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Review of dredge fishing technologies and practice for application in New Zealand

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EXECUTIVE SUMMARY

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We describe the different types of fishing gear used in the main scallop, oyster, and surf clam dredge fisheries worldwide and in New Zealand from information obtained from a literature review, internet search, and discussions with fishers. Where information is available, we discuss the operation of the main dredge types in terms of catching efficiency, safety and ease of use, incidental mortality of non-target and target species, non-target catch, and damage to the environment. We also present recent advances in dredge gear technology designed to minimise the adverse effects on the benthos for each fishery and their potential application in New Zealand dredge fisheries.

Scallops – We found no advances in scallop dredge gear technology that could be applied in New Zealand to reduce fishery effects on the seafloor as well as perform satisfactorily in New Zealand conditions. The Nelson ring-bag dredge results in less damage to scallops and benthic epifauna than the box dredge, but the latter was found to be more efficient and necessary on the hard substrate of Northland and Coromandel.

Oysters – A lightweight prototype 'Roderique dredge' trialled in 1997 resulted in less incidental mortality of oysters than the standard commercial double bit dredge, with similar efficiency. This offers the potential to harvest oysters in Foveaux Strait with a dredge that has fewer adverse environmental effects.

Surf clams – The hydraulic dredge offers the only feasible means of extracting surf clams from fine sand substrates and has little adverse effect on the high-energy surf zone substrate, which recovers soon after the dredge has passed. The current design is therefore acceptable if use is restricted to the surf zone.

1. INTRODUCTION

Dredging has been the main method for harvesting scallops, oysters, and clams worldwide for over 100 years, and apart from minor gear modifications and refinements it continues to be the most commonly used method for these species today.

In New Zealand and internationally fisheries research has, until recently, focused largely on assessing the sustainability of single species fish stocks using population dynamics models (Annala et al. 2001). These models generally use data that can be practically measured, i.e., catch, abundance, growth, mortality, recruitment, etc. Research into fish population dynamics continues to provide the basis for fisheries management decisions globally. It has been suggested, however, that environmental effects of fishing should be considered in both fishery assessments and fisheries management (Sherman 1990, 1992, Turner et al. 1999). For most bulk fishing methods, whether trawling, dredging, lining, set netting, or potting, it is not possible to observe the effect that these activities are having on the seafloor at the time of fishing (Watling & Norse 1998).

Many fisheries have remained productive despite long-term harvesting by mobile fishing methods such as trawling and dredging, and there has been a tendency to assume that the ecosystem sustaining the fishery is also productive and in balance with the harvesting. Dredge fishers in the world's largest scallop fishery on Georges Bank, New England, have noted that scallop production in some heavily dredged areas has increased in recent years (Smolowitz 1998). However, studies have shown that mobile fishing methods can have a major effect on the community structure of the benthic fauna (Caddy 1973, Messieh et al. 1991, Eleftheriou & Roberston 1992, Thrush et al. 1995, Auster et al. 1996, Kaiser et al. 1996, Watling & Norse 1998, Cranfield et al. 1999a, DeAlteris et al. 1999, Collie et al. 2000a). This is particularly pronounced when the frequency of disturbance occurs at intervals less than the time for recovery and also in deeper water such as continental slopes where growth tends to be slow and recovery from a single fishing encounter can take years (Watling & Norse 1998, Collie et al. 2000a).

The drivers of annual productivity of most fisheries are complex and can be related to a range of factors such as climate (Beentjes & Renwick 2001), prey and predator abundance, competition, and disease (Shepherd et al. 1984). To properly understand abundance fluctuations the ecology of the environment that species inhabit also needs to be considered. In New Zealand, the Fisheries Act (1996) provides for the utilisation of fisheries resources while ensuring sustainability, where sustainability means avoiding, remedying, or mitigating any adverse effects of fishing on the aquatic environment. All persons *exercising or performing functions, duties, or powers* under this Act, in relation to the utilisation of fisheries resources or ensuring sustainability, shall take into account that habitats of particular significance for fisheries management should be protected. Similarly, in the United States, legislation enacted in 1996 requires all fisheries management plans to have regard to the significance of the habitat to the fishery. In this regard, the term Essential Fish Habitat (EFH) is defined in legislation and refers to "....those waters and substrate necessary to fish for spawning, breeding, or growth to maturity" (Kurland 1998, Watling & Norse 1998, DeAlteris et al. 1999). This reflects a change in the attitude toward managing fisheries and the importance that habitat plays in the maintenance of a healthy fishery and ecosystem. Further, catches are no longer constrained by gear technology and to ensure sustainability of fish stocks we should also consider the ecology of the area being fished (Langton 1998). This becomes even more pressing as improvements in gear technology such as Global Positioning Systems (GPS), vessel capability, and gear efficiency have resulted in areas that were once marginal fishing grounds being routinely exploited (Smolowitz 1998).

In this report we examine the international literature on dredging and describe the different types of fishing gear used in the main scallop, oyster, and surf clam dredge fisheries around the world and in New Zealand. We discuss the operation of the main dredge types in terms of catching efficiency, safety and ease of use, incidental mortality of non-target and target species including juveniles and spat, catch of non-target species, and damage to the substrate. We also present recent advances, where they exist, in dredge gear technology for each fishery and discuss their relevance to New Zealand dredge fisheries. A glossary of terms used in this report is given in Appendix 1.

1.1 Background on dredging

Dredging is the most common bulk fishing method used to harvest scallops, oysters, and surf clams. Dredging is probably the most invasive and non-selective fishing method used today (Collie et al. 2000a, Collie et al. 2000b, Eleftheriou 2000) and involves towing a dredge across the ocean floor sifting out target species (Caddy 1973, McLoughlin et al. 1991, Messieh et al. 1991, Cryer & Morrison 1997, Michael et al. 1998, Cranfield et al. 1999a). The extent to which the dredge bites into the substrate depends on the target shellfish species, the substrate, and the type of dredge. Hydraulic dredges used for surf clams dig into and liquefy the substrate, and the surf clams are filtered out from the sand (Meyer et al. 1981, Michael et al. 1990, Lambert & Goudreau 1996). Scallop dredging may be relatively less invasive, but the effect is very dependent on the type of gear-substrate interface that disturbs scallops from the substrate and into the dredge bag or box. Scallop dredges that use tickler chains as ground tending gear are generally less invasive than those that use tines. Oyster dredges by necessity dig into the substrate to scoop up the sedentary bivalves.

The main and most apparent effects of continued dredging on a shellfish ground are loss of species heterogeneity and diversity as epibenthic organisms are removed as well as a reduction in habitat complexity as sediment is homogenized (Caddy 1973, Messieh et al. 1991, Currie & Parry 1994, Thrush et al. 1995, Auster et al. 1996, Kaiser et al. 1996, Collie 1998, Watling & Norse 1998, Cranfield et al. 1999a, Turner et al. 1999). A study of the effect of scallop dredging on the benthic communities around Coromandel Peninsula in New Zealand revealed changes in the density and composition of macrofauna, the effect of which was still apparent 3 months after dredging (Thrush et al. 1995). Cranfield et al. (1999a) studied changes in distribution of epifaunal reefs and oysters in Foveaux Strait and concluded that as dredges became heavier and vessels more efficient and powerful, epifaunal reefs were progressively modified and largely destroyed. The result was that oysters also became less abundant and possibly more prone to disease. Epibenthic reefs in Foveaux Strait have recently shown signs of recovery in areas where dredging has been prohibited (Cranfield et al. 2001).

There have been numerous studies of the effects of dredging on the environment but few research programmes have assessed ways to mitigate the adverse effects of dredging through gear modifications and/or innovative technology. The climate of world opinion on acceptable harvest methods is changing, and there are several international studies (discussed below) in the early stages with objectives focusing on developing 'environmentally friendly' harvest methods for scallops and clams. By this we mean harvest methods which provide adequate commercial harvesting capability associated with an acceptable minimal level of damage or mortality to both target and non-target organisms, and minimal environmental perturbation.

1.2 Incidental mortality

During an encounter with a dredge, shellfish other than those landed and retained, can die from damage or stress: this is termed incidental mortality. Studies vary in how incidental mortality is measured and often this is not explicit, but where it has been described in the literature we have provided details of the methods used. Incidental mortality can be either 'direct' or 'indirect'. Direct mortality occurs when the shellfish passes through or under the dredge and remains on the seafloor. Indirect mortality occurs after the shellfish is caught in the dredge and is either washed out of the dredge during landing, or is landed on board the vessel and then discarded if undersized. In both cases mortality may not occur immediately and the shellfish may die from stress, damage, or susceptibility to predation and disease within days to months (McLoughlin et al. 1991, Cryer & Morrison 1997).

2. SCALLOP DREDGE FISHERIES

Scallop dredge design, size, and construction varies greatly around the world and often reflects the local conditions, the scallop species, and precedents or history of gear design and development. For the main scallop fisheries the most commonly used dredges are described.

2.1 Northwest Atlantic scallop fishery

2.1.1 New Bedford scallop dredge

The largest dredge fisheries in the world are the scallop fisheries and the largest of these is in the Gulf of Maine on the Georges Bank (Caddy 1989) where about 12000 km^2 of seabed are dredged annually for the scallop *Placopecten magellanicus* (Collie 1998). This fishery predominantly uses the 'New Bedford' type ring-bag dredge or drag which is used in water deeper than 40 m (Smolowitz 1988) (Figure 1).

The front of the dredge consists of a heavy steel frame, called the bale, with a cutting bar at the aft section. The cutting bar is fitted with steel plated shoes on either end raising both the frame and cutting bar slightly above the seafloor. A pressure plate attached to the top of the frame helps keep the dredge on the seafloor. Sweep chains (also known as 'tickler chains') run from side to side and join the cutting bar to the lower section (section in contact with the seafloor) of the collecting bag, known as the chain or ring-bag. The ring-bag is made of linked steel rings and together with the sweep chains drags on the bottom and conforms to the contours of the seafloor (Smolowitz 1998).

The actual capture of scallops takes place at the leading edge of the gear/substrate interface (Smolowitz 1988) where the cutting bar and sweep chains run over the surface and disturb scallops which swim up and into the ring-bag. Sweep chains were introduced in about 1960 to increase dredge efficiency. Additional chains running from front to back known as rock chains are also used in some cases to prevent boulders from entering the ring-bag. The top of the ring-bag is fitted with coarse meshed twine to allow escapement of finfish. The ring-bag is held apart at the aft by a steel rod called the 'club stick' and this also maintains shape when the dredge is lifted aboard.

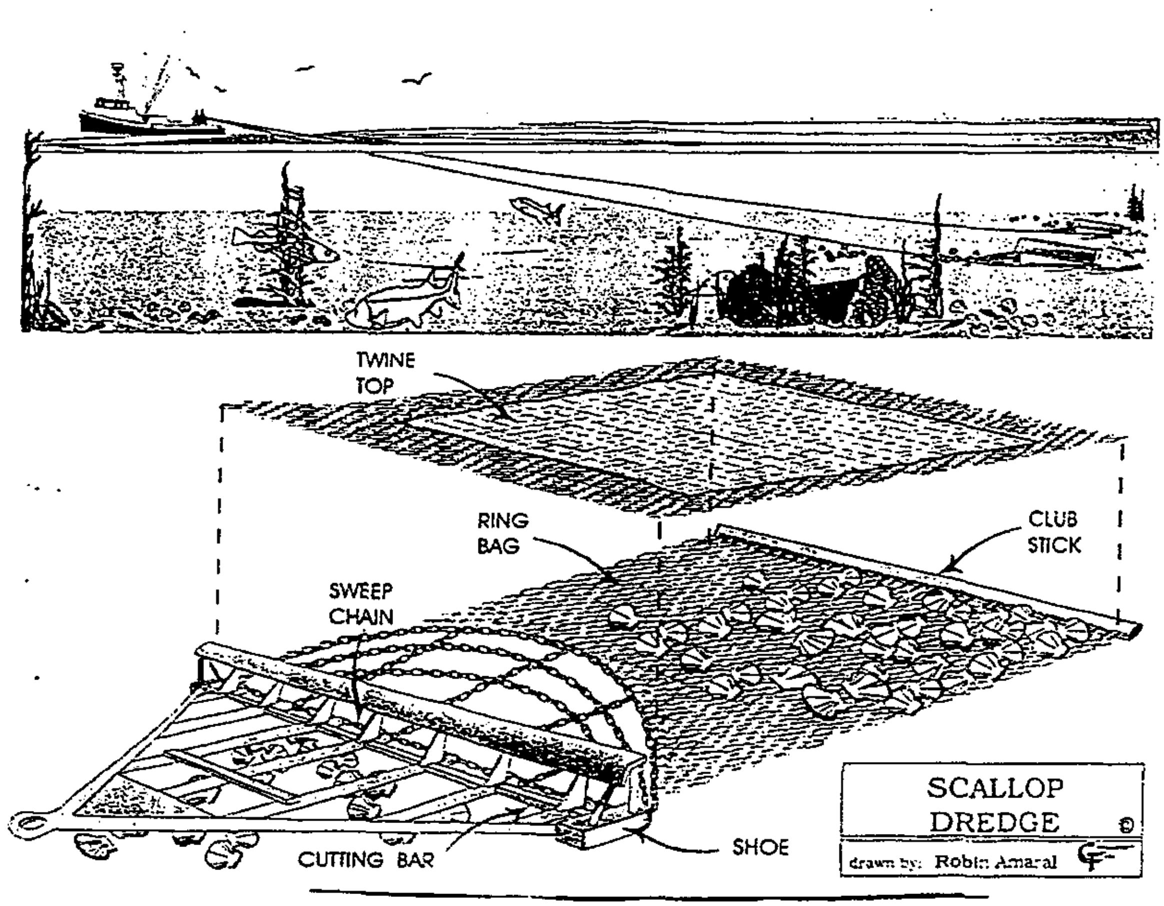

Figure 1: New Bedford ring scallop dredge with top removed (from Smolowitz 1998. Reproduced with permission of Conservation Law Foundation, Massachusetts).

