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EXECUTIVE SUMMARY

Cranfield, H.J.; Michael, K.P. (2001). The surf clam fishery in New Zealand: description of the fishery, its management, and the biology of surf clams.
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Surf clams are bivalves found in the surf zone of exposed sandy beaches throughout New Zealand. The group comprises of seven species of the families Mesodesmatidae (*Paphies donacina*), Mactridae (*Spisula aequilatera, Mactra murchisoni*, and *M. discors*) and Veneridae (*Dosinia anus, D. subrosea*, and *Bassina yatei*). Species composition varies from beach to beach and throughout New Zealand. Surf clams are distributed in discrete depth zones, which allow individual species to be targeted by fishing. Surf clams have a high turnover, and the species mix and biomass of beaches changes over time due to variable recruitment and heavy mortality, especially after severe storms.

Exploratory surveys between 1988 and 1992 found high densities of surf clams off beaches in Poverty Bay, the Kapiti and Manawatu coasts, Marlborough, Pegasus Bay, and Oreti Bay in Southland. These could support new large-scale fisheries. A number of investigations to further explore the fishery potential of discrete lengths of beach have been carried out under special permit on the Kapiti coast, Manawatu coast, and in Marlborough. Four fishing permits were issued between 1986 and 1992, when a moratorium prevented new entrants into the fishery. Landings from these fishing permits have been small and none of the permits are currently being fished. Surf clam populations at these locations are still likely to be in a virgin state. A special permit to investigate surf clams in Southland was issued in 2000.

A CAY harvest strategy would be most appropriate for these species to optimise yields in times of high biomass and reduce the risk of overfishing when biomass is low.

1. INTRODUCTION

1.1 Overview

The surf zone of exposed sandy beaches is a very productive area of the sea. Although superficially it appears barren, it has a high primary productivity that is similar to that in areas of coastal upwelling. The primary production of the surf zone supports a high biomass of mobile crustacea and sedentary bivalves. On many New Zealand surf beaches the bivalve macrofauna is dominated by surf clams. Two intertidal species of surf clams, *Paphies ventricosa* (toheroa), and *P. subtriangulata* (intertidal tuatua), are accessible and well known, and have been the subject of important traditional and recreational hand gathering fisheries since the arrival of Maori and Europeans in New Zealand (Redfearn 1975).

Until recently the species composition and abundance of subtidal surf clams was poorly known because of the inaccessibility of the breaker zone of surf beaches to fishing and sampling. Before the importation of a lightweight hydraulic dredge in 1986 (Michael et al. 1990), the only source of such information was strandings of shellfish after storms (Eggleston & Hickman 1972). Exploratory sampling of the surf zone of New Zealand beaches with the hydraulic dredge found substantial populations of surf clams. Seven species of the families Mesodesmatidae (*Paphies donacina*), Mactridae (*Spisula aequilatera*, *Mactra murchisoni*, and *M. discors*) and Veneridae (*Dosinia anus*, *D. subrosea*, and *Bassina yatei*) were caught (see Cranfield et al. 1994a). These bivalves are buried up to 150 mm beneath the surface of the substrate and cannot be caught by standard shellfish dredges.

The high densities of subtidal surf clams found by these exploratory surveys could be harvested commercially and support new fisheries. The biomass of some of these populations has been estimated in stratified random surveys (Michael et al. 1994, Cranfield et al. 1994a, 1994b, Haddon et al. 1996). The growth rates and sustainable yields of some surf clam species have been investigated in two populations (Cranfield et al. 1993, 1994a, 1996, Cranfield & Michael 2001).

This document summarises the development of the fisheries, their management, and landings. It also summarises the results of resource surveys and investigations into the biology of surf clams. It discusses management of surf clam fisheries, the potential of these fisheries, and identifies constraints to further development.

1.2 Description of the fishery

1.2.1 History of the fishery

In 1985, the New Zealand Fishing Industry Board developed a new hydraulic dredge to investigate the then unknown fishery potential of surf clams. At the time this dredge was being tested, another hydraulic dredge was imported into New Zealand and was made available. Both dredges were tested off the Kapiti coast in 1985 (Michael et al. 1990), and the New Zealand Fishing Industry Board and Fisheries Research Division jointly investigated the extent of the surf clam resource there in 1985 and 1986.

The hydraulic dredging trials in 1985 generated considerable interest in surf clam fisheries. Initial investigations were pursued under the conditions of special permits. The first special permit to investigate the size and nature of the surf clam resource and to carry out handling and marketing trials was issued for investigations off the Kapiti coast in 1986. Five special permits have been issued since 1986. Exploratory resource surveys using hydraulic dredges were also carried out off Cloudy Bay in 1987 (Cranfield & Michael 1987) and 1989 (Michael et al. 1994); Rabbit Island, Nelson in 1988 (Michael & Olsen 1988); Farewell Spit 1987 (Olsen 1987); Clifford Bay, Marlborough in 1989 (Michael et al. 1994); at 16 locations around the New Zealand coast (Cranfield et al. 1996); and the Manawatu coast (Haddon et al. 1996).

On the basis of the results from Cloudy Bay, a fishing company contracted Fisheries Research Division to carry out a dredge survey to estimate the distribution, species composition and biomass of surf clams in Cloudy Bay and Clifford Bay. The biomass estimates from these surveys (Cranfield et al. 1994b, Michael et al. 1994) were used as evidence to support applications for fishing permits in 1992. Commercial fishing began in November 1992.

Limited fishing of surf clams on the Manawatu coast, off Foxton, began in 1992 after the granting of a special permit. Three permits were issued as a result of special permit investigations. A moratorium on the issue of new permits in 1993 prevented further development of surf clam fisheries. Although surf clam fisheries are small at present (2001), they have potential for development and many fishers are interested in pursuing their development.

1.2.2 Management and development of the fishery

Seven species are defined as surf clams in the Fisheries Act of 1983: *Paphies donacina* (PDO), *Spisula aequilatera* (SAE), *Mactra murchisoni* (MMI), *M. discors* (MDI), *Dosinia anus* (DAN), *D. subrosea* (DSR), and *Bassina yatei* (BYA). In all fishery areas, Auckland, Central, South-East, and Southland and Sub-Antarctic, surf clams are 'Part A' species and targeting them is prohibited unless authorised pursuant to the Commercial Fishing Regulations of the Fisheries Act 1983.

Surf clam investigations and fishing have been undertaken pursuant to sections 63, 64 (1) (c), and 66 of the Fisheries Act 1983. The first special permit to assess the surf clam resource off the Kapiti coast in 1986 was issued under section 66. The permit made provision for an annual quota of 300 t green weight for all species combined. This permit was later surrendered to the Minister of Fisheries to avoid conflict with local groups. In 1988, more special permits were issued to assess the surf clam resource of Rabbit Island in Tasman Bay and of Cloudy Bay in Marlborough.

Between 1989 and the end of 1992, when a moratorium was placed on the issue of new permits, two new permits were issued under section 64(1)(c) for the Manawatu coast; one in 1989 for the length of coastline between the Manawatu and Rangitikei rivers. This permit was never used. The other permit was issued in 1992 for the coastline between the Otaki and Ohau rivers. MAF issued a further two permits for Cloudy and Clifford Bays under section 63 of the Fisheries Act (1983) in November 1992. These permits were for landing 31.8 tonnes of surf clams from Cloudy Bay and 35.1 t from Clifford Bay. The permits were based on the yield estimates suggested by Cranfield & Michael (1987) and the biomass estimates reported later in Cranfield et al. (1994b) and Michael et al (1994). In 1995 these permits were increased to 66.2 t and 124.6 t respectively as more precise estimates of sustainable yield became available (Cranfield et al.1994a).

