closed (1993–

96). Although effort declined after the Foveaux Strait oyster fishery was reopened, reported landings remained constant until the 1998–99 fishing year. An increase in daily catch rate between 1992–93 and 1995–96 may be attributed to changes in fishing methods (probably a change from dredging to bottom trawling).

Most of the catch between 1994–95 and 1998–99 was reported from FMA5 (Table 2) where as almost all landings were reported from FMA3 (Table 1).

Table 2: Total estimated catch of New Zealand queen scallops and number of vessel days by Fisheries Management Area (FMA) for the fishing years 1988–89 to 1999–2000. FMA3 includes FRAs 22, 24, and 26; FMA 5 includes FRAs 25, 29, and 30. NULL denotes neither FRA nor FMA were recorded.

Fishing year	Est. catch FMA 3 (t)	No. vessel days FMA 3	Est. catch FMA 5 (t)	No. vessel days FMA 5	Est. catch NULL (t)	No. vessel days NULL
1988–89	34.9	32	0.0			
1989–90	222.1	122	1.0	1		
1990–91	246.0	140	0.0			
1991–92	189.8	130	0.0			
1992–93	101.3	63	1.4	2		
1993–94	93.3	69	32.4	39		
1994–95	17.2	16	132.0	100		
1995–96	16.5	13	139.5	74		
1996–97	21.6	16	102.5	67	3.1	1
1997–98	57.5	17	156.3	54		
1998–99	9.9	11	61.0	28	7.9	4
1999–2000	176.6	117	0.5	1		

2.2.6 Catch per unit effort

We have no measure of how reliable the catch and effort data available from CELR returns are. Catch rate (kg per hour) dropped steadily from the 1991–92 fishing year to 1993–94 before increasing steadily in FMA 3 (Figure 2). There is no information available on what caused the dip in catch rate. Catch rate in FMA 5 increased steadily since the 1991–92 fishing year. Vessels currently fishing New Zealand queen scallops have been involved in the fishery for at least six years and an increase in their operational efficiency may be responsible for the increase in catch rates.

Annual catch (t) follows the same trend as mean number of vessel days fished in both FMAs 3 and 5 (Figures 3 and 4). Since the 1992–93 fishing year, both annual catch and mean number of vessel days fished have decreased in FMA 3 and increased in FMA 5. The decrease in catch and effort in FMA 3 could reflect marketing and price consideration and or stock depletion.

2.2.7 Bycatch

The five most significant reported bycatch species caught by weight (t), for all years combined since the beginning of the 1993–94 fishing year are in order of importance: red cod (4 t), ghost shark (3 t), ling (2t), stargazer (2 t), and rough skate (1 t). The totals for all other species over this time are less than 1 t. Developments in fishing technology have reduced bycatch to a low level and this level of bycatch represents a small proportion of the total catch.

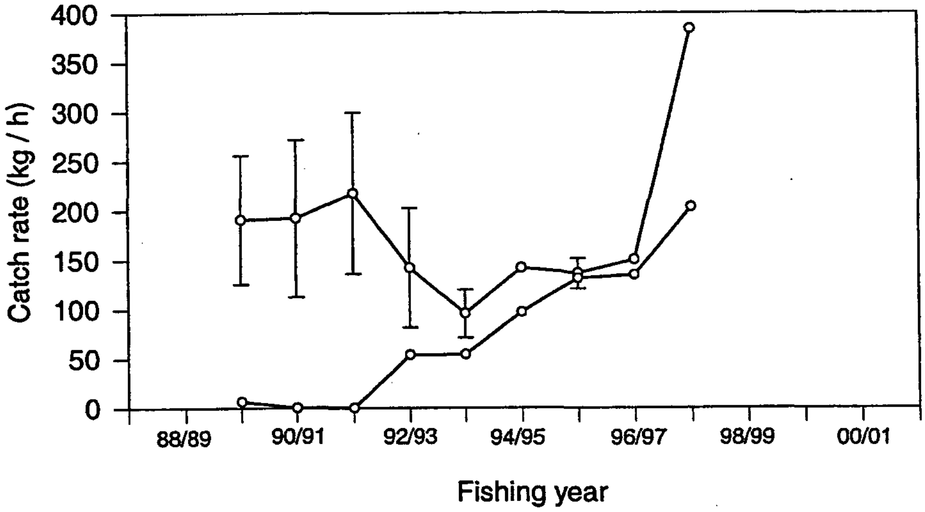

Figure 2: Catch rate from FMAs 3 and 5 by fishing year. Data from Ministry of Fisheries CELRs.

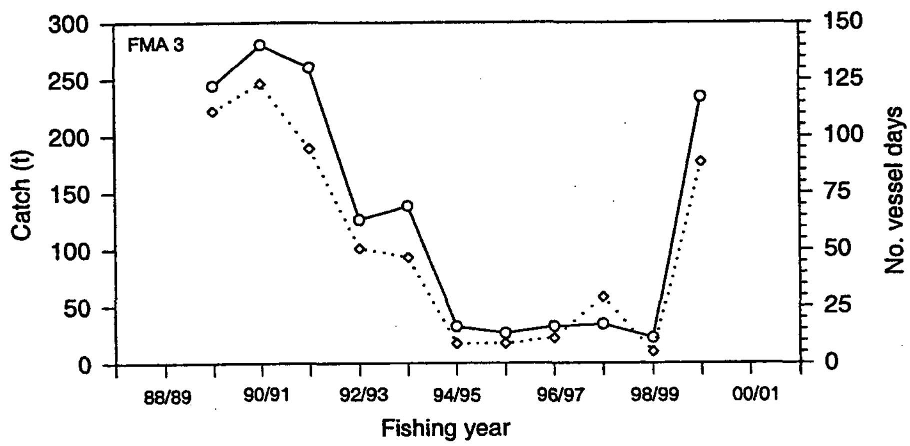

Figure 3: Annual catch (t, dotted line) and number of vessel days (solid line) by fishing year for FMA 3. Data from Ministry of Fisheries CELRs and CLRs.