These dredges are usually 4–5 m wide and fishers are restricted to a total width or combined width of two dredges of 9.1 m (Smolowitz 1988, DuPaul et al. 1996). Vessels normally tow two 4.5 m or two 4 m dredges at a speed of 4.0–5.5 knots and each dredge weighs about 1.8 t (Smolowitz 1988). Heavier gear is used on harder bottoms and chaffing gear is also commonly used. Improvements in vessel capability and horsepower have progressively seen an increase in dredge weight and a move into previously inaccessible areas. The twine cover that allows escapement of finfish is required to have a minimum mesh size of 139 mm. The minimum ring mesh size in the northwest Atlantic scallop fishery is 88.9 mm and is designed to select for larger scallops and less non-target catch (DuPaul et al. 1996). In Canada the ring mesh size in 76.2 mm.

2.1.2 Dredge efficiency and incidental mortality

Catching efficiency of the New Bedford ring-bag dredge is between 15 and 20% (Caddy 1989) indicating that most scallops that interact with the dredge gear are not caught (Table 1). Using a submersible, Caddy (1973) observed dredge tracks immediately after the dredge had passed, and based on the extent of damage to the scallops, estimated that of the scallops that are were not retained but were in the path of the dredge, about 13–17% were lethally damaged (direct mortality) (Table 1). These estimates may be conservative as no long-term studies were carried out to determine if sub-lethally damaged scallops incur mortality due to stress and increased susceptibility to predation or disease. Once on deck, the catch is sorted and culled for large scallops with unwanted discards shovelled overboard. In this process DuPaul et al. (1996) estimated that 7.3% of undersize scallop discards are fatally damaged at the time of landing on the deck (indirect mortality) (Table 1). There may be additional indirect mortality for those scallops that appear to be undamaged after their return to the seafloor, but this was not quantified.

2.1.3 Non-target catch

Ring-bag dredges have poor selectively (Bourne 1995) and non-target catch of finfish and invertebrates, as well as juvenile scallops, is common in the northwest Atlantic scallop fishery (DuPaul et al. 1996, Smolowitz 1998). Increases in minimum ring mesh size from 76.2 mm to 82.6 and then to 88.9 mm resulted in a decrease in the catch of undersize scallops (DuPaul et al. 1996). Finfish non-target catch was equivalent to 70% of U.S. scallop fishery landings between 1991 and 1993 (DuPaul et al. 1996). These data do not take into account discarded unreported non-target catch some of which incurs a high mortality rate when returned to the sea. The twine top was effective in reducing catch of cod, and haddock but not flatfish.

2.1.4 Environmental effects

There are conflicting views on the extent to which the dredge bites into the substrate. For example, a New England scallop fisher suggests that the ring-bag scallop dredge skims over the bottom, only digging in when the ground is uneven, and that scallops swim up into the dredge (Kendal 1998), whereas other reports indicate that these dredges dig into the substrate (Rogers et al. 1998). Sidescan sonar studies on Georges Bank support the latter view and have shown that scallop ring-bag dredge marks occur as pairs of 5 m wide swaths on the bottom, and appear to penetrate several centimetres into the sediment (Schmuck et al. 1995). Environmental effects of dredging noted by Caddy (1989) included the accumulation of shell debris from shucking at sea, the removal of epifauna from scallop grounds, repeated disturbance on the sediment unprotected by epifauna, and consequent silting of scallop beds. Anecdotal reports from a dredge fisher who has worked on Georges Bank for 30 years indicate that dredging over prolonged periods has progressively flattened sand hills (Bennet 1998)

Table 1: Efficiency and incidental mortality of dredges (and oyster tongs). Efficiency is the proportion of shellfish in the path of the dredge that is actually caught. Direct mortality is mortality due to a dredge encounter when the shellfish passes through or under the dredge and remains on the seafloor. Indirect mortality is mortality that occurs after the shellfish is caught in the dredge and is either washed out of the dredge during landing, or is landed on board the vessel and then discarded (undersized). –, no data.

Species	Method	Efficiency (%)	Direct Mortality (%)	Indirect Mortality (%)	Source
Scallops	New Bedford dredge	15–20	13–17	–	Caddy 1973, 1989
		–	–	7.3	Du Paul et al. 1996
	Scottish tooth dredge	13–20	3	–	Chapman et al. 1977
	English channel tooth dredge	6–41	–	–	Dare et al. 1993
	Australian mud dredge	12–22	100	100	McLoughlin et al. 1991
	Nelson ring-bag dredge (*Marlborough Sounds trials*)	58–85	–	–	Cranfield et al. 1996
	Nelson ring-bag dredge (Coromandel trials)	2–9	1–9	11–29	Cryer and Morrison 1997
	New Zealand box dredge	40 (average)	1–29	13–52	Cryer and Morrison 1997
Oysters	East coast US oyster dredge and tongs	2–32	–	–	Chai et al. 1992
	Foveaux Strait oyster dredge (single bit dredge)	7–12	–	–	Stead 1966
	Foveaux Strait oyster dredge (double bit dredge)	8–14	–	–	Stead 1966
		18	–	–	Doonan et al. 1994
		–	spat 19	spat 62	Michael et al. 1998
		–	juveniles 7	juveniles 17	
		–	adults 2	–	

Table 1 – *continued*

Species	Method	Efficiency (%)	Direct Mortality (%)	Indirect Mortality (%)	Source
Oysters	Foveaux Strait Roderique oyster dredge	–	spat 11 juveniles 6 adults 1	spat 48 juveniles 11	Michael et al. 1998
Surf clams	New Zealand rabbit dredge	65	–	–	Michael et al. 1990
		73	–	–	Cranfield et al. 1994

2.1.5 Advances in gear technology

Until recently, development of scallop dredge technology has focused on improving the catching efficiency of the gear with little thought given to devising gear that is efficient but also less damaging to the environment. There is growing international opinion that the damaging effects of mobile fishing methods such a dredging and trawling on the seafloor are no longer acceptable. The basic design of the New Bedford ring-bag dredge has changed little over the last 60 years, except for an increase in weight and dimensions (Smolowitz 1988) and there has been little progress in addressing the issues of incidental mortality and habitat destruction.

In 1994 an inventor in the United States developed a lightweight scallop dredge called the 'Sea Harvester' for use in the Alaskan scallop fishery. The dredge is 3.7 m wide, weighs 295 kg (compared with over 1000 kg for conventional dredges), and rather than using weight it relies on a diving plane to hold the dredge on the seafloor (Tkacz 1994). The dredge rides on skids and short tines rake up scallops into the dredge. Rather than a steel ring-bag the Sea Harvester uses a net and detachable codend. Advantages are reported to be reduced non-target catch and less damage to the seafloor. However, the inventor was unable to fund the necessary research to trial the gear and it does not appear to have been adopted by the Alaskan or the northwest Atlantic scallop fishing industry.

The only significant modifications to the New Bedford dredge in recent times have involved increasing minimum ring size to reduce capture and incidental mortality of juvenile scallops and increasing twine mesh sizes on the top of the ring-bag to reduce finfish non-target catch (DuPaul et al. 1996, Smolowitz 1997).

At a conference on the effects of fishing gear on the New England seafloor held in Massachusetts in 1998 there were no presentations relating to advances in dredge gear and it was recommended at the conclusion of the conference that research be conducted into improving fishing gear to minimise fishing mortality of non target species and damage to the seafloor (Dorsey & Pederson 1998).

In 1998, research was undertaken by MIT Sea Grant College Program (funded by the National Oceanic and Atmospheric Administration, NOAA) in the United States to develop a lighter scallop dredge that uses hydrodynamic forces rather than weight to keep the gear on the bottom (Goudey 1999) (Figure 2). *"The outer frame sides and their shoes drag along the bottom. The main portion of the dredge, where the cutting bar would normally level the bottom, is fitted with pivoting supports that are held to bottom by hydrodynamic force rather than weight. These supports therefore conform to the bottom yet can rise to clear obstacles. The sweep is supported by longitudinal chains which are connected to the pivoting supports. Therefore, the sweep is lifted clear of obstructions while the remainder is allowed to conform to the bottom"* In this design, only the sweeps (tickler chains), base of the narrow depressor plate supports, and the ring-bag are in contact with the bottom. Although the dredge showed promise, its efficiency and effects on the substrate, as compared with the conventional New Bedford dredge, have not yet been determined.

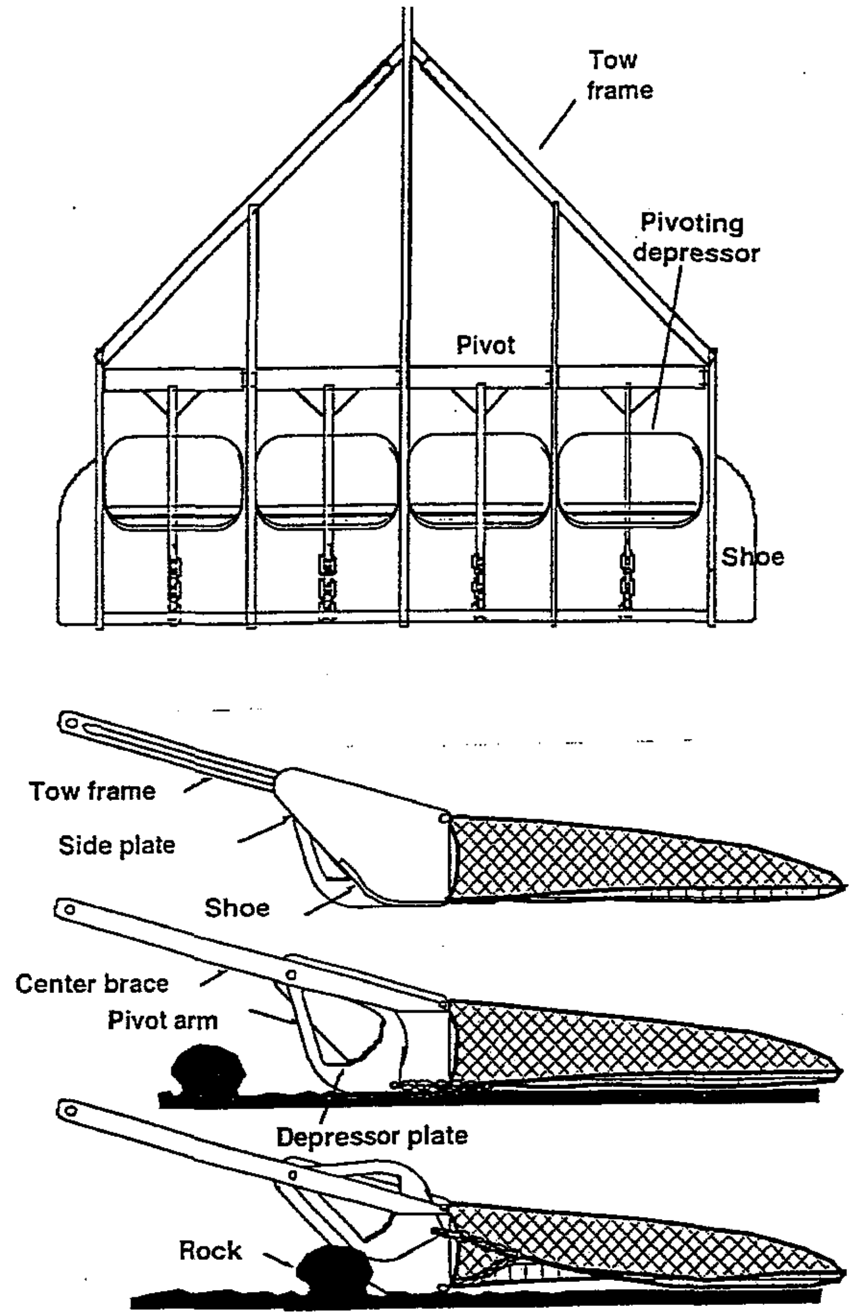

Figure 2: MIT prototype lightweight scallop dredge – "habitat dredge" (from Goudey 1999. Reproduced with permission of MIT, Massachusetts).

2.2 United Kingdom scallop fisheries

2.2.1 Tooth dredge

The standard dredge used in Scotland to harvest the scallop *Pecten maximus,* the 'tooth dredge' is considerably lighter and smaller in nearly all dimensions than the New Bedford dredge with a weight of about 91 kg. It consists of a triangular frame and instead of a cutting bar and tickler chains the ground tending gear consists of a tooth bar with 12 tines that dig into the substrate and rake scallops into a chain bag (Chapman et al. 1977). The bottom of the chain bag is made of 83 mm diameter steel rings and the top of 80 mm stretched mesh. The dredge is about 2 m long and 1.2 m wide. Standard or conventional tooth dredges have a fixed tooth bar and are used mainly on smooth substrate whereas on rough ground a 'spring-loaded' toothbar is used which 'gives' when obstacles are encountered

(Figure 3). The spring loaded dredge is slightly longer and heavier than the standard dredge and has longer tines. The main advantage of the spring-loaded dredge is that less unwanted material, also known as 'trash', is pushed into the dredge mouth.