A special permit to fish for surf clams in Pegasus Bay was granted, pursuant to section 64(1)(c) in July 1994, based on an application filed before November 1992. This permit authorised an annual harvest of 300 t of surf clams with individual catch limits for each of the main species. In April 1995, a section 63 fishing permit replaced this special permit. No other permits have been issued to fish surf clams.

A special permit to fish for surf clams in Southland was granted under section 64(1)(c) in 2000.

Permit holders have sole right to fish a defined length of coastline and have an annual quota (in green weight) for each surf clam species.

1.2.3 Fishing methods

Surf clams are buried in the substrate. As the surf zone becomes more turbulent, wave energy injects more water into the sand and surf clams dig deeper as their anchorage becomes less secure. They cannot be caught with normal shellfish dredges because these dredges do not penetrate the sand deeply and can not be readily pulled through it. The physical packing of the sand grains changes as the dredge applies a force to the sand and it changes from being thixotropic and soft to become dilatant and hard. Such dredges, termed dry dredges, compact the sand ahead of the dredge and crush and damage surf clams. Hydraulic dredges have proved to be the only effective method of harvesting surf clams. These inject water into the substrate just ahead of the dredge, liquefying the substrate so the sand remains thixotropic. The dredge bit bar can move through the sand freely and the dredge can filter the surf clams and large particles from the liquefied substrate. The volume and pressure of water injected into the substrate and the location where the water is applied are critical to achieving the correct level of liquefaction and maintaining a high catch efficiency of undamaged surf clams (Michael et al 1990). Cranfield et al. (1994b) used a water pressure of 280–300 kPa and a flow rate of 400 l per minute from the digging manifold and 150 l per minute at the wash back manifold. Kaimoana (Pacific) Ltd in conjunction with Lincoln Technology Ltd have investigated these factors in detail in a Technology Business Development Grant from the Foundation for Research, Science & Technology titled "Harvesting of subtidal surf clams".

The method used to tow hydraulic dredges is also important. Towing speed must remain constant to allow the water jets time to liquefy the substrate. Winching the vessel and attached dredge up to a set anchor provides the best control and maintains constant towing speeds. The towing of hydraulic dredges directly behind vessels under the vessels power generally results in the dredge digging into the substrate, then pulling free in an erratic manner. This method is inefficient and can damage a high proportion of the surf clams caught (Michael et al. 1990). Fishers off Foxton beach have employed this method of towing, but gave no information on the proportion of surf clams damaged (Haddon et al. 1996). Their system may function satisfactorily as it apparently injects very high volumes of low-pressure water into the substrate. The authors do not specify the volume or pressure of water pumped through the dredge used.

1.2.4 Landings

Although there are fishing permits for Cloudy Bay, Clifford Bay. Pegasus Bay, and the Manawatu coast, the only significant landings have come from Cloudy Bay. Landings of surf clams between 1991 and 1996 have been small. There have been no landings since 1997. The high capital costs of establishing a surf clam fishing operation has slowed development of the fishery. The development of handling techniques and marketing has been constrained by the lack of product.

1.3 Literature review

1.3.1 The surf zone

The surf zone functions as an almost self-contained ecosystem (Longuet-Higgins 1983), regenerating nutrients (Pugh 1983) to support the production of surf diatoms. The algal production of the surf zone can be as high as that found in areas of coastal upwelling (McLachlan & Bate 1984).

Surf diatoms are concentrated within the breaker zone by onshore winds (Sloff et al. 1984, Talbot & Bate 1987, 1988a) providing food for beach bivalves (Rapson 1954, Cassie & Cassie 1960, Ansell 1981). Detritus is concentrated outside the breaker zone (Talbot & Bate 1988b) and could be an important food source for those surf clam species that occur outside the breaker zone.

1.3.2 Fisheries for surf clams in similar environments

In Italy the venerid, *Chamelea gallina*, three other venerids, a solelinid, and a donacid support hydraulic dredge fisheries. Peak annual production of the *Chameleà gallina* fishery was estimated at 100 000 t (green weight) of shellfish caught by 607 vessels (Froglia 1989).

The United States has a hydraulic dredge fishery for the mactrid *Spisula solidissima* in the Mid-Atlantic Bight, in depths from 10 to 55 m (Ropes 1980). Vessel numbers have fluctuated around 100 and the annual catch climbed to around 20 000 t (shucked meat) in the 1960s, and fluctuated around 25 000 t in the 1970s. The fishery has relied on dominant year classes from localised recruitment to support the fishery through the late 1970s and 1980s (Murawski & Serchuk 1989, McCay & Creed 1990).

There is an important artisanal handpicking fishery for the mesodesmatid *Mesodesma donacium* off the beaches of Chile:5000 t of meat (equating to 15 000–20 000 t green weight) are exported annually to Japan (J. Castilla, Pontificia Universidad Catolica de Chile, Santiago, Chile, pers comm). A smaller (200 t green weight annually) artisanal handpicking fishery is pursued in Uruguay for *Mesodesma mactroides* (Defeo et al. 1986, Defeo 1989).

The Japanese surf clam *Spisula sachalinensis* (*Pseudocardium sybillae*) supports a hydraulic dredge fishery in Hokkaido (Nashimoto 1985a, 1985b) and a beam trawl fishery in Sendai Bay (Sasaki 1986, Nakamura et al. 1989).

1.3.3 Management of similar fisheries

Only the U.S. surf clam fishery has used total quota to restrict fishing. The biology of *S. solidissima* and estimation of yield in the fishery are well documented (Ropes 1980, Murawski & Serchuk 1989). Natural mortality, *M*, was estimated by Caddy & Billard (1976) and Murawski & Serchuk (1979), recruitment by Ropes (1980), and YPR by Chang et al. (1976) and Mid-Atlantic Fishery Management Council (1989).

Vessel or fisher numbers were restricted to control fishing effort in the U.S and Italian fisheries (Murawski & Serchuk 1989, Froglia 1989). This did not succeed in limiting effort. In North America, ITQs were introduced in 1992, and vessel numbers have declined as quota was consolidated on fewer vessels (Moore 1993).

In North America, the size limit of *S. solidissima* was initially set at 140 mm (Murawski & Serchuk 1989). Specified spacing of filtration grills on hydraulic dredges has been used instead of size limits in Italy (Froglia 1989) and Japan (Nashimoto et al. 1983, 1988, 1989, Nashimoto 1985a).

1.3.4 New Zealand surf clams

The biology of surf clams has been discussed by Cranfield et al. (1993, 1994a, and 1996) and Haddon et al. (1996). The management of New Zealand surf clam fisheries was discussed by Marsh and Craig (1988), the surf clam working group in 1990, Cranfield et al. (1993, 1994a), and Annala (1993).