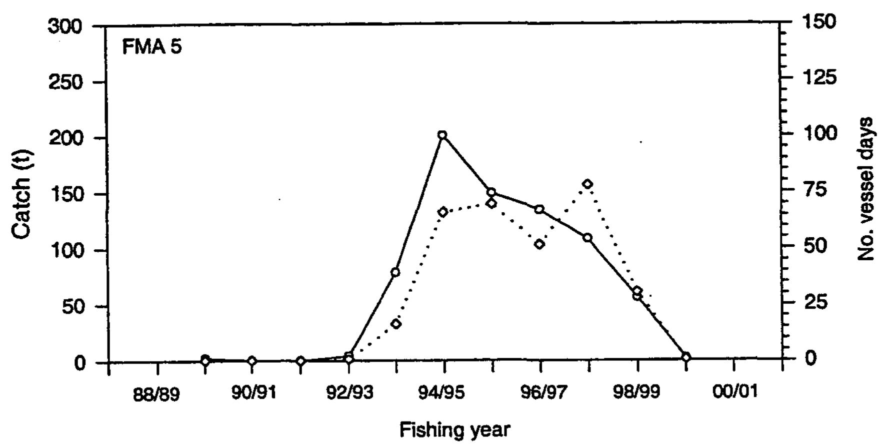

Figure 4: Annual catch (t, dotted line) and number of vessel days (solid line) by fishing year for FMA 5. Data from Ministry of Fisheries CELRs and CLRs.

2.3 Processing

Chilling New Zealand queen scallops immediately after capture is essential to prevent an enzyme in the liver discolouring the flesh (Sanders 1994). In the early development of the fishery, it was considered uneconomic to hand shuck New Zealand queen scallops because of their small size. They were either marketed whole frozen in the shell or mechanically shucked and sold as adductor muscle only. A shucking machine imported from the U.S. in 1986 used a steaming process to open the shells, and an abrasive "staircase" which loosened the shells and mantle from the adductor muscle. This machine was leased, and was returned to the U.S. in 1991. New Zealand queen scallops have been hand shucked (as adductor and gonad) since then: some meats were sold frozen and others were crumbed (Sanders 1994).

2.4 Marketing

Marketing is a limiting factor to further development of the fishery (R.J. Street, fisheries consultant, 7 Gala St, Dunedin, pers. comm.). Although some product (weight and nature of product unspecified) has been exported to the U.S. and Australia, it could not compete with the local product (Sanders 1994). Interest from domestic consumers is growing.

2.5 Recreational and Maori customary fisheries

There are no recreational or Maori customary fisheries for New Zealand queen scallops. New Zealand queen scallops are found in deep water (80–430 m) on the outer continental shelf (Powell 1979). Consequently they are inaccessible to recreational and customary fishers. There are no records of New Zealand queen scallops harvested by recreational fishers and there are no references to New Zealand queen scallops collected by southern Maori in the Ngai Tahu Sea Fisheries Report 1992 (Creswell 1993).

Creswell (1993) reported anecdotal information on the occurrence of New Zealand queen scallops in Paterson Inlet, Stewart Isalnd that could be accessible to recreational fishers. However, as many species in the genus *Chlamys* closely resemble each other, these reports are likely to be species misidentification of *Chlamys gemmulata radiata*, which is commonly found in Paterson Inlet. No *Zygochlamys delicatula* have been recorded from Foveaux Strait or the seas around Stewart Island (Powell 1979 & McKay, unpub. data).

2.6 Other sources of fishing mortality

Incidental mortality of small New Zealand queen scallops and spat from fishing and especially mechanical sorting is likely. The extent of this incidental mortality has not been quantified.

3. RESEARCH

3.1 Stock structure

There is no information about the stock structure of New Zealand queen scallops; they are regarded as a single stock for management purposes. Living specimens have been recorded only from the offshore waters of the South Island east coast (including the Mernoo Bank and Chatham Rise), and around all the subantarctic islands. The highest densities have been found off Otago. The long larval life, probably 40–50 days (see section 4.3), and the strength of the Southland Current, suggests that recruitment to the Otago population could stem from larvae spawned on the Snares shelf.

New Zealand queen scallops have been managed by existing FMAs. This approach will not prevent serial depletion of discrete commercial areas within FMAs, or the removal of bryozoa beds that appear to be important habitat for the settlement and survival of spat.

3.2 Resource surveys

3.2.1 Otago Peninsula to east coast Stewart Island, 1977–79

The limits of distribution of New Zealand queen scallops in New Zealand is Kaikoura to the southern islands including the Snares, Bounty, Antipodes, and Macquarie islands (McKay, unpub. data). No live New Zealand queen scallops have been caught north of Kaikoura, in Foveaux Strait, off Stewart Island, or on the west coast of New Zealand.

McKay (unpub. data) investigated the distribution of New Zealand queen scallops from the Otago Peninsula to Nugget Point between 1977 and 1979. She sampled 89 stations in six evenly spaced transects, in depths of 80–200 m. A large box dredge with 50 mm mesh was used which retained New Zealand queen scallops greater than 50 mm in height. Her sampling was dependent on weather and the availability of R.V. *Munida*, G.R.V. *James Cook*, and R.V. *Tangaroa* for her investigations.

New Zealand queen scallops were most abundant on the mid to outer continental shelf in a depth range of 110–150 m (few were found in less than 100 m) from the Otago Peninsula to the Tautuku Peninsula. Abundance decreased sharply north of the Otago Peninsula and isolated populations were found as far north as Kaikoura (data from New Zealand Oceanographic Institute sampling). New Zealand queen scallop abundance decreased south to Nugget Point and none were caught between Nugget Point and the east coast of Stewart Island.