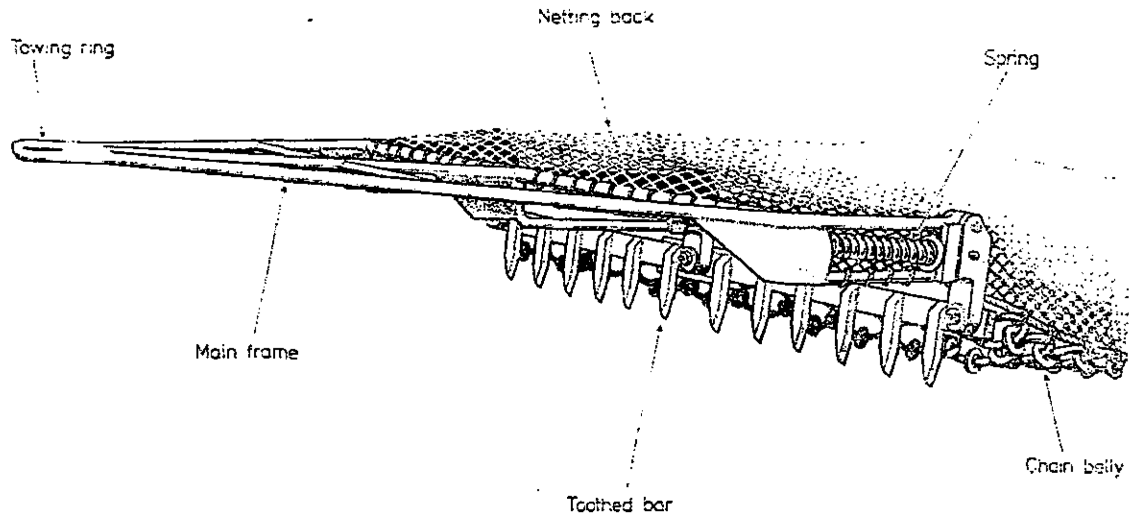

Figure 3: Spring loaded tooth dredge (from Chapman et al. 1977. Crown Copyright 1977. Reproduced with permission of FRS Marine Laboratory, Aberdeen).

The English Channel scallop fishery for *Pecten maximus* use dredges similar to the Scottish spring-loaded dredge but are smaller (75 cm wide, 14 cm high, tooth bar with 9 tines) and vessels deploy gangs of 6 to 20 dredges at a time (Dare et al. 1993, Dare et al. 1994). They are known locally as 'Newhaven Dredges'.

2.2.2 Dredge efficiency and incidental mortality

Gear trials by Chapman et al. (1977) showed that Scottish tooth dredges have low overall efficiency: 20% for standard and 13% for the spring-loaded dredge. Mortality of scallops in the path of the dredge but not caught was estimated at 3% (direct mortality) (Table 1) and was estimated by recovering and tagging scallops from the dredge track, and placing them in an unfished area where they were checked periodically.

Efficiency of the smaller English Channel dredges varies between 6% (rough ground) and 41% (smooth ground) (Table 1). Experimental scallop fishing using commercial dredges showed that dredge efficiency was reduced by bulldozing, bouncing, blockage, and clogged mesh causing a pressure wave. All of these are related to tooth spacing, tow time, spring tension, mesh size, and tooth wear (Dare et al. 1993).

2.2.3 Environmental effects

Divers observing the Scottish dredges noted that both dredges left clear tracks in the sediment and caused damage to the epibenthic organisms, such as crabs and starfish, as well as dislodging heart urchins and molluscs. Soon after the dredge had passed, several predators such as cod, plaice, dogfish, whelks, and hermit crabs, arrived to feed on damaged animals (Chapman et al. 1977).

2.2.4 Advances in gear technology

Although uncommon, some dredges are fitted with depressor boards which keep the gear on the bottom using hydrodynamic forces rather than relying on weight (Anonymous 1984). Water flow is diverted upward over the board, forming a low pressure area over the belly creating suction that causes material to move into the dredge and unwanted material to move out. Diver observations have shown that because these dredges are relatively more stable there is less damage to the scallops. It has been suggested that a toboggan arrangement could be used to keep the gear above the substrate and reduce friction (Anonymous 1984).

The University of Liverpool (Port Erin Marine Laboratory) is involved in 'The 'Ecodredge Project' which involves collaboration between 12 research institutions and representatives of the fishing industry around Europe to look at how design and operation of shellfish dredges affects selectivity of target species and effects on the environment (Anonymous 1999).

2.3 *Australian scallop fisheries*

2.3.1 Australian mud dredge

The main scallop fisheries in Australia are in Victoria, South Australia and Tasmania for *Pecten fumatus* and all fishing is carried out using the the 'Australian mud dredge' also known as 'box dredge' and 'sputnik'. Designed in the 1960s, it consists of a rigid steel box between 2–4 m wide, 2 m in length, a height of about 30 cm and weighing about 500 kg (Figure 4). The box is covered in uniform steel mesh. Only one dredge at a time is towed and is winched aboard at the stern onto a 'self tipper', delivering the contents on to a sorting tray. The self tipper allows the dredge to be deployed and hauled mechanically without being handled by crew and when not fishing the dredge can be stowed there. This arrangement makes the mud dredge very safe to use even in bad weather and is one of the reasons for its popularity with fishers (Gorman 1997). The ground tending gear consists of a tooth bar that digs into the substrate, raking scallops into the box. Tines are about 5 cm long and set 7 cm apart at a 40° angle pointing forward. Both tine length and interval between the tines are adjustable to minimise effects on seafloor and to reduce the catch of undersize scallops. Tow speed is about 3 knots and boats tow for 10 to 30 min. The mud dredge rides on narrow runners that help keep the box slightly off the seafloor. (Specifications and description of the mud dredge were sourced in part from internet websites of Department of Primary Industries, Water and Environment (www.dpiwe.tas.gov.au), and Seafood Industry Victoria (www.siv.com.au)).

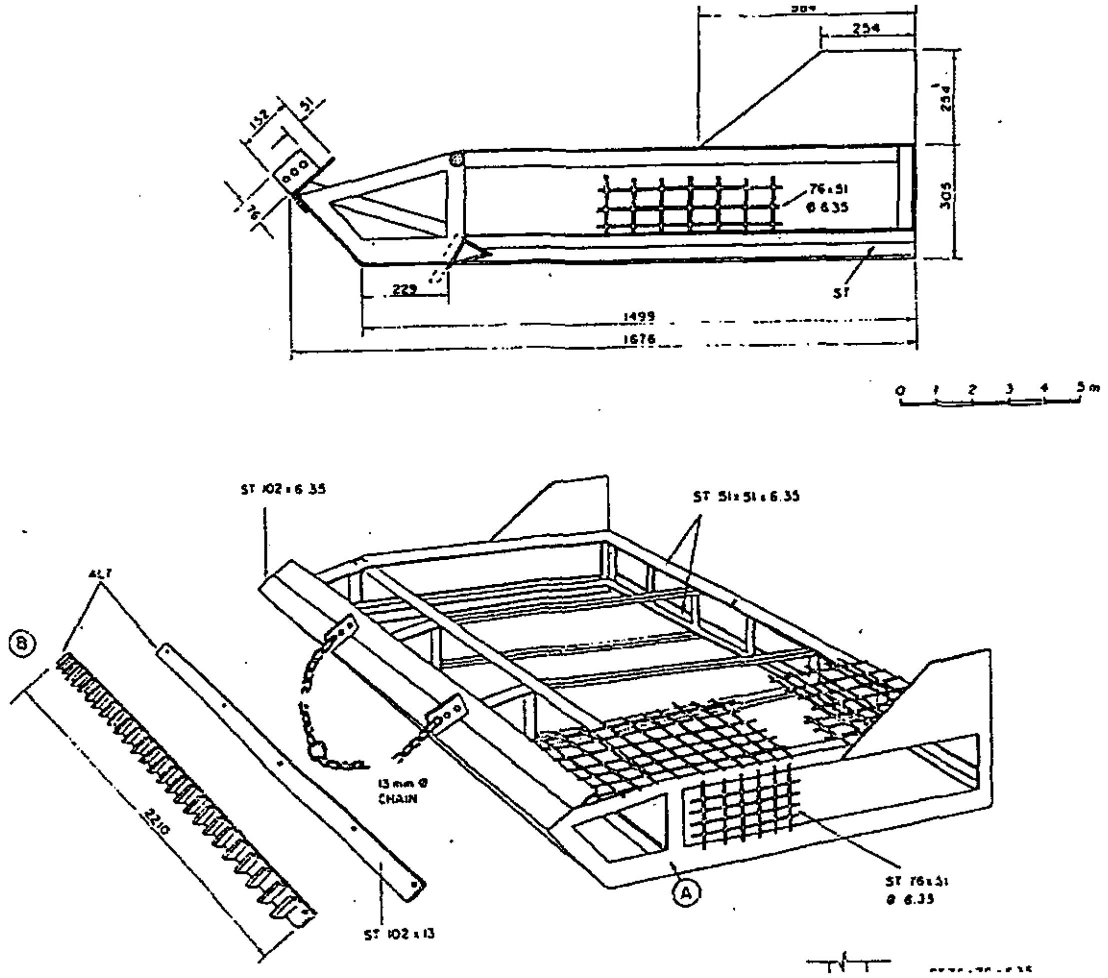

Figure 4: Australian mud dredge (from Zacharin 1989. Reproduced with permission of the author).

2.3.2 Dredge efficiency and incidental mortality

The efficiency of the mud dredge was estimated at about 12% and found to be selective for larger scallops, independent of mesh size (Table 1) (McLoughlin et al. 1991). Efficiency can initially be high, but if tow time is too long it declines as the dredge fills up and acts as a bulldozer, effectively ceasing to fish.

To estimate incidental mortality, a densely populated commercial scallop bed was fished monthly over 12 months and a sample of scallops examined. Results indicated that over time the numbers of dead scallops increased to almost 90% within 100 days (McLoughlin et al. 1991). It was estimated that only 12–22% of scallops in a bed are caught and that the remainder die through direct or indirect mortality from dredging within 8 months of dredging, i.e., incidental mortality is 100% (Table 1). The mud dredge does not maintain constant contact with the bottom (Zacharin 1989, Gorman 1997) and this action may also contribute to the high incidental mortality.

2.3.3 Advances in gear technology

Comparative dredge gear trials were conducted in Australia in 1990 in response to concerns that the mud dredge was both destructive to the seafloor and highly inefficient. This research was undertaken jointly by CSIRO, the Victorian Fishing Industry, the Australian Maritime College, and the Australian Department of Primary Industry and Fisheries. The objective of the programme was to assess current dredge designs and modify and/or develop scallop harvesting gear that was both efficient and yet resulted in less adverse effects on the seafloor. A range of dredge gear was tested, including the New Zealand ring-bag dredge, Scottish mini dredges, the Japanese keti ami ring-bag dredge, a modified Canadian-American dredge with depressor plate (Southern Scallop Harvester), a standard Australian mud dredge, and an experimental prototype mud dredge (Zacharin 1989, McLoughlin 1991, McLoughlin et al. 1993, Gorman 1997). The latter differed from the standard mud dredge in that the box was raised on skids, 100 mm above the seafloor, and the toothed cutter bar was replaced by a bar and slats resembling a 'mouth organ'.

The New Zealand ring-bag dredge was found to be superior both in performance and efficiency to all other dredges (McLoughlin 1991, McLoughlin et al. 1993, Gorman 1997). Other dredges to perform well were those with tickler chains rather than tooth bars, and included the Japanese keti ami dredge and the Southern Scallop Harvester. The Australian mud dredge, both standard and modified, performed poorly in comparison and dredges that outperformed the mud dredges also resulted in less incidental mortality to scallops. Flume tank testing found that the standard mud dredge is subject to many forces while dredging and will be affected by substrate type, warp size and length, tow speed, vessel displacement and motion, and loading in the dredge box. It was concluded that skill is needed to make the mud dredge function at optimal efficiency in a way that maximises catch and minimises damage.

Despite the results of gear trials there have been no changes to the dredge equipment used in southeast Australia and the Australian mud dredge continues to be the only dredge employed by commercial fishers to harvest scallops – it is now referred to as the 'harvester' (Gorman 1997, Gwyther 1998). The major impediment to changing to a ring-bag dredge appears to be that the ring-bag cannot be easily accommodated by the self tipper which is the favoured method of deployment and stowage. The Japanese keti ami dredge, despite performing well, was not considered as a candidate because its long sharp tines make it dangerous to handle in anything but calm seas (McLoughlin et al. 1993). Although the Southern Scallop Harvester showed promise during the trials, subsequent testing by commercial fishers found the dredge to have significantly lower catch rates than the conventional mud dredge and no further development work ensued.

2.4 New Zealand scallop fishery

Dredge fisheries for the New Zealand scallop *Pecten novaezelandiae* are based in four areas, Northland, Coromandel, Chatham Islands, and Nelson (Tasman Bay, Golden Bay, and Marlborough Sounds) (Bull 1989). A trawl fishery for queen scallops (*Chlamys delicatula*) also exists off Otago Peninsula in deepwater at the head of canyons. In New Zealand the type of dredge used depends on the substrate – on the soft bottom seafloor of the Nelson scallop fisheries ring-bag dredges with tickler chains are used; in Northland and Coromandel, where the substrate tends to be is harder, the box dredge, similar in construction to the Australian mud dredge, is used (Bull 1989). In the Chathams, both ring-bag and box dredges are used but both are modified. There are few published specifications of New Zealand scallop dredges, so much of the information presented in this report is based on discussions with members of the scallop fishing industry.