2. REVIEW OF THE FISHERY

2.1 Landings

A summary of the green weight (kg) landed for each species, from each Fisheries Management Area (FMA) and year (data were supplied by the Ministry of Fisheries) is given in Table 1. Landings from Cloudy Bay and Clifford Bay are recorded from FMA 7 and by Fishing Return Area (FRA) 17; Pegasus Bay from FMA 3 and FRA 20; and the Manawatu coast from FMA 2 and FRA 39. Landings from FMAs 1 and 5 are probably errors as there has been no fishing in these areas. A green weight anomaly in 1996 (marked with an asterisk) where 11 149 kg of *Bassina yatei* were caught in area 2 in a single day is unlikely. Table 2 gives the number of days in each year each species were caught. The totals are cumulative days fished by year and species and not the total number of days fished overall.

Table 1: The green weight (kg) landed for each species (*Paphies donacina* (PDO), *Spisula aequilatera* (SAE), *Mactra murchisoni* (MMI), *M. discors* (MDI), *Dosinia anus* (DAN), *D. subrosea* (DSU), and *Bassina yatei* (BYA), landed by commercial fishers from each FMA in each fishing year from 1990 to 1996.

		Year						
FMA	Species	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	Total
1	DSU	0	0	123	0	27	0	150
2	BYA	0	0	0	0	0	11 149	*11 149
3	MDI	0	0	0	0	49	0	49
3	PDO	0	0	0	0	4439	0	4439
5	MDI	0	0	0	0	33	0	33
5	PDO	0	5	0	0	0	0	5
7	BYA	0	0	15	18	11	0	44
7	DAN	0	164	199	264	12	0	639
7	DSU	0	0	80	58	11	0	149
7	MDI	0	254	1 237	3 220	157	0	4 868
7	MMI	58	1768	4 007	13 822	1 136	0	20 791
7	PDO	0	0	2 581	3 037	4 470	0	10 088
7	SAE	75	461	2 339	2 540	185	0	5 600
Total		133	2 652	10 581	22 959	10 530	11 149	58 004

Table 2: The number of days each species (*Paphies donacina* (PDO), *Spisula aequilatera* (SAE), *Mactra murchisoni* (MMI), *M. discors* (MDI), *Dosinia anus* (DAN), *D. subrosea* (DSU), and *Bassina yatei* (BYA)), was fished by commercial fishers in each FMA and fishing year 1990 to 1996.

		Year						
FMA	Species	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	Total
1	DSU	0	0	1	0	1	0	2
2	BYA	0	0	0	0	0	1	1
3	MDI	0	0	1	0	6	0	7
3	PDO	0	0	0	0	1	0	1
5	MDI	0	0	0	0	1	0	1
5	PDO	0	1	0	0	0	0	1
7	BYA	0	0	6	6	2	0	14
7	DAN	0	7	9	11	2	0	29
7	DSU	0	0	9	9	2	0	20
7	MDI	0	6	19	58	3	0	86
7	MMI	2	15	21	57	11	0	106
7	PDO	0	0	15	41	14	0	70
7	SAE	1	14	15	38	8	0	76
Total		3	43	96	220	51	1	414

2.2 Recreational and Maori fisheries

Recreational and traditional harvesting of surf clams has been largely confined to the accessible intertidal species *P. subtriangulata* and *P. ventricosum.* On the Kapiti and Manawatu coasts, *P. subtriangulata* supported important Maori hand-picking fisheries. Steamed and dried tuatua meats were an important part of the diet of local Maoris (Carkeek 1966, Butts 1981, 1982a). Both oral tradition (Marsh & Craig 1988) and the numerous substantial middens of *P. subtriangulata* shell alone clearly show this fishery to have been important for several hundred years. Midden evidence shows that the equally accessible estuarine shellfish (pipi, *Paphies australe*, and cockle, *Austrovenus stutchburyi* and *Cyclomactra ovata*) have been the next most important shellfish hand picked by the Maori.

The offshore surf clam species are rare in middens. They have been as inaccessible to the Maori as to the European. Oral tradition, and midden occurrence, points to the offshore surf clams being harvested only when washed ashore in high tides after storms (Carkeek 1966). *M. murchisoni*, *S. aequilatera*, *B. yatei*, and *D. anus* have been found irregularly and make up only a small proportion of the shells in the few middens that contained them (Best 1918, Carkeek 1966, Butts 1981, 1982a, 1982b). Although *Longimactra elongata* has not been caught in dredging along this coast, Adkin (1948) recorded its presence in middens of the Horowhenua. Carkeek (1966) found that the intertidal toheroa (*P. ventricosum*) occurred more rarely in middens and in much lower proportion than its relative abundance on the beach at the time of his writing. These data suggest that species composition or dominance of particular shellfish along this coast may change over time. Review of the archaeological literature in other areas of New Zealand may reveal different patterns in the harvesting of the intertidal clams, but is likely to show the same pattern in the harvesting of the offshore surf clams.

Maori fishing today is not so intense but is still focused on *P. subtriangulata*, with some hand-picking of *P. ventricosum*. Recreational fishing has centred on hand gathering the accessible intertidal mesodesmatid species, the intertidal tuatua, *P. subtriangulata*, and the toheroa, *P. ventricosum*, with some limited hand-picking of *P. donacina* just below low water (on those beaches where this species extends up the beach to extreme low water). These species are included in non-commercial fishing regulations. Offshore species have been harvested only from occasional storm wracks (e.g., Eggleston & Hickman 1972).

Only catches of tuatua have been recorded in recreational fishing surveys funded by the Ministry of Fisheries. The data do not differentiate between *Paphies subtriangulata* and *P. donacina*, and other species may have also been recorded as tuatua (Table 3).

Table 3: Estimated recreational catches (kg) of tuatua (species not defined) by FMA for 3 summers between 1991 and 1994. The Ministry of Fisheries funded the recreational fishing surveys. Catches less than 500 kg are denoted as 0 and no data by –.

	Year		
FMA	1991–1992	1992–1993	1993–1994
1	0	52 000	237 000
2	–	49 000	7 000
3	21 000	–	–
4	–	–	–
5	0	–	–
6	–	–	–
7	2 000	–	–
8	–	33 000	1000
9	–	–	52 000

The intertidal tuatua (*P. subtriangulata*, PSU) probably represent most of this catch. These data have not been gathered regularly enough to describe fishing patterns, but clearly show that this species is an important recreational fishery in northern New Zealand.

There are no documented records of traditional Maori catches. Much of this traditional catch may be included in the recreational catch data.

2.3 Other sources of fishing mortality

The catch efficiency of hydraulic dredges is the percentage of surf clams in the path of the dredge that are captured. In investigations of catch efficiency, Michael et al. (1990) found that the "Rabbit" hydraulic dredge was 65% efficient on the Manawatu Coast. Cranfield et al. (1994b) found their smaller experimental hydraulic dredge was 73% efficient in Clifford Bay. Surf clams not caught by the dredge probably pass beneath the bit bar and do not come in contact with the dredge. Most of these surf clams are unlikely to be damaged in the process. Likewise, small surf clams passing through the filtration grill of the dredge are unlikely to be damaged or suffer mortality. However, surf clams could be damaged (some fatally) as the dredges alternately dig into the seabed and skip over it fishing in rough sea conditions. The same can happen when the dredges are not operating efficiently in liquefying the seabed. We do not know how much mortality poorly functioning dredges can cause.

Surf clams caught in the dredge and discarded after sorting may not rebury into the seabed very quickly and may be washed ashore and die. The rate of mortality from this cause is unknown and would be dependent on the weather and strength of the tidal current.