New Zealand queen scallops were abundant on substrates dominated by bryozoa and *Sclerasterias mollis*, but less common on *Panopea* and *Glycymeris laticostata* shells, and brittle star (*Ophiocoma bollonsi*) dominated substrates to the south. New Zealand queen scallops occurred on bryozoa off Nugget Point, but were less abundant there than off the Otago Peninsula.

3.2.2 Otago, 1983

Fisheries Research Division investigated the distribution and relative abundance of New Zealand queen scallops off Otago with a dredge survey in October 1983. The survey area was from Cornish Head (45°85' S, 170°40' E) and Quoin Point (46°10' S, 171°10' E), an area of high concentration of New Zealand queen scallops identified by fishers and McKay's surveys in the late 1970s. A grid survey sampled 69 stations in a depth range of 66–166 m. The area was divided into a grid of two minutes of latitude and three minutes of longitude and tows planned at the intersections. Allowance was made for extra tows to define areas of high relative abundance when they were encountered. One additional shot was made at 299 m. Gear trials using scallop and oyster dredges, and a prawn trawl were also carried out to find the most efficient sampling tools. Information on scallop height and bycatch species was also collected.

Two types of scallop dredges, ring-bag and box, proved the most suitable sampling tools. The prawn trawl took too long to sample each station because of the long shooting and hauling times, and the large volume of material caught increased the sorting time. The oyster dredges saturated too quickly and caught only small numbers of New Zealand queen scallops. The scallop dredges also saturated but caught large numbers of New Zealand queen scallops. The scallop ring bag dredge was used until it was damaged beyond repair. The scallop box dredge was used for the remainder of the survey. Catches with the scallop ring bag and box dredges were comparable in similar areas and the sampling efficiency of both dredges was considered to be similar.

Ten minute tows were made in the direction of the tidal current at a towing speed of 2 knots and a warp length to depth ratio of 4–5: 1. The length of each tow was determined from radar fixes of the start and end positions. The accuracy of station positions and the distance towed is not known. The recorded distances averaged 0.6 n.mile (range of 0.4 n.mile–1.0 n.mile).

Forty-three percent of the dredges were landed full and probably became full at some point early in the tow after which they ceased to catch scallops. This was mainly a problem on substrates dominated by bryozoan, sponge, and molluscan shell debris. Gear saturation did not occur on tows on hydroid dominated substrates. The high proportion of full tows and the unknown accuracy of the distances towed meant that the density of scallops could not be estimated reliably.

New Zealand queen scallops were present throughout the area surveyed and distributed in long patches orientated along the slope of the continental shelf. They were most abundant in depths beyond 130 m, on the plateau between the Taiaroa and Papanui Canyons, and south to the southern most station surveyed. In this area 12 tows sampled more than 1000 New Zealand queen scallops per tow, the largest catch was 4766. North of the Taiaroa Canyon catches diminished steadily towards the Karitane Canyon; few were caught north of there. Few queen scallops were caught in depths shallower than 110 m. The mean number of scallops caught per tow, for all stations was 583. Although the biomass could not be estimated reliably, the survey showed that there were large quantities of New Zealand queen scallops off the Otago coast.

3.2.3 Indications of New Zealand queen scallop habitat from dredge contents

Dredge samples from the 1977–79 surveys, which contained large numbers of New Zealand queen scallops, were dominated by bryozoa, together with starfish (*Sclerastrias mollis*), spider crabs (*Leptomithrax longipes*), *Munida gregaria*, and the anemone (*Bundodactis chrysobathys*); these species are characteristic of the Otago middle and outer shelf epibenthos (Probert et al. 1979). Dredge samples from the 1983 survey were dominated by catches of bryozoa, shell debris (*Turridae*, *Panopea*, and venerid shell), hydroids, and sponges. Few anemones were caught in 1983.

3.3 Biology

McKay (unpub. data) investigated the breeding cycle (spawning, larval biology, settlement, and recruitment) of New Zealand queen scallops on the continental shelf off the Otago Peninsula. Her study site was an area 5 miles square on the northwestern corner of the plateau between the Taiaroa and Papanui canyons, in depths of 120–145 m. Sampling was carried out at approximately monthly intervals from August 1977 to January 1979. McKay used the same box dredge she used to investigate distribution to collect samples for reproductive cycle studies. A similar dredge lined with 10 mm mesh was used to sample height (shell dorsal-ventral axis) frequencies and to study population size structure and growth. We analysed these data using the computer programme MULTIFAN (Fournier et al. 1990) to estimate growth rate and compared published estimates of growth rates for similar species overseas.

We measured the prodissoconchs (shells of settled larvae still visible on the outer shell) of New Zealand queen scallops to estimate the size at which larvae settle. Published data on the habitat and length of larvae life of similar species were used to infer the length of larval life for New Zealand queen scallops. We also examined height frequency distributions from dredge tows throughout the survey area to assess whether the population size structures, and in particular juvenile height modes, were similar. Height frequency distributions were tested to establish if they were significantly different, and to give some indication of settlement and recruitment.

3.3.1 Spawning

McKay (unpub. data) studied the breeding cycle of New Zealand queen scallops by following changes in two condition indices; (1) total dry weight divided by shell cavity volume (after Medcof & Needler 1941) and (2) the dry weight of the gonad divided by shell volume (after Giese 1959). These indices were measured in monthly samples of 20 individuals over 50 mm in height. Histological samples of 10–20 individuals were also taken each month. The diameter of oocytes in female gonads was measured through the year. The fecundity of 17 female scallops in March 1978 was determined by weighing the gonad and teasing out a known weight of gonad into 25 ml of water, then counting the eggs in 5 ml aliquots. Gonads of 25 individuals of various sizes were sectioned to determine the size at first maturity.

The seasonal gonad condition indices (Figure 5) indicate a small discrete spawning event between October and November 1977, followed by prolonged major spawning between January and March culminating in the complete spawning out of gonads by May. A similar pattern was observed in the following summer. New Zealand queen scallop condition gradually increased after spawning (from May) but gonad condition remained low until September when it increased rapidly.