2.4.1 Nelson scallop fishery

2.4.1.1 Nelson ring bag dredge

The Nelson scallop fishery is the largest in New Zealand and the main scallop beds are in 10–25 m on a soft muddy substrate (Anonymous 1998) suited to the ring-bag dredge. The Nelson ring-bag dredge replaced the box dredge about 20 years ago and is considered superior by the fishing industry (Russell Mincher, CEO Challenger Scallop Enhancement Company, pers. comm.). The construction of the ring-bag dredge varies from fisher to fisher and specifications are largely dictated by the vessel type, power, and handling gear used to tow the dredge. Ministry of Fisheries (Challenger Area Commercial Fishing) Regulations 1986 restrict the width of the dredge to a maximum to 2.5 m, only two dredges at a time may be towed, and tines are not permitted. Ring size is optional and varies between skippers, but is usually 30 mm diameter and varies with location in the ring-bag. The ring-bag dredge consists of a chain bag composed of linked steel rings on the bottom panel and synthetic 100 mm trawl mesh on the top panel (Figures 5–8). Specifications vary among vessels, but dredges are generally about 2.4 m wide, 2.7 m long, and weight ranges from about 250 to 450 kg. Nelson ring-bag dredges do not have cutting bars or tines and are not designed to dig into the substrate; tickler chains are used as the ground tending gear and only these and the ring-bag are in contact with the substrate. The leading edge of the ring-bag is shaped in an arc and attached to either side of a steel headframe designed to maintain a mouth opening of about 0.5 m. The headframe is raised on short skids keeping it clear of the seafloor.

The tickler chain passes over the ground just before the ring-bag and is also shaped in an arc. Scallops disturbed by the tickler chain swim up and are prevented from escaping by the meshed top panel which is fully attached to the headframe and lies above and ahead of the tickler chain. The lower bar of the headframe is designed to act as a pressure bar and is angled downward helping to keep the dredge on the bottom as well as creating turbulence behind the bar, drawing scallops into the dredge. The dredge is towed by upper and lower bridles (3.5 m long) attached to either side of the headframe which join to a single warp. Warp length to depth ratio is between 3:1 and 5:1.

Vessels generally tow two dredges at a time and tow length is about 15 minutes on average at 3 knots, although tow time is dictated by fullness of the dredge and this is gauged through experience. Towing at higher speeds and/or inefficient gear set-up will cause the dredge to 'fly up' (leave the bottom), but normally the gear is in contact with the bottom throughout the tow. After hauling, the dredge is emptied through the mouth onto a sorting table at the stern of the vessel.

2.4.1.2 Dredge efficiency and incidental mortality

In 1996 Cranfield et al. (1996) estimated dredge efficiency of two ring-bag dredges, one belonged to the Ministry of Fisheries and the other to the Challenger Scallop Enhancement Company. Both dredges were used to conduct biomass surveys in the Nelson scallop fishery. Dredge efficiency was determined by comparing scallop estimates by divers (considered to be absolute estimates) followed by dredging the same sites in Tasman Bay, Golden Bay, and Marlborough Sounds. There was no statistical difference between efficiencies of these dredges and data were combined. The mean efficiency was estimated at 70% (range 58–85%) (Table 1).

Dredge efficiency trials were also conducted in the Coromandel (around Mercury Island) in 1997 using a Nelson ring-bag dredge, the box dredge (described below), and the Japanese keti ami ring-bag dredge (Cryer & Morrison 1997). Estimates of efficiency were carried out by diving over freshly dredged tracks and by comparing density determined from dredging and diving sites. The results indicated that the Nelson ring-bag efficiency was low at between 2–9%, although Cryer & Morrison (1997) suggested that the location of the trials on the harder substrate of the Coromandel may have underestimated efficiency for the ring-bag dredge (Table 1). Given the efficiency estimates by Cranfield et al. (1996) of 70% for the ring-bag dredge in the Nelson fishery this seems to be a reasonable assumption.

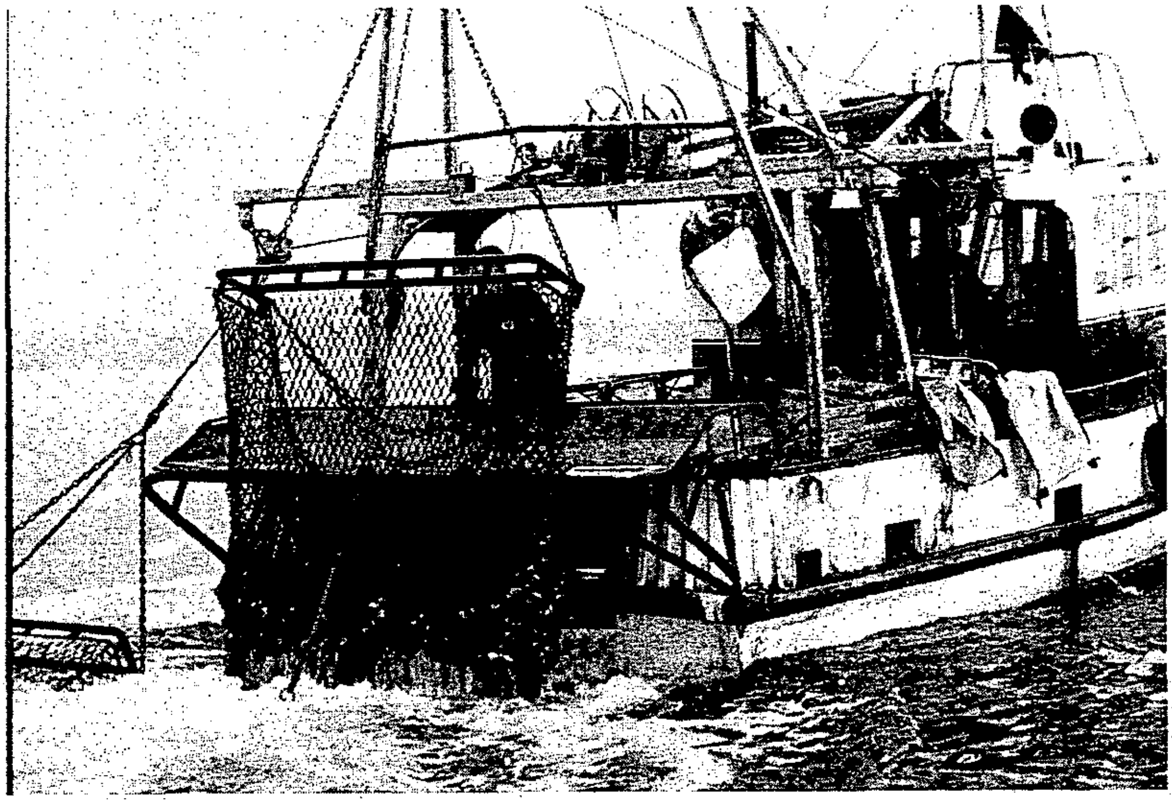

Figure 5: Vessel towing two Nelson ring bag dredges. Both dredges have been hauled and one is being emptied on to the sorting table (photo by Challenger Scallop Enhancement Company Ltd).

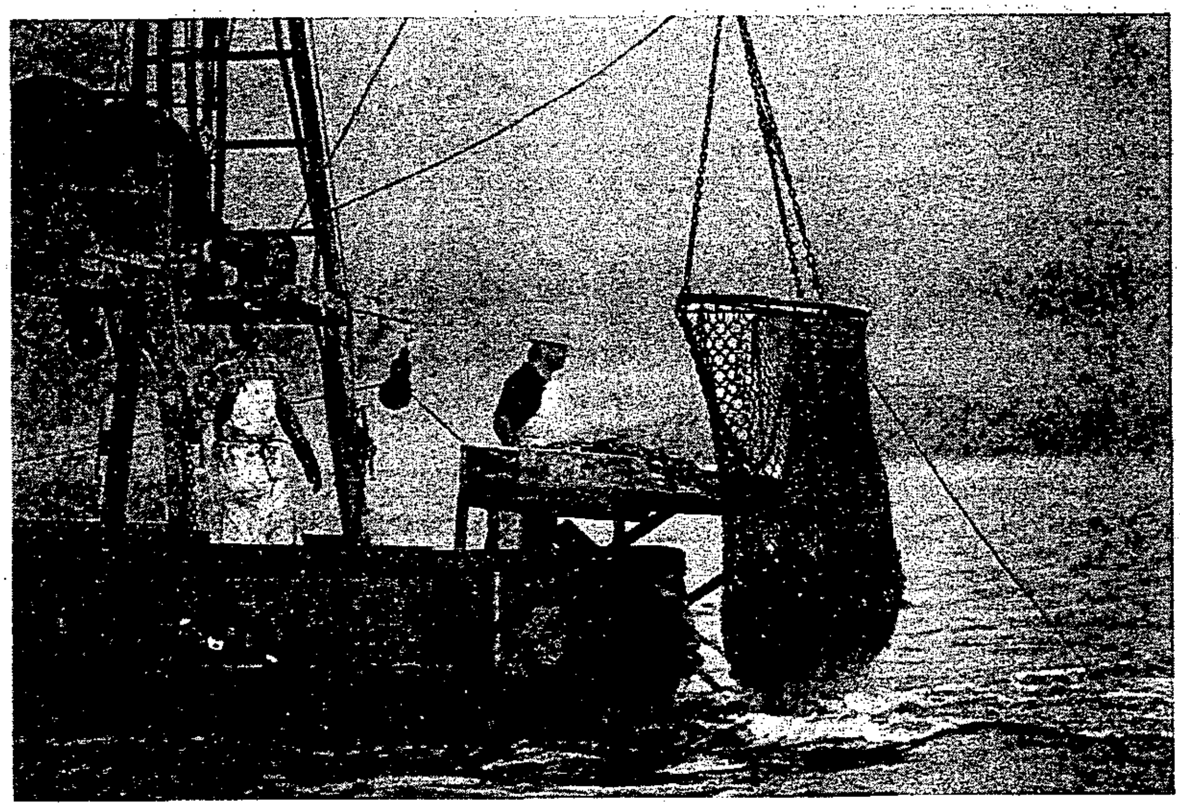

Figure 6: Nelson scallop ring bag dredge being hauled (photo by Challenger Scallop Enhancement Co. Ltd).

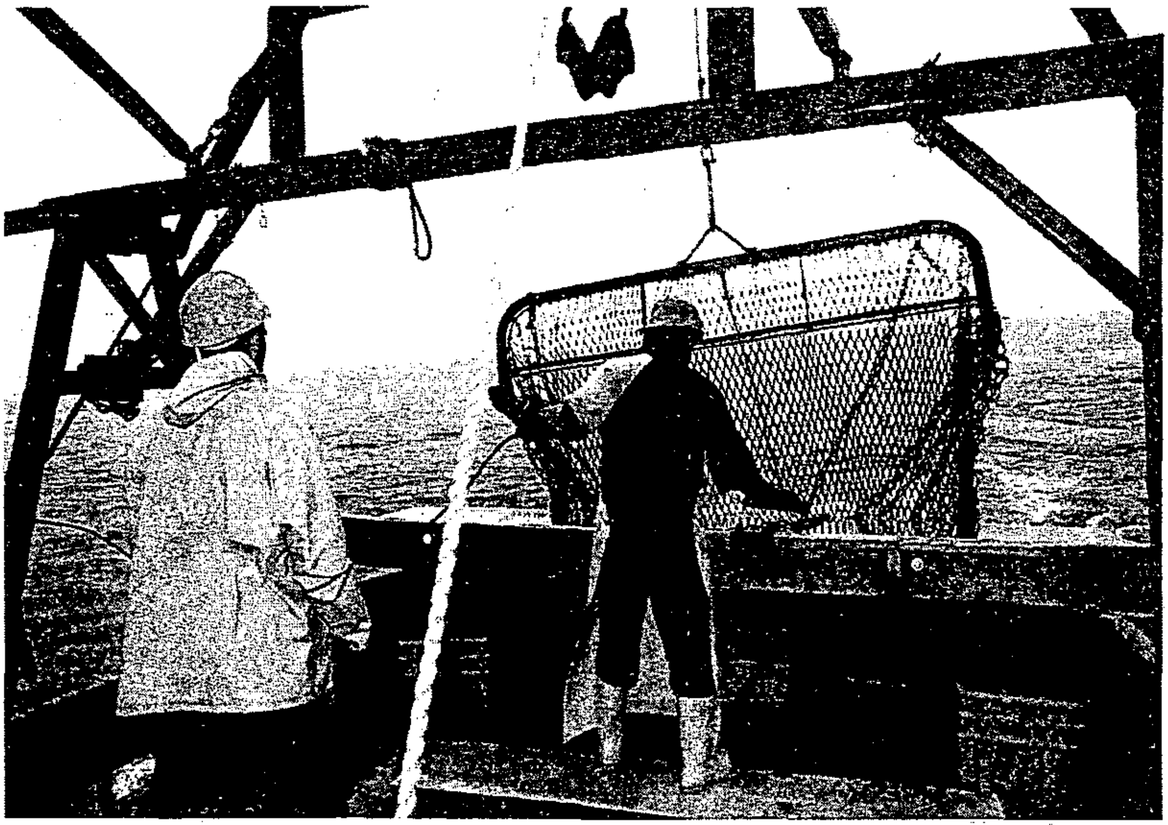

Figure 7: Nelson scallop ring bag dredge being hauled showing the head frame (photo by Challenger Scallop Enhancement Co. Ltd).