3. RESEARCH

3.1 Stock structure

No information is available on stock structure in surf clams. All species have a free-swimming larval life of probably 20–30 days (cf. Redfearn 1964) so gene flow should not be restricted over moderate distances. Smith et al. (1989) studied the variation in electromorphs of the inter-tidal tuatua, *P. subtriangulata*, and found evidence that gene flow was restricted between northern and central New Zealand. They related this to the major current patterns. Similar patterns can be expected in other surf clams species.

3.2 Resource surveys

Stratified random surveys of the biomass of individual clam species have been carried out in Cloudy Bay, Marlborough, in 1989 (Cranfield et al. 1994b), in Clifford Bay, Marlborough, in 1989 (Michael et al. 1994), and a segment of the Manawatu coast in 1992 (Haddon et al. 1996).

The distribution of surf clams around New Zealand, their zonation with depth, and biomass were studied in 450 m wide survey strips of beaches at 16 locations (Figure 1) in 1991 (Cranfield et al. 1994a). The east coasts of the North and South Islands, Southland, and central New Zealand were sampled; weather conditions precluded sampling on much of the west coast of the North Island.

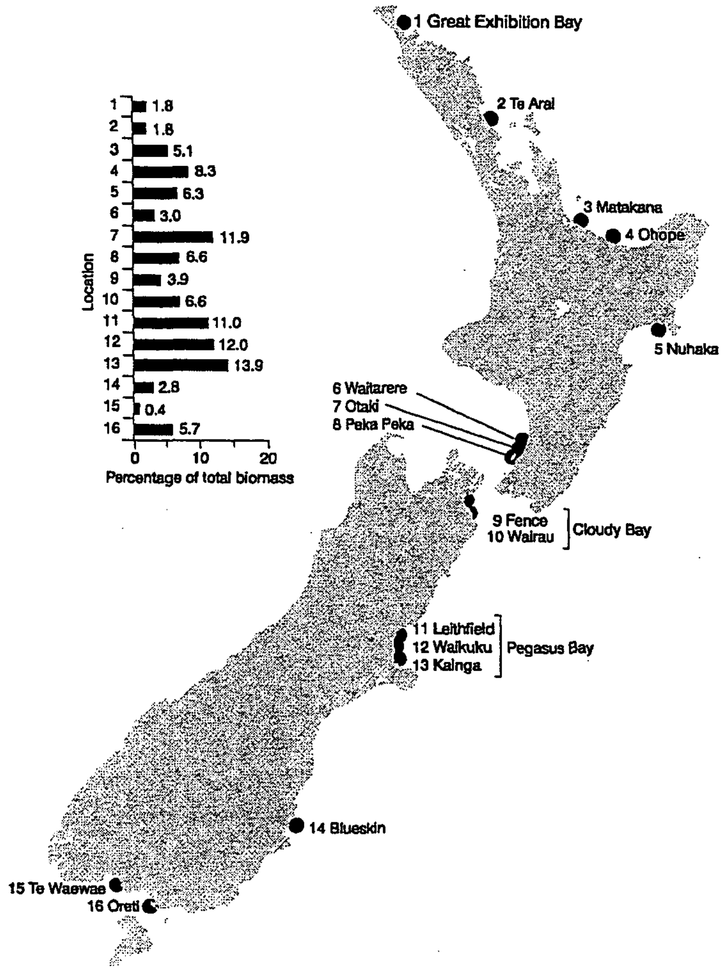

Figure 1: The 16 sites where the biomass of surf clams was estimated from 450 m wide survey strips and the percentage of the combined biomass from all sites, for each survey strip (Cranfield et al. 1994a).

3.2.1 Distribution of species

Three families of surf clams dominate in different regions of New Zealand. Venerid clams dominate the beaches of northern New Zealand, the mactrids dominate the central and southern beaches, and the mesodesmatid was commonest in central beaches. At the northern locations, the venerids, *D. anus* and *D. subrosea*, make up the major proportion of the surf clam biomass, and *D. anus* is abundant at all other North Island locations. The mactrids and mesodesmatid become increasingly abundant south of Ohope. At Ohope, *S. aequilatera* accounts for 30% of the biomass. The mesodesmatid, *P. donacina*, is most abundant around central New Zealand from Nuhaka on the east coast, south to the Kapiti coast, Cloudy Bay and as far south as Pegasus Bay. The mactrids, *M. murchisoni*, *M. discors*, and *S. aequilatera*, are most abundant in the South Island. *M murchisoni* and *M. discors* dominate in Southland (Blueskin Bay, Te Waewae, and Oreti) where they account for more than 80% of the total biomass (Cranfield et al. 1994a).

3.2.2 Zonation of species with depth

Surf clams were caught in depths between low water and 10 m, with each species distributed over a distinct depth zone. The species follow the same order of succession throughout New Zealand, but the depth distribution of each species varied between locations (Cranfield et al. 1994a). The depth distribution of species is given in Table 4.

Table 4: The depth at which each species is most abundant and the depth range in which they occur in the North and South Islands. Depths are given as depth below chart datum (Cranfield et al. 1994).

Species	Optimal depth range (m)	North Island depth range (m)	South Island depth range (m)
Paphies donacina	2–3	2–4	2–4
Spisula aequilatera	3–7	3–5	4–8
Mactra murchisoni	4–8	4	5–6
Mactra discors	3–7	4–6	3–7
Dosinia anus	4–10	5–8	6–10
Dosinia subrosea	6–10	6–10	5–8
Bassina yatei	6–9	6–9	6–9

3.3 Other studies

Haddon et al. (1996) investigated the distribution of surf clams off Foxton beach and found *P. donacina* densities peaked below 2 and 3 m, and no individuals were found deeper than 4 m. *S. aequilatera* densities peaked between 2 and 3 m, but it was found out to 9 m. The mean size of populations of both species decreased inshore. The densities of *M. murchisoni* peaked at 3–4 m, but were abundant below 6 m. The densities of *M. discors* peaked between 3 and 5 m and were common out to 9 m. *D. anus* was common at all depths, but peak densities were between 5 and 7 m. They also found that the mean size of *P. donacina* and *S. aequilatera* (the shallow water species) became smaller towards the shoreline whereas the mean size of the deeper water group, *M. murchisoni, M. discors* and *D. anus,* became larger towards the shore.

3.3.1 Growth

Growth rates of five species of surf clams (*Paphies donacina, Spisula aequilatera, Mactra murchisoni, M. discors* and *Dosinia anus*) were estimated at two locations; Cloudy Bay, Marlborough, and on the Kapiti coast, from analyses of sequential length frequency samples with the computer program MULTIFAN (Fournier et al. 1990) and analyses of incremental growth of marked individuals over a one year period using the computer program GROTAG. MULTIFAN estimates rely primarily on the growth of juvenile year classes. GROTAG estimates growth rate from growth increments of individual clams that in this investigation were on average larger than the juvenile year classes that were important in the MULTIFAN estimates. The age-based estimates of growth from MULTIFAN are not comparable with the length-based estimates of growth from GROTAG, but graphical comparisons show that for each species of surf clam their estimates of growth rate were similar (Cranfield et al. 1996).

Von Bertalanffy growth curves were fitted to length frequency distributions for each species using the computer programme MULTIFAN. Four versions of the MULTIFAN model were fitted to these data (Cranfield et al. 1996 and Cranfield & Michael 2001) The results are given in Table 5.