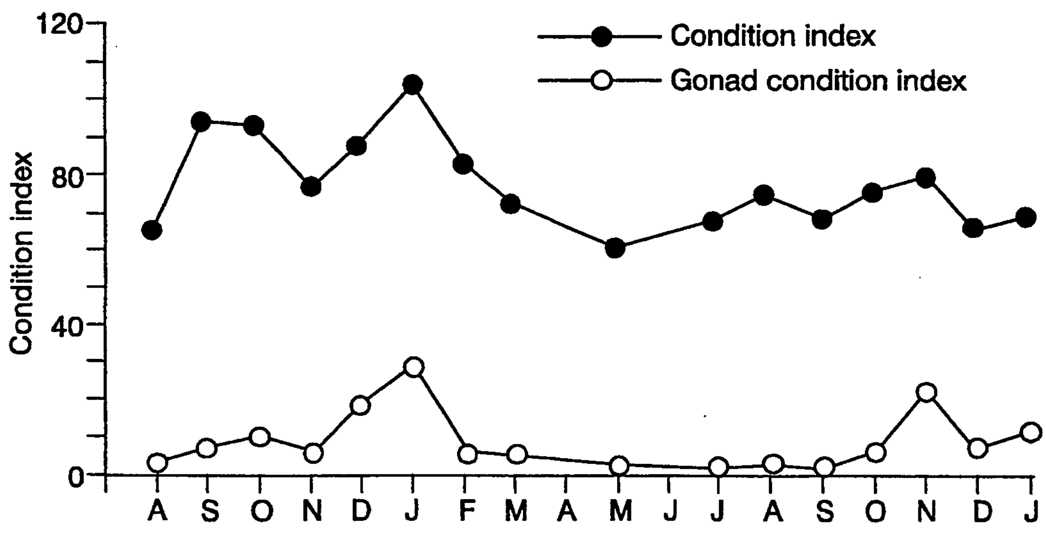

Figure 5: Seasonal changes in southern queen scallop condition and gonad condition from population samples taken between Taiaroa and Papanui canyons, 1977–79 (source: McKay, unpub.data).

The histological investigation of the gonad cycle confirmed this pattern of spawning. New Zealand queen scallops are dioecious (the sexes are separate). Between August and October the gonads of both males and females showed only early stages of differentiation. Follicles of males were small with spermatagonia and spermatocytes around the periphery and oogonia and oocytes around the periphery in females. Between October and November the follicles expanded rapidly, male gonads becoming filled with spematocytes and spermatids and females with small developing oocytes. Between December and March the ripe follicles of the males became packed with spermatids and the lumens filled with sperm while the follicles of females became packed with full-grown ova (60 µm in diameter). Little interfollicular space remained. Between March and May partially spent individuals were common. Completely empty follicles were scattered through the gonads of some males while in others all the follicles were partially emptied. The gonads of females were in a similar condition. Between April and May many individuals were completely spawned out. Follicles of males had only small numbers of residual spermatids and spermatocytes. Follicles of females had regressing small ova and oocytes. Between June and July the regression continued with connective tissue developing between the follicles that became completely empty. The mean diameter of follicles in female gonads measured through the year parallels the gonad cycle determined histologically (Figure 6).

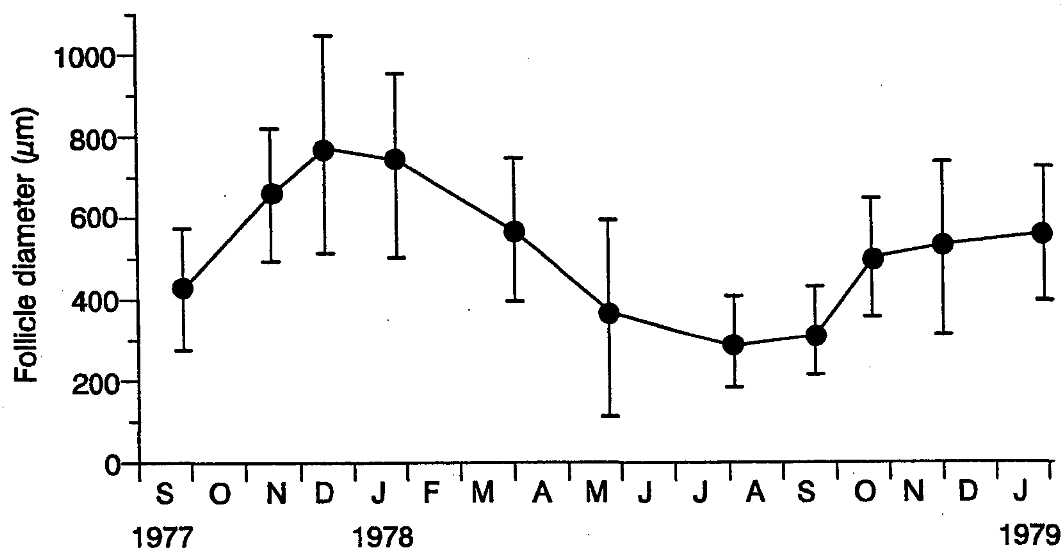

Figure 6: Seasonal changes in mean diameter (with error bars of 1 standard deviation) of follicles in females from population samples taken between Taiaroa and Papanui canyons, 1977–79 (source: McKay, unpub.data).

The oocyte diameters in female gonads through the season (Figure 7) indicate that the mature egg is between 60 and 70 mm in size. These data confirm the partial spawning between October and November in 1977 as well as the complete spawning out between February and May 1978. Maximum egg size in the first spawning period was larger (90 µm) than in the second (70 µm).

Males were found to be sexually mature at 31 mm and females at 43 mm. A regression of total egg production against gonad weight (Figure 8) shows a close linear relationship and indicates a maximum fecundity of 11×10^{6} in an individual with a 4.5 g gonad. As most New Zealand queen scallops were partially spent by March, this figure is likely to be conservative.