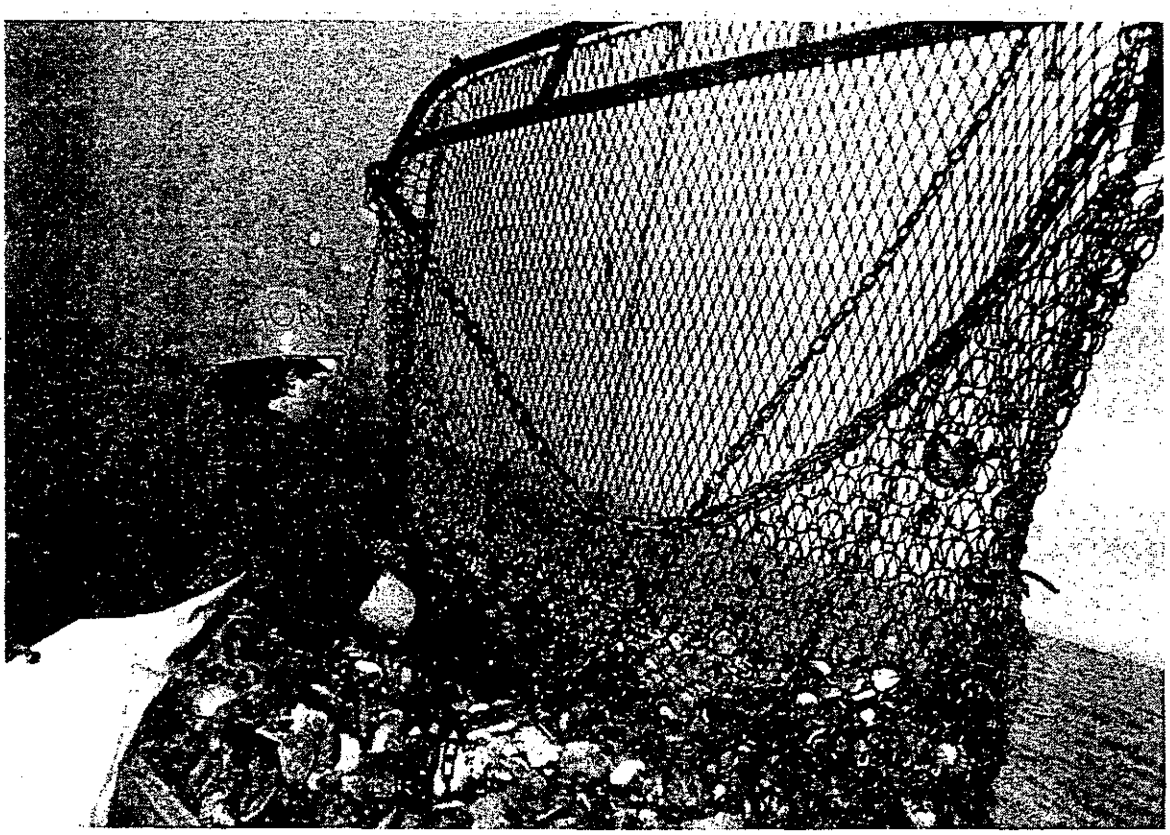

Figure 8: Nelson scallop ring bag dredge being emptied showing the headframe, tickler chain, linked rings of the bottom panel and twine cover of the top panel (photo by Challenger Scallop Enhancement Co. Ltd).

Indirect mortality, measured by shell breakage, was between 1 and 10% for scallops retained (landed), and breakage increased with scallop size (Cryer & Morrison 1997). Direct mortality for those scallops not retained but located by divers in or near the dive track was between 0.5 and 2.6%. To account for mortality that may occur following a dredge encounter, samples of scallops that were retained by the dredge, and those that were missed by the dredge were tagged and placed on the seafloor below a bouy in habitat similar to that from where they were dredged. Scallops were retrieved a month later by divers and examined. When deaths over the next month of scallops that had encountered the gear were taken into account, the estimated indirect mortality from the ring-bag dredge was 11–29%, again increasing with scallop size, and direct mortality 1–9% (Table 1). The higher mortality for retained scallops may occur when scallops are tipped into the sorting tray. This has implications for undersize scallops that are returned to the water.

Encounters with dredges were also found to retard growth rate and this was more severe for scallops landed on deck compared to those missed, and also for scallops caught using the dredges with tines (box and keti ami dredges) compared with those caught using the ring-bag dredges (Cryer & Morrison 1997).

2.4.1.3 Non-target catch

No studies of non-target catch from ring-bag dredges operating in the Nelson area have been undertaken, but catch of non-target species has been reported to include greenlipped mussels, nesting mussels, horse mussels, eleven armed spiny starfish, whelks, heart urchins, hermit crabs, kina, octopus, and flatfish (Russell Mincher, pers. comm.). During commercial fishing operations, undersize scallops are graded out and returned to the sea, but the management regime of enhancement and rotational fishing often results in catches of a single recruited cohort with few pre- recruits.

2.4.1.4 Environmental effects

Although the Nelson ring-bag dredge leaves a track in the substrate (Cryer & Morrison 1997), this is probably less defined than that produced by designs that use a cutting bar or tines to dig scallops out of the substrate. No studies have been carried out to look at the environmental effects of ring-bag dredging in the Nelson scallop dredge fishery, but a review by Gardner (1995) listed five potential effects of dredging on the marine environment of the southern scallop fishery.

1. Incidental mortality of target and non-target species.
2. Increased predation of species in the dredge track through exposure of infaunal species to predators and scavengers.
3. Alteration in chemistry and substrate texture.
4. Detrimental effects of suspending sediment on filter feeders.
5. Increased rates of benthic/pelagic nutrient flux leading to increased phytoplankton production.

The management practice of enhancement and rotational fishing allows discrete scallop beds and the associated environment to recover to some extent between rotations.

2.4.1.5 Advances in gear technology

There have been no recent modifications to the Nelson ring-bag dredge nor are there any immediate plans to modify the current design which is considered by local fishers and the fishing industry to be very effective with comparatively little environmental effect compared with the box dredge used in the North Island.

2.4.2 Northland and Coromandel scallop fisheries

Scallop fisheries in the North Island are divided into two separately managed areas, the Northland and Coromandel scallop fisheries (Cryer 2001). The dividing line between them runs from Cape Rodney to the northernmost tip of Great Barrier Island, and historically the main Northland fishery beds are found in Bream Bay, Ranganui Bay, Doubtless Bay, and from Whangaroa to Matauri Bay (Cryer 2001). More recently scallop fisheries have been developed in Spirits and Tom Bowling Bays between North Cape and Cape Reinga. The Coromandel scallop fishery includes the Hauraki Gulf and Bay of Plenty.

2.4.2.1 *Box dredge*

Scallops are commercially dredged in both Northland and Coromandel using the self tipping box dredge, usually between 10 and 30 m depth (Bull 1989, Cryer & Morrison 1997, Cryer 2001). The box dredge is considered by commercial fishers to be better suited to the hard bottom characteristic of these areas. The dredge is similar to the Australian mud dredge (described above) in design and operation, but it is considerably lighter. The specifications vary between fishers and reflect individual preferences and the substrate type most commonly dredged. Ministry of Fisheries (Auckland and Kermadec Areas Commercial Fishing) Regulations (1986) allow two dredges to be towed at once. If a single dredge is towed, the maximum width is 2.5 m, or if two dredges are used, width must not exceed 1.4 m each. There is no minimum mesh size, but the minimum legal size of scallop is 100 mm. The box dredge generally has a width of 2.44 m, length of 2.4 m, height of 400–500 mm and weighs about 150–200 kg (Figure 9). The box frame is constructed of 40 x 40 x 5 mm angle steel and is covered in 3 mm steel mesh with 100 mm mesh size. The dredge rides on 19 mm steel runners that keep the box frame slightly off the bottom.

The gear-substrate interface consists of a bar fitted with tines that dig into the substrate to a depth of about 5 cm; dislodged scallops are lifted up and into the meshed box as the dredge moves forward. The tooth bar set up is probably the most variable aspect of the box dredge. Tooth bar specifications for a box dredge used by a Coromandel fisher were: tine length 145 mm, width 30 mm, thickness 10 mm, angled forward at 45°. The spacing between the tines varies, but is usually about 90 mm and a single dredge might have as many as 22 tines. In general, the harder the substrate the shorter the tines, which wear out and need frequent replacement. The spacing between the tines is designed to allow escape of scallops less than 100 mm. Box dredges have a dive board or plate on the top bar above the tooth bar which maintains downward pressure keeping the box on the bottom. Chains are attached to either side of the dive board and these join into a single wire warp.

Vessels generally tow one box dredge at a time at about 2.5–3 knots and tow length is 5–30 min, depending on fullness of the dredge. Towing at higher speeds and/or inefficient gear set up will cause the dredge to 'fly up', but normally the gear is in contact with the bottom throughout the tow. A NIWA diver following a box dredge noted that it remained on the bottom throughout the tow (Glen Carbines, NIWA, pers. comm.). After hauling, the dredge is emptied through the mouth onto a sorting table at the stern of the vessel. Like the Australian mud dredge, vessels winch dredges aboard at the stern onto a self tipper which delivers the contents on to a sorting tray. The dredge can be deployed and hauled mechanically without being handled by crew.

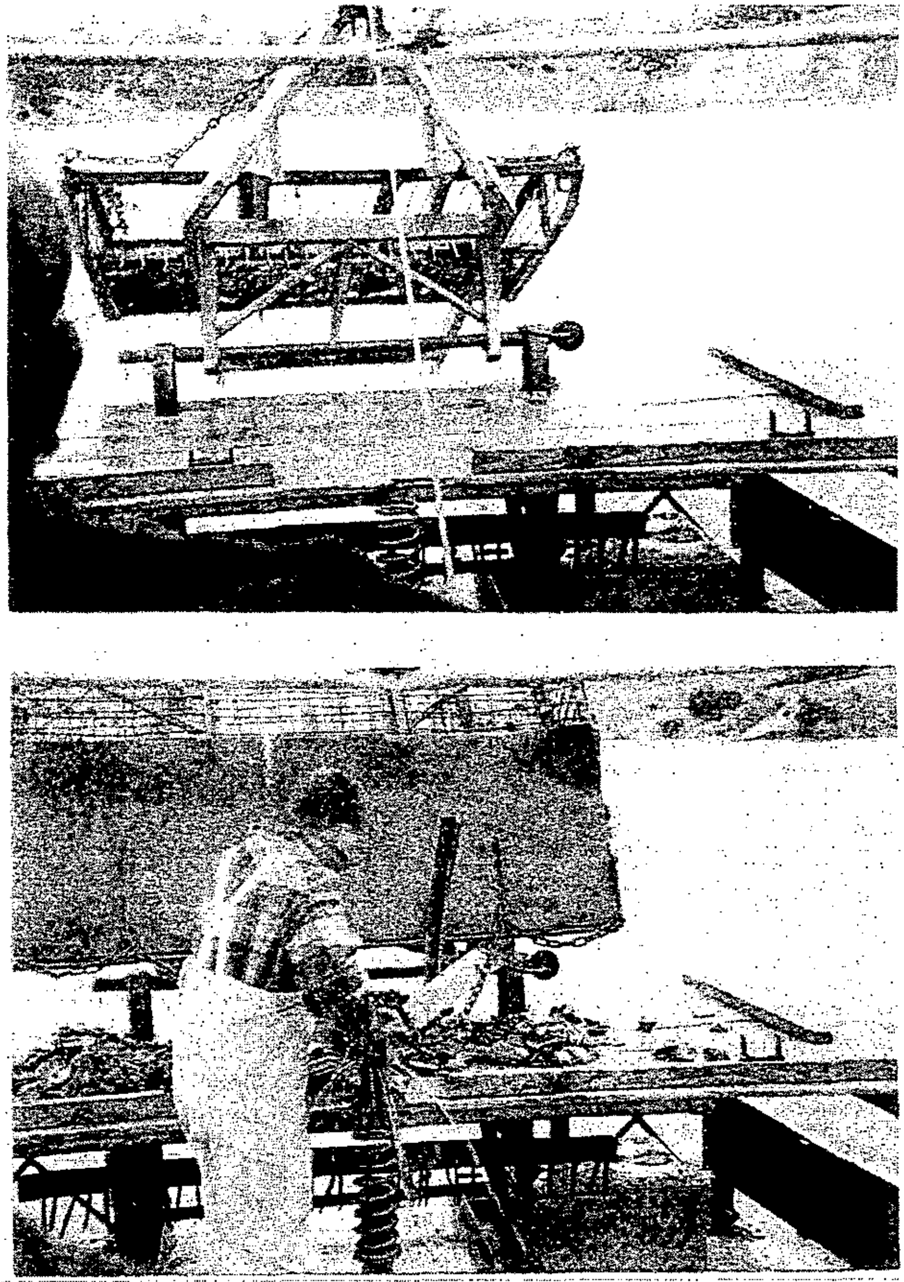

Figure 9: Coromandel and Northland box dredge on self tipper. Top: dredge hauled onto self tipper ready for emptying. The tines are visible on the lower front of the dredge. Bottom: scallops have been tipped onto sorting table. The dive plate is visible (photos by Martin Cryer).

2.4.2.2 Dredge efficiency and incidental mortality

Efficiency trials in the Coromandel in 1997 using the box dredge (see Nelson scallop fishery for details) (Cryer & Morrison 1997) indicated that box dredge efficiency is between 24 and 90% for legal sized scallops and efficiency increases with scallop size. A subsequent study off Waiheke Island in soft sediment gave efficiencies between 17 and 49% (Cryer & Parkinson 1999); the long-term efficiency average of the box dredge is estimated at about 40% (Table 1) (Cryer & Morrison 1997). The box dredge was more efficient than both the Nelson ring-bag (2–9%) and the Japanese keti ami dredge (5–20%) for legal sized scallops in the Coromandel (Cryer & Morrison 1997). The results indicated to fishers that the box dredge is most suited to the northern scallop fisheries.