Growth increment data were analysed using GROTAG (Francis 1988). The Von Bertalanffy model with the parameterisation of Francis (1988a) was fitted to these data. The GROTAG model modified to incorporate an asymptotic reduction in growth rate fitted some of the data better (Cranfield et al. 1996, Cranfield & Michael 2001). The results are given in Table 6.

Table 5: Von Bertalanffy parameter estimates (with standard errors) for MULTIFAN best-fit models for all species form Cloudy Bay and the Kapiti coast, 1990–91. Amplitude and phase parameters describe seasonal growth. s.d., standard deviation, c, constant, v, variable. Estimates of t_0 were calculated by $t_0 = T - a_1$ where T is the time in years between the nominal birth date and the first sample containing individuals of year 1 (0+ year class), assigned month 1 samples in MULTIFAN. Nominal birth dates were assigned as the first week in March for all species based on our knowledge of the histology of the reproductive cycles of two species (authors unpublished data on *M. murchisoni* and *P. donacina*). a_1 is the estimated age of the year class 1 in the month 1 sample calculated by the MULTIFAN model.

Species	*P. donacina*		*S. aequilatera*		*M. murchisoni*		*M. discors*	
Cloudy Bay								
s.d.	v		v		c		c	
Number of age classes	10		5		8		7	
k (year^{-1})	0.33	(0.01)	1.01	(0.02)	0.57	(0.01)	0.41	(0.03)
L_∞ (mm)	94.10	(0.29)	60.30	(0.92)	88.00	(0.44)	68.00	(0.35)
t_0 (years)	-0.10	(0.03)	0.40	(0.02)	0.10	(0.02)	0.20	(0.09)
Amplitude ϕ_1	0.95	(0.01)	0.95	(0.01)	0.95	(0.01)	0.95	(0.01)
Phase ϕ_2 (years)	0.00	(0.02)	0.30	(0.01)	0.12	(0.01)	0.06	(0.03)
Average s.d. (mm)	4.37	(0.47)	5.40	(0.57)	5.74	(0.58)	4.04	(0.20)
Ratio s.d.	1.89		0.52		1.00		1.00	
Kapiti coast								
s.d.			v		c		v	
Number of age classes			3		6		8	
K (year^{-1})			0.80	(0.03)	0.60	(0.02)	0.35	(0.10)
L_∞ (mm)			52.10	(0.25)	72.30	(0.41)	60.10	(0.89)
t_0 (years)			0.20	(0.3)	0.40	(0.02)	0.30	(0.13)
Amplitude ϕ_1			0.95	(0.01)	0.95	(0.01)	0.95	(0.01)
Phase ϕ_2 (years)			0.94	(0.01)	0.93	(0.02)	0.66	(0.03)
Average s.d.			4.90	(0.20)	5.12	(0.26)	3.61	(1.67)
Ratio s.d.			0.62	(0.01)	1.00		0.58	(0.08)

Expected increments of the five species of surf clams from the Kapiti coast and Cloudy Bay estimated from MULTIFAN and GROTAG are shown in Figure 2. Expected increments from GROTAG show no consistent pattern between locations, but MULTIFAN data show Cloudy Bay surf clams have a greater expected increment.

Growth data from the mark-recapture experiments at both North Island and South Island sites show that individual growth is highly variable and may change with depth. Limiting growth experiments to more precise depth zones may reduce variation in growth and make among-site comparisons more meaningful.

Table 6: Growth parameters estimated by GROTAG analyses for Cloudy Bay (1991–92) and Kapiti coast surf clams (1992–93). The Von Bertalanffy growth parameters L_∞ and k are replaced with g_α and g_β mean annual growth rates at sizes α and β, respectively, where α and β are chosen to cover the range of sizes of surf clams at marking, and transitional length L^*, at which the model 2 allows an asymptotic reduction on growth rate. 95% confidence intervals of g_α and g_β are in parenthesis. Von Bertalanffy parameters are estimated from formulae, $L_\infty = (\beta g_\alpha - \alpha g_\beta)/(g_\alpha - g_\beta)$ and $k = -\log[1 + (g_\alpha - g_\beta)/(\alpha - \beta)]$.

Cloudy Bay species	α (mm)	g_α (mm year $^{-1}$)		β (mm)	g_β (mm year $^{-1}$)		L^* (mm)	L_∞ (mm)	k (mm year $^{-1}$)	residual error
Paphies donacina	50	10.26	(9.7-10.8)	80	1.41	(1.1-1.7)	80.0	84.8	0.33	1.25
Spisula aequilatera	30	22.71	(22.2-23.0)	50	6.23	(6.0-6.4)	55.0	57.6	1.01	2.04
Mactra murchisoni	40	17.83	(17.4-18.2)	70	4.65	(4.3-4.9)	80.0	80.6	0.57	1.42
Mactra discors	35	11.01	(10.5-11.7)	55	2.69	(2.4-2.9)	62.0	61.5	0.41	0.63
Dosinia anus	20	12.50	(12.0-13.2)	55	1.99	(1.8-2.2)	63.0	61.6	-	0.44

Kapiti coast species	α (mm)	g_α (mm year $^{-1}$)		β (mm)	g_β (mm year $^{-1}$)		L^* (mm)	L_∞ (mm)	k (mm year $^{-1}$)	residual error
Paphies donacina	58	2.31	na	77	1.97	na	na			1.19
Spisula aequilatera	30	18.74	(16.4 - 20.8)	50	3.50	(0.9 - 6.0)	na			2.31
Mactra murchisoni	30	35.70	(33.2 - 38.0)	70	2.03	(1.2 - 2.6)	70	72.4	1.84	2.00
Mactra discors	40	5.27	(3.9 - 6.3)	65	1.30	(0.0 - 2.7)	na			1.25
Dosinia anus	20	13.52	(13.3 - 14.0)	48	2.05	(1.7 - 2.5)	50	53.0	0.53	2.49