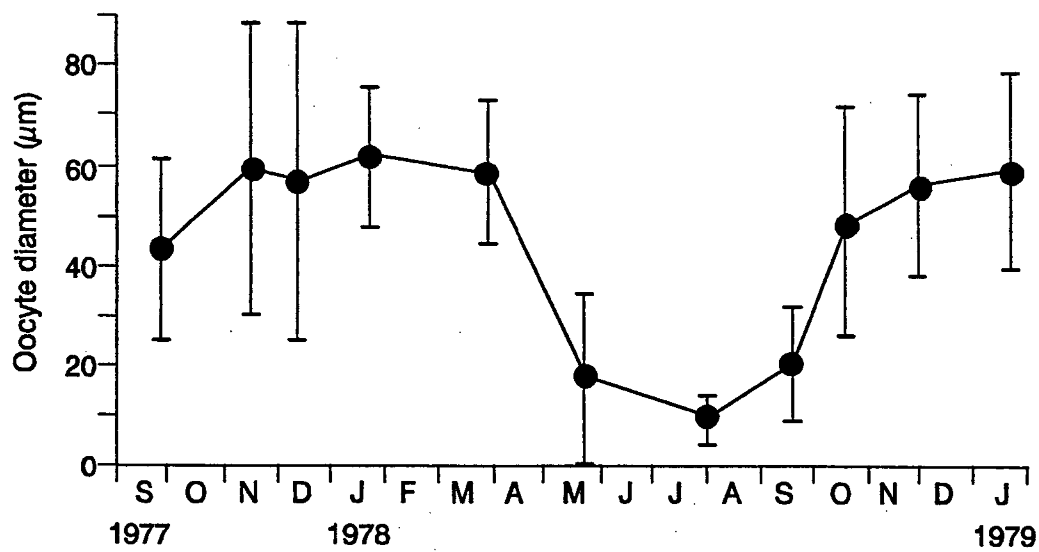

Figure 7: Seasonal changes in mean oocyte diameter (with error bars of 1 standard deviation) from population samples taken between Taiaroa and Papanui canyons, 1977–79 (source: McKay, unpub.data).

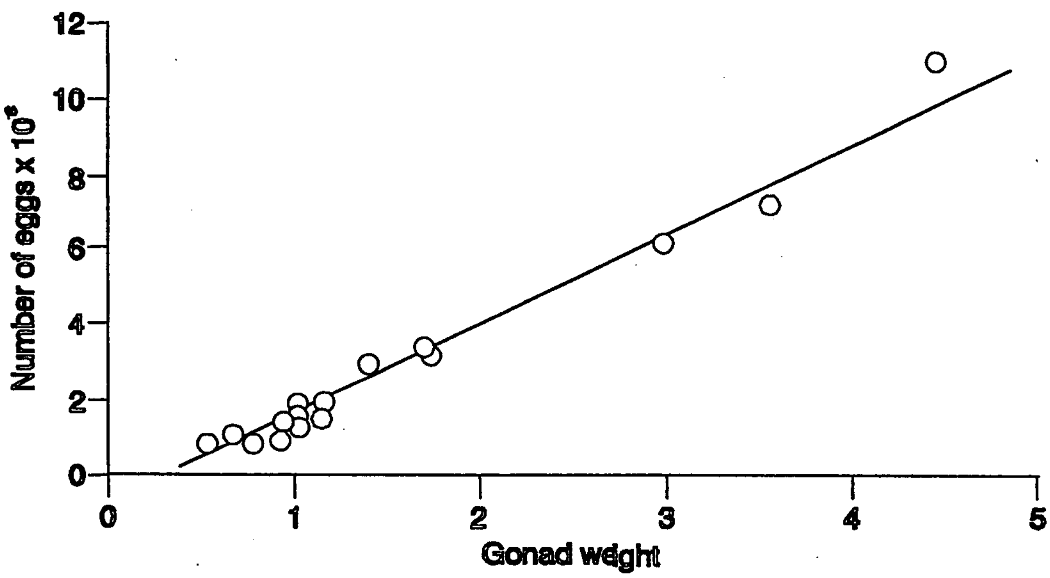

Figure 8: The relationship between gonad weight (g) and total egg production from population samples taken between Taiaroa and Papanui canyons, March 1978 (source: McKay, unpub.data).

Studies of the gonad cycles of *Chlamys varia* (Shafee & Lucas 1980), *C. opercularis* (Le Pennec 1982, Brand et al. 1980, Taylor & Venn 1978), *Argopecten gibbus* (Miller et al. 1981, Allen 1979) and *A. irradians* (Sastry 1963) show that these species follow a similar breeding strategy of early partial spawning in late spring followed by a complete spawning in late autumn. In each of these species, the earlier (and generally smaller-scale) spring spawning gave rise to the most significant spatfall.

3.3.2 Larval life

The approximate length of the larval life of New Zealand queen scallops has been inferred from data on similar pectinid species. Egg and dissoconch size and water temperature data from the Otago shelf have been used to interpolate length of the larval life (Table 3 and Figure 9).

Table 3: Mean egg size at spawning, number of days the larvae are in the plankton, settlement size of spat, depth, and temperature ranges of five similar pectinid species; *Chlamys islandica* (Gruffydd 1976), *C. opercularis* (egg size Aravindakshan 1955; larval life and settlement Le Pennec 1982), *Argopecten gibbus* (egg size and larval life Costello et al. 1973), and *A. irradians* (egg size Loosanoff & Davis 1963; larval life and sea temperatures, Sastry 1963; Castagna & Duggan, 1971).