Indirect mortality measured by shell breakage was between 0 and 18% for scallops retained (landed), and breakage increased with scallop size (Cryer & Morrison 1997). Direct mortality for those scallops not retained but located by divers in or near the dive track was between 0 and 8%. However, when deaths over the next month of scallops that had encountered the gear were taken into account the estimated total indirect mortality from the box dredge was between 13 and 52%, increasing with size, and total direct mortality was 1 to 29% (Table 1) (see section 2.4.1.2 for method). The higher mortality for retained scallops may occur when scallops are tipped on to the sorting tray. Thus, although the box dredge was found to be more efficient than the Japanese keti ami and Nelson ring-bag dredges in capturing legal sized scallops, it results in more breakage and higher mortality. These results contrast with estimates of shell breakage by two scallop fishers from Northland and Coromandel where breakage was reported to be minimal if gear is well tuned – breakage was estimated at about 12–24 broken scallops per 6000 (0.2–0.4%) (Tom Hunt and Karl Aislabie, pers. comm.).

2.4.2.3 Non-target catch

Fishers report that non-target catch is minimal in frequently dredged areas; some starfish are landed and more recently tubeworms (unidentified species) have become a problem. Catches of the target species are also reported to be generally clean with undersize scallops and sediment passing through the 100 mm mesh size. The dredge efficiency trials indicated that twice as many legal sized scallops are caught as undersized scallops (Cryer & Morrison 1997).

2.4.2.4 Environmental effects

The box dredge leaves a clearly defined track formed by the tines digging into the substrate (Cryer & Morrison 1997). If the dredge becomes full, it begins to 'bulldoze' sediment ahead of the dredge and ceases to function effectively. Often the dredge will fly up when it is full and this is obvious to the fisher who will then haul the gear. Crabs (species unknown) were observed moving into the dredge track within minutes to prey on damaged scallops, epifauna, or exposed infauna (Glen Carbines. NIWA, pers. comm..).

A study of the sponge and bryozoan community between North Cape and Cape Reinga, and the extent to which fishing affected benthic community structure, was carried out in 1999 (Cryer et al. 2000). The epibenthic communities of sponges and bryozoans were found to be diverse, comprising many endemic species. Comparisons with epibenthic fauna samples collected from non-target catch from scallop dredging between 1996 and 1998, indicated that sponges and other epibenthic filter feeding colonial animals were most affected by scallop dredging in this region, with a marked decline in richness of sponges. The results of the survey suggest that scallop dredging has had a significant impact on the diversity and richness of epibenthic fauna in this area and by inference other areas in Northland that are more heavily fished.

2.4.2.5 Advances in gear technology

The most recent advances to the box dredge include the dive plate and modifications to the tooth plate, such as adjustable angle of attack and variable tooth length. There are no immediate plans to modify the current design or change to an alternative dredge. The comparatively low efficiencies of the Japanese and Nelson ring-bag dredges determined from these gear trials has probably reinforced the suitability of the box dredge in the northern scallop fisheries and dissuaded fishers from changing to a less destructive ring-bag design.

2.4.3 Chatham Islands scallop fishery

The Chatham Islands scallop fishery is based predominantly in the northeast off Kaingaroa in depths between 30 and 80 m (Ken Pascoe, scallop dredge fisher, pers. comm..). Of the seven boats that dredge for scallops, six use a ring-bag dredge similar to that used in the Nelson scallop fishery, except that the Chathams dredge uses a bar fitted with spring-loaded tynes. One fisher uses a modified box dredge and self tipper arrangement with a steel ring-bag on the bottom and 5 cm wire mesh on the top. Four shoes or skids fitted to each corner keep the box off the bottom and the only parts of the dredge in contact with the bottom are the shoes, tines, and fore-section of the ring-bag.

Oysters (*Ostrea chilensis*) are a major non-target catch of scallop dredging in the Chathams and at times comprise a greater proportion of the catch than scallops. Other non-target catch species include giant stargazer (*Kathetostoma giganteum*), red gurnard (*Chelidonichthys kumu*), flatfish (*Pelotretus flavilatus, Peltorhampus novaezeelandiae, Rhombosolea* spp.) queen scallops (*Chlamys delicatula*), juvenile conger eels (*Bassanago* spp.), and octopus (*Octopus* spp.).

3. DREDGE OYSTER FISHERIES

3.1 East coast United States and Canada

There are dredge oyster fisheries on the east coast of the United States and Canada for the American or Eastern oyster (*Crassostrea virginica*) (Chai et al. 1992, Rothschild et al. 1994, McKenzie 1996, Langan 1998). Most of these fisheries are in shallow sub-tidal areas in bays or estuaries from New Brunswick to the Gulf of Mexico (McKenzie 1996). Unlike scallop fisheries, there is comparatively little information published on oyster dredging or gear specifications. Methods used to harvest oysters include hand tongs, patent tongs (hydraulic), dredge, and diving. Tongs consist of a basket arrangement with short tines and are operated like scissors, grabbing oysters from the seafloor in shallow depths. Dredges tend to be small and lightweight compared to the New Zealand oyster dredge with a toothed bar and chain bag.

Chai et al. (1992) compared catches of oyster dredge with diver estimates and those from hydraulic tongs and estimated dredge efficiency to be between 2 and 32% (Table 1). The tong density estimates, however, were not significantly different from diver estimates. Lenihan & Peterson (1997) studied the effects of oyster harvesting and concluded that dredging reduces biogenic reef height, which in turn affects hydrodynamic flow and has consequences for oyster recruitment, growth, and survival.

3.2 New Zealand dredge oyster fisheries

3.2.1 Foveaux Strait

The Bluff oyster, *Ostrea chilensis,* has been commercially dredged in Foveaux Strait for over 130 years (Cranfield et al. 1999a, Michael et al. 2001). More recently, oysters are harvested by recreational fishers using improvised small dredges towed from recreational craft.

3.2.1.1 Foveaux oyster dredge

The commercial oyster dredge consists of a ring-bag attached to a heavy steel frame. A cutting bar known in the oyster industry as a bit bar provides the gear substrate interface. Unlike scallops, oysters are sedentary and are often attached to shells of other oysters on the seafloor. The bit bar is designed to dig into the substrate to a depth of several centimetres scraping up oysters into the ring-bag.

Early dredges were about 3.35 m wide with a single bit bar (single bit dredge) designed to fish on one side only. These dredges were constructed of light gauge steel and were lightweight (150 kg). The ring-bag had steel rings (67 mm diameter) on the bottom panel and light twine mesh on the top panel. The ring-bag was permanently fastened aft by a light steel pole and was emptied through the mouth by manually lifting the ring-bag over the mouth. The single bit dredge could be towed only into or with the tide to prevent it from rolling over and fishers were obliged to work strips oriented parallel to the tidal currents. It also had a tendency to lift easily off the bottom (Milton Roderique, oyster dredge fisher, pers. comm.).

Between 1968 and 1972 the single bit dredge was replaced with a double bit dredge constructed of heavier gauge steel with steel rings on both top and bottom panels, increasing the weight to about 400 kg (Michael et al. 1998, Cranfield et al. 1999a). This dredge can operate on either side and be towed in any direction, allowing new grounds to be exploited. As vessels and winches became more powerful, dredge weight was increased again in 1984 to about 530 kg to strengthen the dredge and improve efficiency – this design is in use today (Figure 10). Although the heavier double bit dredge can still fly up off the bottom, this is less of a problem than with the single bit dredge. The ring-bag is emptied at the aft by unfastening steel poles that secure the ring-bag and the contents are released on to a sorting table. Vessels normally tow two double bit dredges at a time from wire warps and each dredge is towed off individual derricks, both on the vessels port side (Michael et al. 2001). Specifications for a Foveaux Strait double bit dredge currently in use are: weight 550 kg, overall length 1.65 m, overall width 3.32 m, mouth height 0.44 m, bit bar depth 0.08 m (Keith Michael, NIWA, pers. comm.).

Fisheries (Commercial Fishing) Regulations (1986) restrict fishers to two dredges per vessel and each dredge may have a bar or bit not exceeding 3.35 m in length. Fishers cannot be in possession of any oyster that can pass through a circular metal ring of less than 58 mm inside diameter.

Figure 10: Foveaux Strait double bit bar oyster dredge being emptied on to sorting table (photo by Keith Michael).

3.2.1.2 Advances in gear technology

In 1997 the Ministry of Fisheries contracted NIWA to study incidental mortality and effects of dredging on the substrate. During these experiments a standard commercial double bit dredge and a modified dredge designed by Milton Roderique (dredge oyster fisher) were used (Michael et al. 1998) (Figure 11). The new design was about 200 kg lighter than the standard double bit bar dredge, at about 320 kg. The reduction in weight was achieved by using a lighter double bit construction, replacing one steel ring panel with lightweight buoyant mesh (top panel), and using lightweight poles to close the chain bag (Cranfield 1997). Gear efficiency trials were not conducted, but observations indicated that the Roderique dredge was as efficient as the standard commercial dredge (Milton Roderique, pers. comm.). The lighter design, however, may also restrict fishers to certain locations and conditions in the same manner as the earlier single bit dredge, and therefore provide protection for some oyster beds. Despite similar efficiencies and the proven benefits of using lighter gear (reduced incidental mortality, less effect on epifauna), there have been no moves to adopt the modified Roderique oyster dredge in the Foveaux Strait oyster fishery.

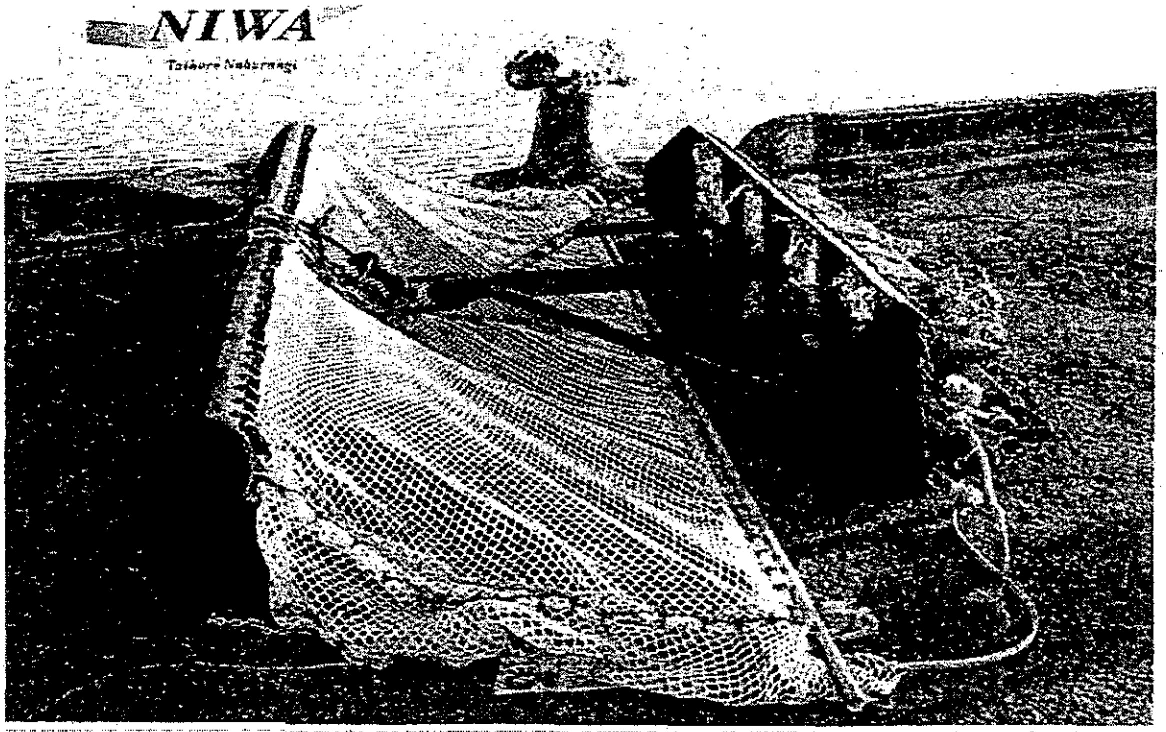

Figure 11: Roderique lightweight oyster dredge on the left with twine top panel (photo by Keith Michael).

3.2.1.3 Dredge efficiency and incidental mortality

The first estimates of oyster dredge efficiency in Foveaux Strait were carried out in the mid 1960s by Stead (1966) using divers to count oysters remaining in tracks immediately after the dredge had passed. Estimates varied between dredge design and bottom type. For a single bit dredge, efficiency was estimated at 7% and 17 % for soft and hard ground, a modified single bit dredge with a dive plate and corrugated bit bar had efficiencies of 3% and 18%, and a double bit dredge (similar to the design used today) had efficiencies of 8% and 14%, respectively (Table 1). Thus, efficiency was low on soft bottoms and higher on harder bottoms for all dredge types tested. Divers observed that on soft bottoms the bit bar initially bit deeply into the substrate filling the bag quickly and pushing sediment ahead of the dredge, with efficiency declining as the ring-bag became clogged with oysters and benthic material. On harder bottoms, dredges tended not to bite in to the same extent and therefore less sediment and epibenthic material is pushed into the dredge mouth, resulting in improved efficiency. Cranfield (1977) carried out oyster dredge efficiency trials in Foveaux Strait in 1973 and achieved similar estimates.

In 1990, dredge efficiency of a commercial double bit oyster dredge was estimated at 18% from the ratio of oyster population estimates from dive surveys (absolute abundance) to those from dredge surveys in the same areas in Foveaux Strait (Doonan et al. 1994) (Table 1).

Studies suggest that mortality is related to dredge weight. For example, incidental mortality was greater for oysters fished with the heavy standard dredge than those fished with the lightweight Roderique dredge and for both dredges mortality was inversely proportional to oyster size, i.e., spat were the most prone to damage, followed by juveniles, and then adults (Michael et al. 1998, Cranfield et al. 1999b).