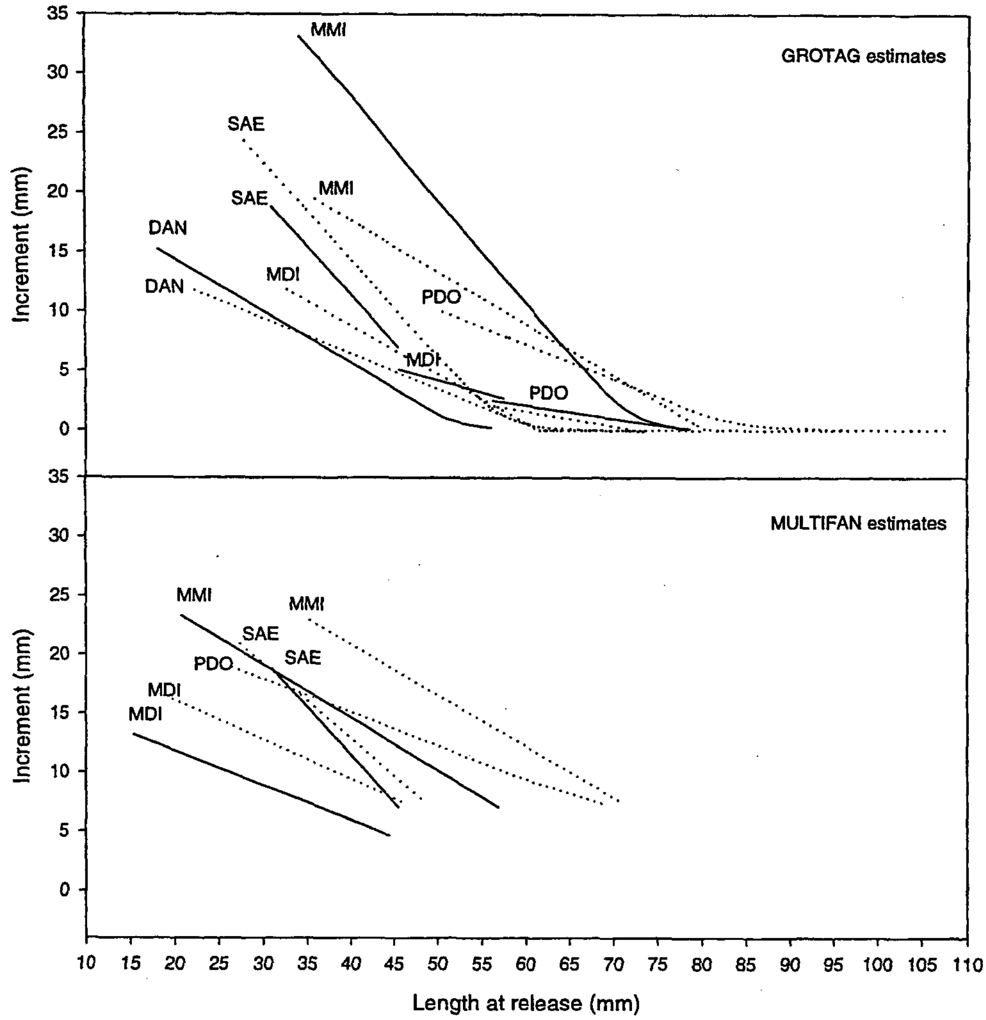

Figure 2: Graphical comparison of growth rates estimated by GROTAG (top) and MULTIFAN (bottom), for the five species of surf clam, PDO, *Paphies donacina*; SAE, *Spisula aequilatera*; MMI, *Mactra murchisoni*; MDO, *M. discors* and DAN, *Dosinia anus* on the Kapiti coast (solid lines) and Cloudy Bay (dotted lines). Top figure gives the expected mean annual length increment of surf clams plotted against length at release from GROTAG models. The lower figure gives expected mean annual growth at age from the MULTIFAN best-fit models is plotted against the mean length at each age. GROTAG estimates describe growth in the size range of marked clams recaptured for the year October 1992 and October 1993 at liberty only. Caution should be used when inferring population growth parameters from these data.

No age axis is given because length at age differs between species. The mactrids *Spisula aequilatera* and *Mactra murchisoni* grow the fastest. Individuals of each surf clam species grew larger at Cloudy Bay than on the Kapiti coast. A combination of barriers to gene flow (Smith et al. 1989) and different environmental factors at the two locations are most likely to account for these differences in maximum size and growth rate.

3.3.2 Recruitment patterns

Conroy et al. (1993) showed that patterns in recruitment of surf clams varied from year to year. Large numbers of juveniles *M. discors* were sampled on the Kapiti coast in 1990 but juveniles of *M. murchisoni* were scarce. In 1991, the pattern of recruitment was reversed, with large numbers of juvenile *M. murchisoni* caught.

3.4 Biomass estimates

Biomasses of surf clams have been estimated in Cloudy Bay and Clifford Bay, Marlborough, Rabbit Island, Nelson, and along Foxton beach on the Manawatu coast. A summary of results is shown in Table 7.

Table 7: A summary of biomass estimates in tonnes green weight with standard deviation in parentheses from exploratory surveys of Cloudy Bay, Marlborough (Cranfield et al. (1994b), Rabbit Island Nelson (Michael & Olsen 1988), Clifford Bay, Marlborough (Michael et al. 1994), and Foxton beach, Manawatu coast (Haddon et al. 1996). – denotes no data.

Area Species	Cloudy Bay		Clifford Bay		Foxton Beach		Rabbit Island	
Length of beach (km)	11		21		27.5		8	
Paphies donacina	154	(60)	284	(123)	171	–	108	–
Spisula aequilatera	53	(22)	358	(152)	29	–	–	–
Mactra murchisoni	248	(96)	192	(79)	145	–	*146	–
Mactra discors	55	(28)	89	(3)	195	–	*	–
Dosinia anus	72	(30)	5	(3)	491	–	146	–
Dosinia subrosea	21	–	–	–	–	–	–	–
Bassina yatei	123	(50)	0.2	(0.8)	–	–	–	–

* The biomass estimates for *Mactra murchisoni* and *Mactra discors* are combined, as the species were not separated in the sampling.

The biomass of surf clams around New Zealand was estimated in 450 m wide survey strips on beaches at 16 locations in 1991 (Cranfield et al. 1994a). The east coasts of the North and South Islands, Southland, and central New Zealand were sampled; weather conditions precluded sampling on much of the west coast of the North Island. The estimates of biomass are given in Table 8.

Table 8: Estimates of biomass (t) and area for the 450 m-wide survey strips of beaches, the mean biomass per square metre of beach (kg/m²), and the mean biomass per metre of beach (kg/m) at 16 locations around New Zealand

Location	Biomass (t)	c.v.	95 % CI Lower		95 % CI Upper	Area (km^2)	Biomass kg/m^2	Biomass kg/m
Great Exhibition Bay	1.03	21	0.3	–	1.9	270	0.003	2.2
Te Arai	1.02	37	0.6	–	1.5	190	0.005	2.2
Matakana	29.45	91	0	–	81.8	440	0.066	65.4
Ohope	47.87	17	31.6	–	65.0	1 030	0.046	106.3
Nuhaka	63.75	31	24.4	–	103.1	530	0.120	141.6
Waitarere	17.33	20	15.0	–	19.8	558	0.031	38.5
Otaki	66.30	18	46.0	–	57.8	525	0.126	147.3
Peka Peka	36.89	23	30.6	–	43.2	509	0.072	81.9
Fence	21.51	21	18.2	–	25.0	547	0.039	47.9
Wairau	36.73	22	30.2	–	43.2	827	0.044	81.6
Leithfield	63.29	21	36.3	–	90.3	985	0.064	140.6
Waikuku	68.72	12	53.0	–	84.8	404	0.170	152.7
Kainga	80.15	18	52.1	–	108.3	751	0.106	178.1
Blueskin *	16.05	55	0	–	33.4	360	0.044	35.6
Te Waewae	2.24	56	0	–	4.7	1 137	0.001	4.9
Oreti	32.85	14	23.8	–	41.9	730	0.045	73.0

* Sampling incomplete

The data of Haddon et al. (1996) from Foxton beach and Cranfield et al. (1993) from Waitarere 10 km south can be compared. Surf clam biomass along Foxton beach equated to 37.5 t/km of coastline (based on 100% dredge efficiency); and off Waitarere (in a 450 m wide strips of beach and using a dredge efficiency of 73%) 38.5 t/km. At Foxton beach in 1992, 50% of the biomass was *D. anus*, 19% *M. discors*, 16% *P. donacina*, 14% *M. murchisoni*, 3% *S. aequilatera*. At Waitarere in 1991 62% of the biomass was *D. anus*, 21% *M. murchisoni*, 10.8% *M. discos*, 3% *P. donacina* only 1% *S. aequilatera*. The data are quite similar. Difference in species represented may relate to difference in vulnerability to the two types of dredge. The shape and depth of burial of each species may make each species more or less vulnerable to each of the two dredge types. The difference in species composition at the two locations may also relate to systematic changes in the degree of exposure along the coast (northern beaches are more exposed to ocean swells than southern beaches), or differences in recruitment patterns between the two sampling years (c.f. Conroy et al. 1993).