Species	Egg size (µm)	Days in plankton	Settlement size (µm)	Temperature (°C)	Depth range (m)
Argopecten					
A. irradians	60	10–19	170–190	20–28	0.3–1
A. gibbus	60	16	235–270	23	18–55
Chlamys					
C. opercularis	70	30–35	180–210	15–17	8–24
C. islandica	70	70	305	6–8	20–100
Z. delicatula	80	~ 40–50	250	12–13	110–160

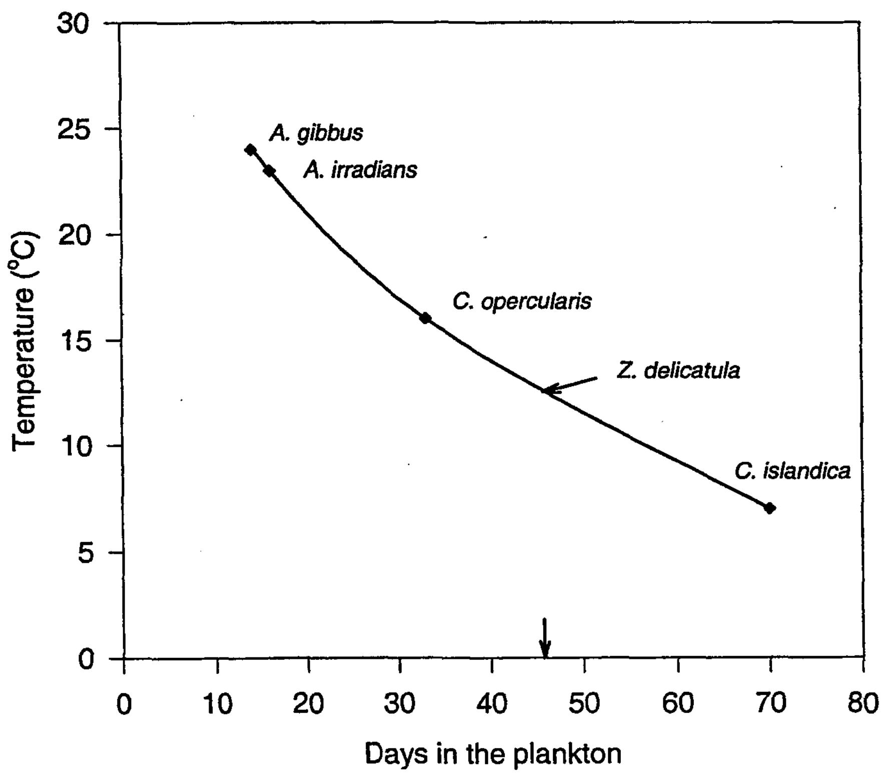

Figure 9: The number of days larvae are in the plankton before settlement and summer sea temperatures for *Chlamys islandica*, *C. opercularis*, *Argopecten gibbus*, and *A. irradians* (Data sources Table 3) and the inferred length of larvae life for *Zygochlamys delicatula*.

The length of larval life of all these small pectinid species is closely related to dissoconch size and water temperature. The prodissoconchs of *Z. delicatula* indicate that the larvae settle at a length of between 240 and 250 µm (authors' unpublished data), similar to *A. gibbus*. The water temperature on the edge of the Otago Shelf (110–160 m) in summer is between 12 and 13 °C (Jillett 1969). The egg size, settlement size, and temperature of the habitat point to *Zygochlamys delicatula* having a larval life of 40–50 days.

Most of the subtropical water of the Southland Current flows south across the Snares shelf before turning north up the east coast of the South Island (Heath 1973). The segment of the Southland Current flowing through Foveaux Strait has a velocity of 0.08 m s^{-1} (Heath 1973); along the Otago shelf its velocity is also 0.08 m s^{-1} (Heath 1972). No eddies that could retain larvae have been found within the Southland Current. If the planktonic life of the *Z. delicatula* is in the order of 40–50 days, then larvae settling off the Otago Peninsula are likely to have been spawned some 270 to 380 km upstream. These natal populations could be in the region of the Snares shelf.

3.3.3 Settlement

In the 1983 survey we found that juvenile New Zealand queen scallops were byssually attached to fragments of bryozoa and other biogenic debris, including the shells of other *Chlamys* species and *Tiostrea*. These debris were retained in the dredge providing a representative sample of byssually attached juveniles. The frequency distributions of samples from this survey showed that size composition of the populations differed over the survey area. Some juvenile modes were missing from some areas and other modes were poorly represented, especially from those tows on different substrate types. Settlement probably varies spatially and temporally. The estimated 40–50 days larval life may result in New Zealand queen scallop larvae being well mixed (vertically and horizontally) in the water column. Predation of newly settled spat may also affect the pattern of recruitment and add to the variability in year class representation.

3.3.4 Growth and age structure

There is no information on the growth of New Zealand queen scallops. To derive growth estimates we used monthly height frequency data from McKay (unpub. data). These distributions showed strong modal structure and the progression of modes through time. We estimated growth rate using the computer programme MULTIFAN by making some assumptions about the data (given below). It is likely that the smaller size classes were under represented in McKay's samples as many of the small New Zealand queen scallops (2–15 mm) would have been byssually attached to debris and may have been overlooked in the sorting. Free livings spat 10 mm or less long, probably were not retained by the dredge.

Von Bertalanffy growth curves were fitted to the height frequency distributions. The MULTIFAN model simultaneously analyses multiple sets of height frequency samples using a robust likelihood method to estimate the proportion of scallops in each age class and the Von Bertalanffy growth parameters L , k, and t_0. Estimates of t_0 were calculated by $t_0 = T - a_1$ where a_1 is the estimated age of the year class 1 in the month 1 sample calculated by the MULTIFAN model, and T is the time in years between the nominal birth date and the first sample containing individuals of the 0+ year class (year 1 in MULTIFAN, which assigns the first month of their appearance as month 1). Nominal birth dates were assigned as the November based on the onset of spring spawning (*see* section 4.3.1).