Indirect mortality for spat was 48% for the Roderique dredge, and 62% for the standard dredge) and for juveniles it was 11% and 17 % respectively; adult oysters are retained and so indirect mortality of landed oysters is not relevant (Table 1). Direct mortality of oysters for the Roderique dredge was 11% for spat, 6% for juveniles and 1% for adults, compared to 19%, 7% and 2%, respectively for the standard double bit dredge. Note that these mortalities are based on a single dredge encounter and most oyster beds are heavily fished with oysters likely to have multiple dredge encounters each season. In summary, although incidental mortality occurs during dredging, it is less severe for the lighter Roderique dredge.

3.2.1.4 Non-target catch

Non-target finfish catch includes the occasional southern pigfish (*Congiopodus leucopaecilus*) or witch (*Arnoglossus scapha*). The 2001 oyster survey also recorded benthic fauna catch to gauge the effects of dredging on the environment (NIWA unpublished data).

3.2.1.5 Environmental effects

Diver observations of the standard and Roderique dredge showed that contact with the substrate is intermittent (5–30% contact for the latter) and contact declined as the dredge became full (Michael et al. 1998). The standard dredge was found to penetrate up to 20 mm into the substrate forming well defined tracks on the seafloor with ridges of sediment along the track edges. Sediment tended to pass through the ring-bag, where it became suspended in the water column and was carried away by tidal currents. After the dredge had passed, paddle crabs (*Ovalipes catharus*) and spiny dogfish (*Squalus acanthias*) were observed entering the dredge track to prey on damaged or disturbed epifauna, mainly crushed nesting mussels (*Modiolarca impacta*).

Before dredging, much of the Foveaux Strait seafloor was covered in epifaunal reefs (Cranfield et al. 1999a). Dredging has removed this epifauna and altered the complexity and structure dramatically. Areas that had been closed because of the *Bonamia* infections had recovered to the extent that when fishers were permitted back after four years they encountered patches of epifaunal reef (Cranfield et al. 2001). However as dredging continued, patches of epifaunal reefs declined progressively each year, indicating that dredging had again had a significant effect on the epibenthic fauna of this area.

On the basis of the observed partial recovery of epifaunal reefs over four years, Cranfield et al. (2001) suggested that a rotational fishing programme would allow recovery of the benthos and mitigate some of the adverse effects of oyster dredging in Foveaux Strait. Rotational fishing is used to great effect in the Nelson scallop fishery (Anonymous 1998) and in Japan where scallop production has increased markedly since adopting this management regime (Ito & Byakuno 1989). Cranfield et al. (2001) also suggested enhancing habitat by seeding with oyster shells, which form a three-dimensional structure on the seafloor suitable for colonising by epibenthic fauna and ultimately oysters.

3.3 Other dredge oyster fisheries in New Zealand

Dredge oysters, *Ostrea chilensis*, are also non-target catch of the Nelson and Chatham Island scallop fisheries. The ring-bag dredges (described above) used in these fisheries are designed primarily to target scallops and are not modified to improve oyster catch (Russell Mincher, pers. comm.).

4. SURF CLAM DREDGE FISHERIES

4.1 Worldwide

Surf clam is a generic term that refers to endobenthic or infaunal bivalve molluscs found below mean low water usually between 1 and 10 m, and often in the hard sand of the surf zone. To harvest surf clams, a hydraulic dredge is used to liquefy the substrate and dislodge the shellfish. The hydraulic dredge concept of harvesting surf clams was first introduced in the 1940s (Yancey & Welch 1968) and is used throughout the world in a range of depths and substrates (Kauwling & Bakus 1979, Smolowitz & Nulk 1982, Messieh et al. 1991, Nashimoto et al. 1994, Lambert & Goudreau 1996, Pravoni et al. 1998). In many countries using hydraulic dredges is a relatively new method of harvesting surf clams. Unlike scallop dredges the design of surf clam hydraulic dredges varies little between countries and in all cases the concept is the same; high pressure water is used to liquefy the substrate and the resulting slurry is penetrated by a dredge bit and directed on to filtration grills on the underside of the dredge frame. Sediment, debris, and undersize shellfish are forced through the grill by water jets and shellfish that are retained pass into a capture bag attached to the aft of the dredge or are airlifted to the surface.

Estimates of dredge efficiency for the Stimpson's surf clam (*Mactromeris polynma*) caught off Gulf of St Lawrence with a New England hydraulic dredge were 90%; up to 66% of clams were left on the bottom and 20% of those retained were damaged (Lambert & Goudreau 1996). Similarly, for the surf clam *Spisula solidissima* off Long Beach, New York, efficiency was 91% with mortality of missed clams between 30 and 92%; exposed clams missed by the dredge, both damaged and undamaged, were predated by crabs, starfish, and snails (Meyer et al. 1981). For the Japanese surf clam, hydraulic dredge efficiency was estimated to be 65%.

Sidescan sonar studies on Georges Bank showed that hydraulic dredge marks occur as single 5 m wide swaths that penetrate the sediment as much as 20 cm (Schmuck et al. 1995). Diver observations on Stimpson's surf clam have shown that the hydraulic dredge track is between 12 and 15 cm deep, dependent on the length of the bit used (Lambert & Goudreau 1996). Although the dredge leaves behind a well defined track there is no evidence of long term adverse affects to benthic infauna with the possible exception of those species that are not able to rebury themselves after being dislodged (Lambert & Goudreau 1996). Weinberg & Nordahl (1995) studied the effect of surf clam dredging on recruitment of *Spisula solidissima* and concluded that recruitment is reduced by intense dredging and that predation is higher in dredged areas.

4.2 New Zealand surf clam fishery

4.2.1 Fishery

The common New Zealand bivalve surf clams, *Mactra murchisoni, M. discors, Spisula aequilatera, Paphies donacina, Dosinia anus, D. subtrosea,* and *Bassina yatei* are found on exposed sandy beaches through New Zealand (Cranfield et al. 1994, Haddon et al. 1996). Intertidal species include tuatua (*P. subtriangulata*) and the less common toheroa (*Paphies ventriculosa*). Although several permits have been issued for surf clam harvesting in New Zealand, none are currently active and much of the work by researchers and commercial fishers using hydraulic dredges has been either exploratory or carried out to trial dredge gear.

4.2.2 Hydraulic dredge

The most commonly used dredge in New Zealand has been the hydraulic rabbit dredge, designed in Japan to harvest horse mussels in depths of 25 to 30 m (see Michael et al. (1990) for a detailed description of gear specifications) The rabbit dredge is constructed of stainless steel, weighs about 87 kg with a length and width of about 1.3 m, and height of 30 cm (Figures 12–13). Key components of the dredge include the frame within which sits the filtration grill and bit, a digging water jet manifold, and the wash-back manifold. The front 200 mm of the grill is bent down toward the seafloor at 45° forming the bit. The grill and bit arrangement pivots at several points at the aft of the dredge frame, allowing adjustment of the angle of attack. The top of the frame has 30 mm trawl mesh to prevent shellfish from passing over the top of the dredge and to direct the shellfish into the trailing catch bag (1.3 x 1.8 m) also made of 30 mm trawl mesh which trails. The dredge is towed by a single warp joined to a chain bridle attached at the top front of the dredge in three places. Pressurised water for the digging and wash-back manifold is supplied from the vessel using a single-stage turbine pump. The digging manifold has 15 nozzles that spray water into the sand and the wash-back manifold has 13 nozzles, which are directed at the filtration grill (see Figure 12).

To maintain a slow and constant speed, and prevent the dredge from lifting off the bottom, the dredge is moved forward by winching the vessel and dredge on a warp attached to an anchor (see Michael et al. (1990) for details). Towing speed needs to be slow enough to enable the water jets to liquefy the sand before the bit passes through the substrate and optimum speed is about 6 $m.min^{-1}$. As the dredge moves forward, the bit digs into the sand to a depth of about 180 mm and dislodges surf clams, sediment, and debris which are pushed on to the filtration grill. The wash-back water jets force sediment and debris down through the grill and large surf clams pass over the grill and into the catch bag at the aft of the dredge. Any remaining sediment is washed out of the catch bag. The dredge is hauled when the vessel reaches the anchor.

An Olsen dredge developed by MAF Fisheries (now NIWA) was also trialled along with the rabbit dredge (Michael et al. 1990). The Olsen dredge operates on the same principle as the rabbit dredge, but is heavier (100 kg), half as wide, rides on skids, and the catch is airlifted to the surface. The Olsen dredge was difficult to keep in contact with the bottom and the airlift system frequently became blocked, particularly in shallow water. It was concluded that it was not suitable for surf clam dredging in New Zealand.

4.2.3 Dredge efficiency and incidental mortality

Michael et al. (1990) carried out efficiency experiments using the rabbit dredge and estimated mean catch efficiency at 65% (i.e., 35% of clams were left behind) (Table 1). In a subsequent survey, Cranfield et al. (1994) estimated dredge efficiency at 73% using a dredge of similar design (Table 1). Examination of clams retained by the rabbit dredge showed that no shells were damaged, but that some clams had severed or partly severed feet (Michael et al. 1990). The proportions of damaged surf clams were *Paphies* 21%, *Mactra*12%, *Spisula* 5%, and *Dosinia* 0%. The rabbit dredge was found to be size selective, but this varied between species as the surf clams have different shapes. *Paphies donacina* and *P. subtriangulata* less than about 50 mm passed through the grill. Selectivity was presumed to be dependent on the width between individual filtration grills.

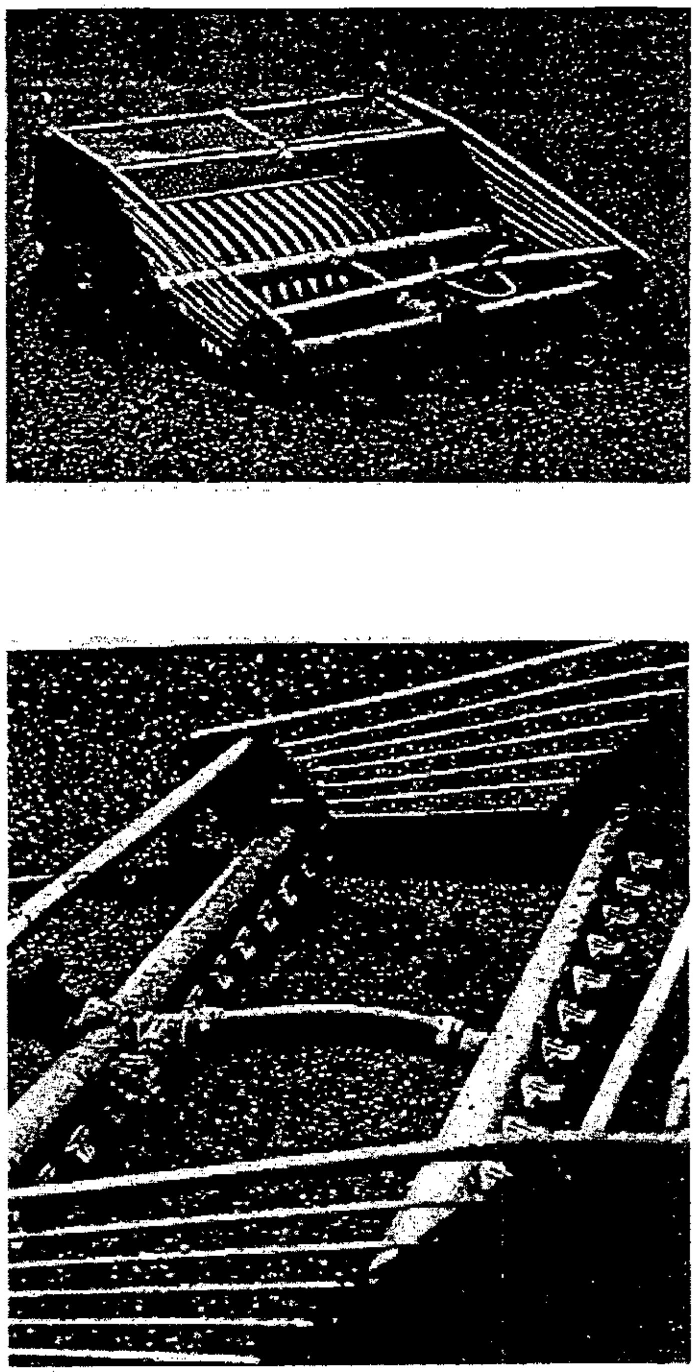

Figure 12: Top: the rabbit dredge showing the filtration grid; Bottom: rabbit dredge showing digging and wash-back water jet manifolds (from Michael et al. 1990).