3.5 Yield estimates

3.5.1 Estimates of Maximum Constant Yield (MCY)

In 1989 yield estimates for surf clam species were required for managing a fishery in Cloudy Bay. In the absence of any data from which to estimate mortality or $F_{0.1}$, the management regimes for similar species around the world were reviewed. In the U.S., a fishery for the surf clam *Spisula solidissima* has been managed since 1976 using estimates of yield per recruit to estimate the maximum sustainable yield (Chang et al. 1976). In 1988 the yield was re-estimated from a stochastic simulation model that used a harvest strategy that maximised the constant yield but buffered the effects of variable recruitment (Mid-Atlantic Fishery Management Council 1985). This independent estimate of MSY was the same as that estimated in 1976 from yield per recruit analysis. In 1985 this MSY represented a harvest of 4.5% of the exploited biomass and as the U.S. population had been fished sustainably at this level of exploitation, it was taken as a surrogate estimate of a conservative harvest level for New Zealand surf clams. As a further precaution, this yield was used to estimate a maximum constant yield for the virgin biomass.

Method 1 for estimating yield for new fisheries (Annala & Sullivan 1997) is

$$MCY = 0.25 * F_{0.1} * B_o$$

Here 0.045 was used as a substitute for $0.25*F_{0.1}$ (or $0.25*M$) until further data on growth and mortality of surf clams were available.

Because of the zonation of species with depth, fishers could target individual species so a yield was estimated for each individual species. It was assumed that each species would be similarly productive, so the 4.5% figure was used to estimate the yield for all seven species. The MCY estimates for Cloudy Bay in 1989 was 39.7 t. and for Clifford Bay was 43 t (Cranfield et al. 1994b).

The growth and mortality data for individual species of surf clams at Cloudy Bay and on the Kapiti coast (Cranfield et al. 1993) were used in a yield per recruit analysis (Cranfield et al. 1996.) to estimate $F_{0.1}$ for surf clams at both sites (Cranfield et al. 1993) in 1993. The estimates of $F_{0.1}$ for five of the seven species of surf clams in Cloudy Bay and four of the six species of surf clams on the Kapiti coast for the likely range of natural mortality in each species, are shown in Table 9.

Table 9: Estimates for $F_{0.1}$ obtained from yield per recruit analysis for five species of surf clams using figure for natural mortality that bracket those estimated for maximum ages. Data for *Paphies donacina* on the Kapiti coast were inadequate to run a yield per recruit analysis

Cloudy Bay

M. murchisoni		*M. discors*		*S. aequilatera*		*P. donacina*		*D. anus*	
M	$F_{0.1}$	*M*	$F_{0.1}$	*M*	$F_{0.1}$	*M*	$F_{0.1}$	*M*	$F_{0.1}$
0.35	0.43	0.30	0.46	0.55	1.06	0.25	0.36	0.20	0.25
0.40	0.50	0.35	0.54	0.60	1.16	0.30	0.44	0.25	0.33
0.45	0.57	0.40	0.64	0.65	1.26	0.35	0.52	0.30	0.42
				0.70	1.37				

Kapiti coast

M. murchisoni		*M. discors*		*S. aequilatera*		*D. anus*	
M	$F_{0.1}$	*M*	$F_{0.1}$	*M*	$F_{0.1}$	*M*	$F_{0.1}$
0.40	0.70	0.30	0.56	0.70	1.12	0.15	0.27
0.45	0.79	0.35	0.66	0.80	1.34	0.20	0.35
0.50	0.89	0.40	0.77	0.90	1.56	0.25	0.44
		0.45	0.87			0.30	0.54

Using the lowest value of $F_{0.1}$, the recalculated MCY yields for Cloudy Bay are shown in Table 10 and for Clifford Bay in Table 11.

Table 10: MCY estimates for surf clams in Cloudy Bay. Virgin biomass estimates from Cranfield et al (1994c)

	Virgin biomass (B_0) (t)	$F_{0.1}$	MCY (t)
Paphies donacina	172	0.36	15.5
Spisula aequilatera	62	1.06	16.4
Mactra murchisoni	287	0.43	30.8
Mactra discors	54	0.46	6.2
Dosinia anus	74	0.25	4.6
*Dosinia subrosea**	22	0.25	1.4
*Bassina yatei**	127	0.25	7.9
Total			82.8

* In the absence of data on growth and mortality of these species, the estimate of $F_{0.1}$ for *Dosinia* anus has been used. As these species appear to be similar ecologically, this assumption is unlikely to give rise to great errors.

Table 11: MCY estimates for surf clams in Clifford Bay. Virgin biomass (B_0) estimates from Michael et al. (1994)

	Virgin biomass (B_0) (t)	$F_{0.1}$	MCY (t)
Paphies donacina	287	0.36	25.8
Spisula aequilatera	359	1.06	95.1
Mactra murchisoni	200	0.43	21.5
Mactra discors	107	0.46	12.3
Dosinia anus	9	0.25	0.5
*Bassina yatei**	10	0.25	0.6
Total			155.8

* In the absence of data on growth and mortality of these species, the estimate of $F_{0.1}$ for *Dosinia* anus has been used. As this species appears to be similar ecologically, this assumption is unlikely to give rise to great errors.

MCY yields for linear kilometres of beach at 15 sites around New Zealand have been estimated using the estimate of $F_{0.1}$ from Cloudy Bay for the seven South Island sites, and estimates of $F_{0.1}$ from the Kapiti coast for eight North Island sites (Cranfield et al. 1994.b), (Table 12).

Table 12: MCY estimates (t) from virgin biomass in 450 m transects at 15 of the 16 locations sampled around New Zealand (data from Blueskin Bay inadequate to estimate yields) summed by species and expanded to estimate yield per kilometre of beach at those locations.

	F_{al} North Island*	Great Exhibition Bay (1)	Te Arai (2)	Matakana Island (3)	Ohope (4)	Nuhaka (5)	Waitarere (6)	Otaki (7)	Peka Peka (8)
Paphies subtriangulata	0.36 **	0	0	0.02	0.037	0	0.002	0.059	0.004
Paphies donacina	0.36 **	0	0	0	0	2.830	0.052	2.307	1.328
Spisula aequilatera	1.12	0	0	0.03	4.584	0.050	0.028	0.133	0.181
Mactra murchisoni	0.70	0	0	0.03	0.989	0.327	1.046	1.098	0.714
Mactra discors	0.56	0	0	0.10	0.198	0	0.252	0.993	0.805
Dosinia anus	0.27	0.032	0.017	1.77	1.705	2.254	0.719	2.085	0.973
Dosinia subrosea	0.27 ‡	0.031	0.050	0.13	0.034	0.036	0.025	0.009	0
Bassina yatei	0.27 ‡	0	0	0.01	0.003	0	0.009	0.005	0.004
Total yield summed for all species (t)		0.63	0.67	2.08	7.551	5.497	2.133	6.690	4.0627
Yield expanded to 1 km of beach (t)		.141	.149	4.639	16.781	12.217	4.742	14.86	9.028