Four versions of the MULTIFAN model were fitted to these data: (1), the standard deviation of the heights of all age classes was held constant; (2), the standard deviation was allowed to vary among age classes; (3), the standard deviation of age classes was held constant and growth was allowed to vary seasonally; and (4), the standard deviation of age classes was allowed to vary and growth was allowed to vary seasonally. Francis & Francis (1992) and Cranfield et al. (1996) used the same approach to analyse growth in other fish and shellfish species. The significance of improvement of fit within models by adding year classes was tested for significance at the level of 0.90 (Type 2 errors are more serious than Type 1 errors in estimating *k*; Fournier et al. 1990), and significance of improvement of fit between models was tested at the 0.95 level.

The first size frequency sample in which the smallest New Zealand queen scallops were caught (July 1978) was assigned Month 1 for the MULTIFAN analysis (Fournier et al. 1990). New Zealand queen scallops probably spawn in November and settle in January. The smallest byssually attached spat (about 2 mm) appeared in July. Although there were a few spat 4–6 mm present between February and April, we assumed they were the tail end of the year 2 (1+ year class) as most greater than 6 mm. spat because they were not present in the previous samples. New Zealand queen scallop height frequency distributions from individual tows showed marked differences in size composition and especially the presence and strength of juvenile modes, probably from spatial and temporal variations in settlement and recruitment. This could have a confounding effect on the analysis. As we had no height at age information to constrain the model, we used estimates of the annual increments of juvenile modes from the data to indicate minimum and maximum heights for juvenile year classes. We assumed MULTIFAN year 1 (0+ age class) in month 1 were 2–6 mm in height and year two 6–14 mm. Results of the analysis are shown in Table 4 and a growth curve shown in Figure 10.

Table 4: Von Bertalanffy parameter estimates for MULTIFAN best-fit models for queen scallops, from height frequency distributions sampled 1977–79 off Otago (McKay, unpub.data). Amplitude and phase parameters describe seasonal growth. s.d., standard deviation; v, variable.

s.d.	v
Number of age classes	10
k (year^{-1})	0.187
L (mm)	67.6
t_0 (years)	0.36
Amplitude f_1	0.802
Phase f_2 (years)	0.306
Average s.d. (mm)	3.26
Ratio s.d.	1.915

This estimate of growth is very sensitive to two main assumptions. 1. That the height frequencies represent the population height frequency and the samples are not biased by spatial or temporal distribution of the small size classes, and 2. that the height at age constraint is within the population height range for the given age. We cannot validate either of these assumptions. The MULTIFAN estimate of K is driven by the progression of the first two size modes. The estimated mean size of the first year class in month 1 is 0.16 mm, smaller than observed in the samples. This may be influenced by the big autumn spawning settling out and the numbers of very small juveniles (4 mm pr less) increasing in frequency in the subsequent samples. Estimated mean heights at age for year 2 and older year classes are consistent with the modes observed in the height frequency samples.

The heights of modes determined from both 1978 and 1983 October sample distributions are consistent. Heights of external interruption rings on shells of three New Zealand queen scallops collected in October 1983 are consistent with MULTIFAN estimates of height at age. If check rings could be validated they would provide a useful tool for estimating growth rates, age and mortality.

These data suggest New Zealand queen scallops become sexually mature at 4 years for males and 5 years for females. As length is slightly less than height, New Zealand queen scallops are likely to enter the fishery from about 8 years old.

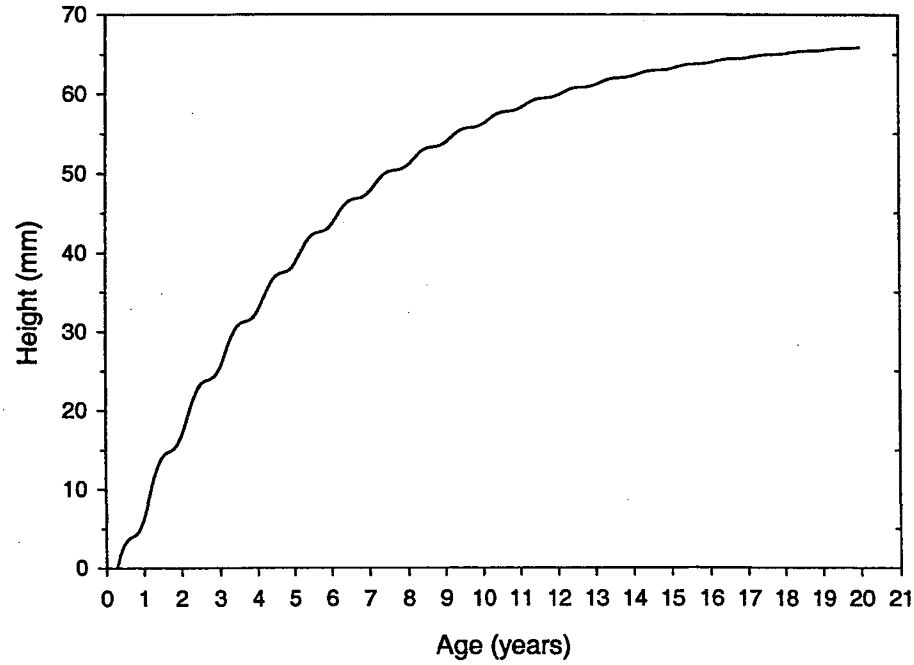

Figure 10: Estimated seasonal growth curve for queen scallops off the Otago Peninsula 1977–79, from the computer program MULTIFAN from McKay, unpub.data.

3.3.5 Growth rates of similar pectinid species

The growth rates of five similar small pectinid species are compared with that found for New Zealand queen scallops (Figure 11). The fastest growing species are found in warm waters, *Argopecten irradians* (bay scallop) grows to over 60 mm in a year, then spawns and dies (Barber & Blake 1983). *Argopecten gibbus* (calico scallop) is also a fast growing species reaching 50 mm in the first year and 75–80 mm at a maximum age of 18–20 months when it spawns and dies (Roe et al. 1971). In cooler waters, *Chlamys islandica* takes 6 years to reach 50 mm and grows to 70 mm in 12 years, spawning many times before death (Wiborg 1963). *Chlamys varia* (Rodhouse & Burnell 1978) and *Z. delicatula* have growth rates similar to that of *C. islandica*, but appear to have a higher rate of mortality. The growth rate of *C. opercularis* (Taylor & Venn 1978) falls half way between the fast and slow growing groups.