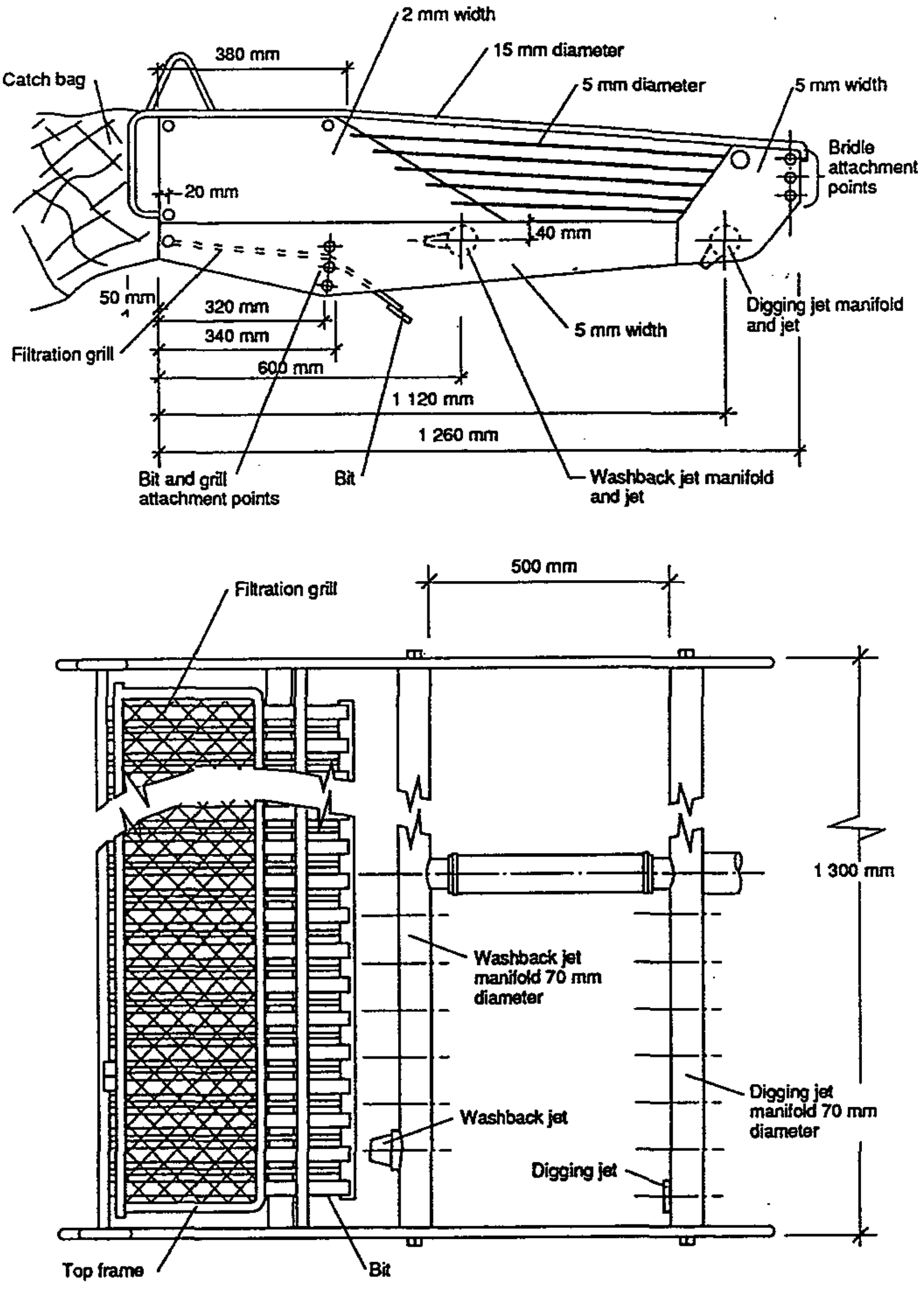

Figure 13: Diagrammatic drawing of a rabbit dredge with specifications (from Michael et al. 1990)

4.2.4 Environmental effects

In New Zealand, surf clams inhabit the surf zone, a high-energy environment oxygenated to considerable depths and characterised by high sand mobility. Species that live here must adapt to turbulence and shifting sand (Michael et al. 1990). Divers observed that the rabbit dredge forms a well defined track 130 cm wide and 12–25 cm deep, but, within 20 min there were few traces of the track and within 24 hours the track was indistinguishable, indicating that recovery of the substrate is rapid. Surf clams that were dislodged and brought to the surface but not captured by the rabbit dredge reburied in 10 to 20 min with the deeper species taking longer to rebury (Michael et al. 1990). No predation was observed on exposed clams. Shallow water environments such as the surf zone or those subjected to frequent natural disturbance tend to recover faster from the effects of mobile fishing compared to those in deeper water (Kaiser et al. 1996, Rogers et al. 1998, Watling & Norse 1998, DeAlteris et al. 1999, Collie et al. 2000a). Michael et al. (1990) concluded that the rabbit dredge has little adverse effect on the surf zone substrate.

4.2.5 Advances in gear technology

Kaimoana Fisheries and Southern Clams (Dunedin) have fished commercially for surf clams using a hydraulic dredge similar to the rabbit dredge, but no longer do so because of problems with the dredge. The dredge did not properly liquefy the sand and resulted in damaged shells (Simon Gilmour, Director Southern Clams, pers. comm.). These companies are interested in a high quality live product for export and this requires care in extraction. They are currently investigating importing an Italian designed hydraulic dredge to cope with the unique sediment found in this part of New Zealand.

A modified hydraulic dredge with vibrating filtration grill to reduce capture of undersized surf clams has been trialled in Italy (Rambaldi et al. 1999). Although undersized clams are sieved out during fishing, there is more mechanical damage to clams using the vibrating grill.

5. APPLICATION OF DREDGE TECHNOLOGIES TO NEW ZEALAND FISHERIES

In this section we discuss the application in New Zealand of technological advances in dredge gear design that reduce the adverse effects on the benthos, increase dredge efficiency, reduce non-target catch, and reduce mortality of target and non-target species.

Internationally, work is only just starting on development of dredge designs that minimise damage to the seafloor and there are currently few alternatives to the conventional scallop and oyster dredges that have been used worldwide for decades. Much of the information on dredge gear modification is found outside the primary literature, making it difficult to source. By definition, dredging is a method that disturbs the seafloor and it could be argued that all dredges adversely affect the environment. This is borne out by the paucity of technological advances in dredge design that reduce environmental effects on the seafloor.

Dorsey & Pederson (1998) summarised the findings of the conference on the effects of fishing gear on the New England seafloor in 1998 and made the following recommendations:

- No options were suggested to mitigate the inefficiencies and environmental problems associated with dredging and if retained as a legitimate method then options such as areas closed to dredging should be investigated.
- Fishers need to collaborate with scientists to design research, and industry, fisheries managers, and science providers should convene a workshop to discuss the issues.
- Research is needed into the relationship between fish and habitats to provide a scientific and technical basis for management decisions.
- Research is needed into developing gear that minimises damage to the substrate.

A common problem in determining the effects of fishing on the environment throughout the world is lack of control sites where mobile fishing has not occurred (Thrush et al. 1995, Bradshaw et al. 1999). Baird et al. (2002) quantified the intensity of mobile fishing methods throughout New Zealand and showed that for key trawl and dredge fisheries on the continental shelf, the seafloor is repeatedly and frequently fished. Internationally, there is support for the concept of closed areas to mobile fishing (McAllister & Spiller 1994, Dorsey & Pederson 1998, Turner et al. 1999) and/or the practice of rotating areas to allow recovery (Cranfield et al. 2001). The closure of areas in the Foveaux Strait oyster fishery to prevent *Bonamia* from spreading and allow the oyster population to rebuild, also resulted in recovery of the epibenthic fauna (Cranfield et al. 2001) demonstrating the potential of closed areas or rotational fishing practices to mitigate or remedy adverse environmental effects of oyster dredging. Other areas recently closed to fishing include 19 seamounts spread throughout New Zealand's Exclusive Economic Zone. Closed areas such as these provide controls that can be compared to adjacent fished areas to assess the effects of fishing on the environment.

5.1 Scallops

The toothed box dredge and Nelson ring-bag dredge used in northern New Zealand scallop fisheries leave four to five times more scallops behind than are retained and have similar efficiencies to scallop dredges used throughout the world. Although both dredges have a negative effect on the seafloor and cause mortality of scallops both retained and missed, this is more severe for the toothed box dredge (Cryer & Morrison 1997) (McLoughlin 1991, McLoughlin et al. 1993, Gorman 1997). However, it appears that the box dredge is more suitable to the hard substrate of Northland and Coromandel scallop fisheries and fishers would be very reluctant to change to a ring-bag dredge which has been shown to be less efficient on hard substrate. On the other hand, the Nelson ring-bag dredge is extremely efficient in the Challenger fishery area, leaving only 30% of the scallops encountered behind in the dredge track.

Our literature review indicates that the only success in reducing the effects of dredging on the seafloor was to make the scallop dredge lighter, and this was achieved in Alaska by replacing the chain ring-bag with a synthetic mesh codend and using a diving plane rather than weight to keep the dredge on the bottom (Tkacz 1994). New Zealand dredges are already lighter than those used in most other countries. Further, the Nelson ring-bag was found by the Australians to cause the least damage to scallops caught and those missed, as well as being one of the most efficient of all the main dredge types used worldwide (McLoughlin 1991, McLoughlin et al. 1993, Gorman 1997).

The MIT prototype dredge, with five individual sweep chains connected to pivoting depressor plates replacing the cutting bar, showed promise, but its efficiency and effects on the environment have not been determined (Goudey 1999) (see Figure 2). This dredge appears to be considerably heavier in construction than the Nelson ring-bag dredge which uses only sweep chains rather than a cutting bar as the ground tending gear.

We conclude that there are currently no developments in scallop dredge gear technology that could be applied to New Zealand that will reduce environmental effects on the seafloor as well as allow the gear to perform satisfactorily. Dredge design reflects the target species and the environment, including substrate type. In New Zealand, the Nelson ring-bag dredge and the box dredge used in Northland and Coromandel are designs that are considered most effective at catching scallops in the substrates found in these areas.

5.2 Oysters

Dredging for oysters has been responsible for the loss of biogenic reefs in Foveaux Strait and as the weight of dredges has progressively increased over time the adverse effects of dredging have become more severe (Michael et al. 1998, Cranfield et al. 1999a). The lighter single bit dredge trialled in 1997 indicated that efficiency was similar to the present standard double bit dredge, but that incidental mortality of oysters was less (Michael et al. 1998). Presumably the lighter dredge also has less damaging effects on the benthic fauna than the standard heavier dredge. This offers the potential to harvest oysters in Foveaux Strait with a dredge that has less adverse environmental effects. More extensive trials would be warranted however, including dredge efficiency estimates before the lighter dredge could be introduced.

5.3 Surf clams

Commercial surf clam harvesting in New Zealand is still in its exploratory phase and there are currently no active permits. The hydraulic dredge seems to offer the only feasible means of extraction from the fine sand substrates and has little adverse effect on the high energy surf zone substrate, which recovers soon after the dredge has passed (Michael et al. 1990). The current design is therefore acceptable if use is restricted to the surf zone.

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Appendix 1. Glossary of terms used

Bale – a steel towing frame attached to the front of a New Bedford ring-bag dredge.

Benthic community – the community of organisms that live on, near, or in the bottom sediments of the seafloor.

Biogenic reef – ridge or rise above the seafloor made up of organisms or debris composed of the hard parts of organisms such as bits of shell, teeth, or bone.

Bit bar – the cutting bar in Foveaux Strait oyster dredges.

Box dredge – a type of scallop dredge that uses a box constructed of steel framing and steel mesh as the collection device. The box is usually dragged over the bottom on narrow runners that keep the box slightly off the seafloor.

Chaffing gear – prevents damage to gear by reducing wear on the underside of the dredge.

Club stick – a steel rod at the aft of a New Bedford ring-bag dredge that holds the ring-bag apart and maintains shape when the dredge is lifted aboard.

Cutting bar – A steel bar attached transversely to the leading edge of the dredge. It digs into the substrate and forces the shellfish into the dredge.

Dredge – Device towed over the seabed for the collection of shellfish and includes a box dredge, a ring-bag dredge, and a hydraulic dredge.

Dredge efficiency – As a dredge passes over shellfish on the seafloor some shellfish in the track of the dredge are retained and others are missed. Dredge efficiency pertains to the ratio of caught to missed shellfish and is usually expressed as a percent or proportion.

Endobenthic fauna (also known as infaunal) – organisms found within the sediment of ocean floor.

Epibenthic fauna – organisms that inhabit the region just above the ocean floor to a height of about 3 m.

Epifauna – organisms that live on, but not within or under the ocean floor.

Epifaunal reef – reef formed by epifauna.

Gear-substrate interface – the part of the dredge that initially comes into contact with the substrate and transfers shellfish from the substrate into the dredge. It differs among dredge type and could be the cutting bar, tines, or chains.

Ground tending gear – part of the dredge that interacts with the substrate (analogous to gear-substrate interface).

Homogenised sediment – sediment that is uniform in nature after repeated exposure to dredging. Much of the epifauna has been removed with loss in species heterogeneity.

Hydraulic dredge – a type of dredge that uses pressurised water to liquefy the sand substrate containing shellfish ahead of the dredge. The dredge is usually dragged over the bottom on narrow runners that keep it slightly off the seafloor.

Incidental mortality – mortality of shellfish that interact with the dredge but are not retained. Includes shellfish that pass through or under the dredge (direct mortality), or those that are caught by the dredge but are undersized and returned to the sea (indirect mortality).

Non-target catch – species, caught as bycatch of dredging that do not include the target species.

Pressure plate (also known as a diving plane and depressor board) – a steel plate attached to the top of the dredge that helps to keep the dredge on the seafloor through hydrodynamic pressure created by forward movement of the dredge.

Ring bag (also known as chain bag) – collection bag constructed of steel rings that is towed behind the dredge.

Ring bag dredge – a type of dredge that uses a ring-bag constructed of steel rings as the collection device. The bag is usually dragged over the bottom and conforms to the shape of the seafloor.

Ring mesh – diameter of rings that comprise the ring-bag.

Rockhopper chain – chains that run longtitudinally from front to back ahead of the dredge to prevent boulders from entering the ring-bag.

Shucking – a term that refers to removing the meat from the shell.

Species heterogeneity (species diversity) – measure of the number of different species present.

Tickler chains (sweep chains) – chains that are attached transversely ahead of the dredge, most commonly found on scallop ring-bag dredges. The chains drag along the seafloor and disturb scallops which swim up off the bottom and into the collection bag. Tickler chains can be used together with a cutting bar or instead of a cutting bar.

Tines – steel teeth attached to the tooth bar.

Tooth bar – bar fitted with tines designed to rake scallops out of the substrate into the dredge.