	F_{al} South Island†	Fence (9)	Wairau (10)	Leithfield (11)	Waikuku (12)	Kainga (13)	Te Waewae (15)	Oreti (16)
Paphies subtriangulata	0.36 **	0	0	0	0	0	0	0
Paphies donacina	0.36 **	0.028	0.019	1.521	2.341	2.005	0	0
Spisula aequilatera	1.06	0.002	0.040	8.336	8.638	5.140	0.266	0.397
Mactra murchisoni	0.43	0.096	2.231	1.340	0.219	1.059	0.108	0.116
Mactra discors	0.46	0.083	0.098	0	0	0	0	3.487
Dosinia anus	0.25	0.200	0.357	0.107	0.163	1.773	0.014	0
Dosinia subrosea	0.25 †	0.055	0.038	0.040	0	.008	0	0
Bassina yatei	0.25 †	0.228	0.520	0.002	0	0	0	0
Total yield summed for all species (t)		1.838	3.303	11.354	11.361	9.985	0.388	4.000
Yield expanded to 1 km of beach (t)		4.086	7.340	25.231	25.248	22.189	0.864	8.890

* Assumes that F_{al} estimated at Peka Peka will be the same (or similar) at all other North Island locations.
** No estimate of F_{al} is available for *P. subtriangulata* so that for *P. donacina* from Cloudy Bay has been substituted.
F_{al} has been estimated only at Cloudy Bay so far for *P. donacina*. In the absence of North Island data this value has been used as a substitute.
† Assumes that F_{al} estimated at Cloudy Bay will be the same (or similar) at all other South Island locations.
‡ Assumes that these species related to *D. anus* and living in the same part of the surf zone will be similar and F_{al} for *D. anus* can be used as a substitute for their F_{al}.

3.5.2 Estimation of Current Annual Yield (CAY)

Although CAY has not been estimated for any surf clam population in New Zealand, the earlier estimates of virgin biomass in Cloudy and Clifford Bays show that CAY yields for different species are two to three times larger than MCY estimates because of the considerable accumulation of adult year classes in these virgin populations.

4. FACTORS MODIFYING YIELDS

4.1 Precision of biomass estimates

The factors influencing the distribution and relative abundance of surf clams on New Zealand beaches are poorly understood so we are unable to stratify sampling designs to include all sources of variation. On many beaches, the 1 metre depth contours are only 40–50 m apart; small errors in measuring the stratum boundaries they define will result in large errors in estimates of stratum area. Where there are large changes in density between adjacent strata, these errors could result in inaccurate estimates of biomass.

4.2 Variability of recruitment

Year class strength of surf clams varies widely from year to year (Cranfield et al.1993 and Conroy et al. 1993). Recruitment variability may be due to environmental factors, predation, or disease, but these must act very specifically to affect only one or two of the range of species at the localities investigated. The turbulent nature of the surf zone suggests that surf clams could be prone to periodic catastrophic mortality from erosional events during storms, and therefore they are likely to produce large numbers of recruits and be able to rapidly recolonise beaches after such storms. Surf clams are present on many New Zealand beaches at below commercial densities. Settlement from larvae dispersed from any of these low density populations could rapidly replenish depleted stocks. Such replenishment occurred in the U.S. surf clam fishery in 1976 after a widespread anoxic fish kill killed surf clams within the main fishery area, but not elsewhere (Ropes 1980).

Sporadic and localised recruitment events have maintained the U.S. surf clam fishery for up to 10 years. This suggests caution in the approach to harvesting until more is known of the reliability of recruitment in New Zealand. A CAY harvesting regime that estimates the biomass of surf clams annually would provide data on the local variation in recruitment, reduce the risks of recruitment overfishing, and result in a higher average yield to the fisher if biomass varies greatly from year to year. (Cranfield et al. 1994b, Haddon et al. 1996.)

4.3 Size and age at first harvest

A YPR model has not been used to estimate optimum size limits for each species. Discarded undersized clams may be too slow to rebury to avoid being swept ashore or becoming the victims of predators. Regulations specifying filtration grill spacing on dredges can achieve the desired selectivity *in situ.* Because of the very different shapes of the clam species, it could be difficult to optimise YPR for all species this way.

5. MANAGEMENT IMPLICATIONS

5.1 Variation in biomass

Species composition of surf clams varies around New Zealand and factors that affect biomass vary widely between beaches and even within them (Cranfield et al. 1994a). The biomass of every beach fished will need to be estimated to estimate yields. Although biomass can be estimated efficiently, this requirement will impose some costs in developing and managing the fishery. It may be better to obtain preliminary biomass estimates and to set the initial harvest at a very conservative level to allow a fishery to commence. As individual fisheries develop, and better data on distribution become available, improved estimates of the biomass could be made and the sustainable yield (CAY) could then be estimated more precisely.

5.2 Serial depletion

Surf clams are highly localised sedentary stocks. Hydraulic dredging will be able to substantially deplete local stocks and could easily, serially deplete stocks that are close to ports or launching sites (see Froglia 1989.)

5.3 Variation in population parameters between species

Every species has a different growth rate, and a different optimal harvest level. The zonation of species with depth will probably allow individual species to be targeted by fishers. Haddon et al. (1996) disagree with this viewpoint, but these authors towed the dredge perpendicular to the shore rather than parallel, which would certainly make targeting individual species difficult. To avoid sequential serial depletion of valuable species, and to allow for the different productivity of each species (the most productive species being three to four times more productive than the least), each species may need to be managed separately.

5.4 Usefulness of CPUE in monitoring surf clam abundance

Because of the high efficiency of hydraulic dredges, CPUE could give a good measure of abundance of surf clams. However, fishers are likely to follow a rotational dredging strategy within the area fished and hence CPUE in any one year will reflect abundance in only a proportion of that area and the population. Furthermore, even within the area fished different species may be targeted (possibly differently in different years) depending on market needs. CPUE will therefore be of limited value in monitoring relative abundance of surf clams in this fishery.

5.5 Variation in recruitment and mortality

Variation in recruitment, and the probability of high mortality from storms, could result in the biomass varying greatly from year to year. An MCY strategy could increase the risk to the stock when biomass is low and result in under-exploitation when biomass is high. A CAY strategy would minimise the risks to the stock from overfishing when it is at very low levels. A CAY strategy could also result in higher yields from the fishery by fully exploiting the stock when biomass is high.

5.6 Other factors

5.6.1 Environmental effects of dredging

The surf zone is ecologically largely self-contained. Nevertheless, the impact of harvesting sub-tidal surf clams on stocks of intertidal tuatua and toheroa should be monitored. Sediments of the surf zone are being resuspended constantly as the energy of waves is dissipated on the beach. Although the immediate impact of hydraulic dredging is indiscernible a few hours after the passage of the dredge, hydraulic dredges have a greater potential to modify the environment than any dredge previously used in New Zealand. The ecological consequences of their widespread and intensive use should be assessed.

5.7 State of the stocks

All New Zealand stocks are effectively still in a virgin state. The level of fishing in Cloudy Bay and at Foxton beach will not have reduced these populations below virgin levels. Given the variable recruitment of surf clams and the probability of high mortality, virgin biomass (and fished biomass) is likely to vary widely.

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