Growth of pectinids decreases below the photic zone. Both the depth and temperature ranges of these species (Table 4) are likely to have an effect on their growth rates. *Z. delicatula* occurs below the photic zone in cool (12–13 °C), deep (110–160 m) subtropical water, and its growth rate is likely to be in the slowest group.

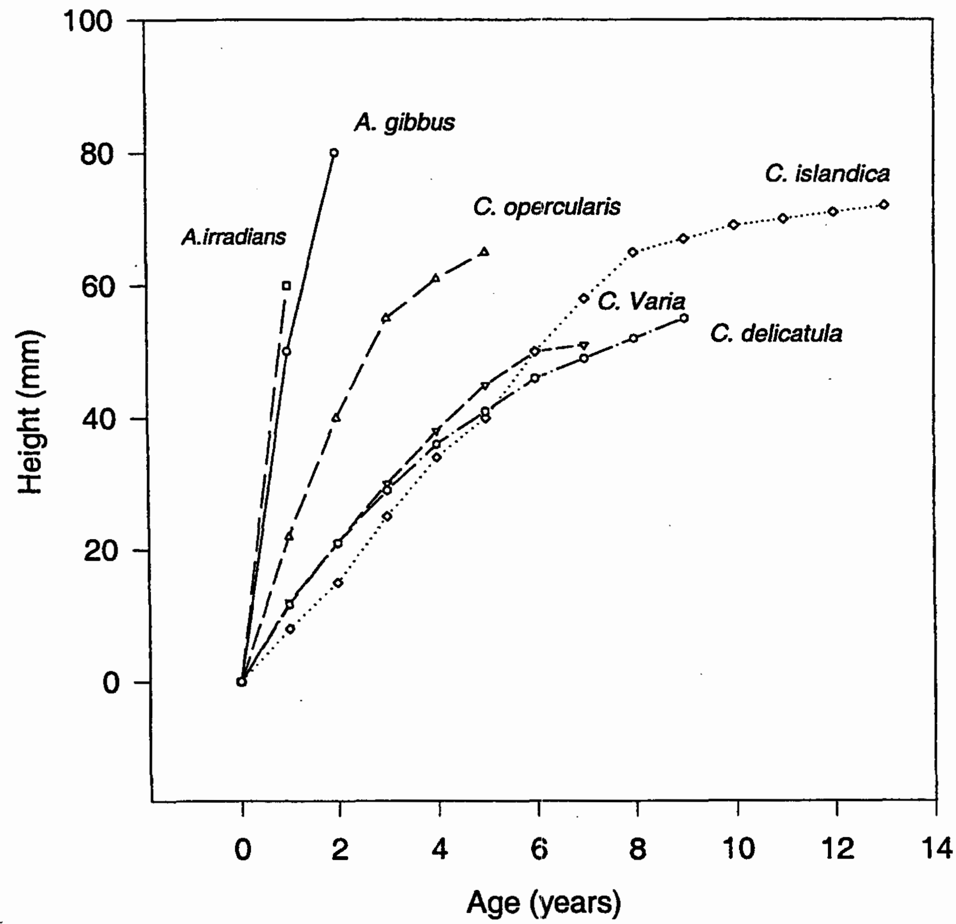

Figure 11: The growth rates of six pectinid species (For data sources, see text).

3.3.6 Mortality

There are no estimates of mortality for New Zealand queen scallops.

3.4 Biomass estimates

There are no biomass estimates for New Zealand queen scallops.

3.5 Yield estimates

There are no yield estimates for New Zealand queen scallops. The competitive TACC of 750 t of green weight for FMA 3 set on 1 December 1990 was probably based on the highest recorded catch of over 711 t in the 1985–86 fishing year in that area. There is no catch limit in FMA 5.

4. MANAGEMENT IMPLICATIONS

The New Zealand queen scallop fishery is considered stable. The number of vessels active in the fishery increased in 1990, but the catch has not increased. Recent annual landings average at less than 100 t landed green weight per vessel and the competitive TACC of 750 t in FMA 3 has never been attained. From the 1992–93 fishing year a moratorium on the issue of new permits was invoked. Reported low product value and difficulties in processing and marketing New Zealand queen scallops have constrained development of the fishery. If these constraints were overcome, it is likely to generate renewed interest in the fishery.

Little is known about the growth, age, and recruitment of New Zealand queen scallops and how the species responds to fishing. It was not possible to estimate their biomass as the depth and current strength at which they are found did not allow catch efficiency of the sampling gear to be estimated. In the 1983 surveys, many of the sample tows became saturated before the end of the tow and we could not estimate the distance towed accurately from the start and end of tow positions derived by radar. Even relative biomass estimates are likely to be imprecise as catch efficiency of the gear is almost certainly highly variable.

The close association of bryozoa and New Zealand queen scallops, and the heavy settlement of New Zealand queen scallops on bryozoa may play an important part in the high densities occurring off the Otago shelf. The frequent passage of fishing gear with their bobbins and ground ropes could readily destroy bryozoa thickets and may ultimately impact the fishery (Batson & Probert 2000).

The state of the stock cannot be determined from the data available. CPUE data are collected by FMA or FRA. These areas are too large for detailed analysis. The New Zealand queen scallop fishery covers an extensive area, but nothing is known about the sustainability of the current exploitation rate. Catch and effort data should be collected on a fine spatial scale, preferably by tow with start and finish positions from GPS, to allow a better assessment of the impacts of localised fishing on scallops and their habitat. The sustainability of a 750 t TACC in FMA 3 should be reassess considering available data on the biology of New Zealand queen scallops and likely impacts of trawling on their habitat.

5. ACKNOWLEDGMENTS

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