New Zealand Fisheries Technical Report No. 21 1990 ISSN 0113-2

Design and performance of two hydraulic subtidal clam dredges in New Zealand

K. P. Michael
G. P. Olsen
B. T. Hvid
and
H. J. Cranfield

MAF

Design and performance of two hydraulic subtidal clam dredges in New Zealand

K. P. Michael
G. P. Olsen*
B. T. Hvid
and
H. J. Cranfield

*New Zealand Fishing Industry Board

New Zealand Fisheries
Technical Report No. 21
1990

Published by MAF Fisheries
Wellington
1990

Inquiries to:
The Editor, MAF Fisheries Greta Point,
P.O. Box 297, Wellington,
New Zealand.

MAF Fisheries is the fisheries business group of the New Zealand Ministry of Agriculture and Fisheries. The name MAF Fisheries was formalised on 1 November 1989 and replaces MAFFish, which was established on 1 April 1987. MAFFish combined the functions of the old Fisheries Research Division and Fisheries Management Division and the fisheries functions of the old Economics Division.

The *New Zealand Fisheries Technical Report* series in part continues the *Fisheries Research Division Occasional Publication* series. Conference proceedings and bibliographies are now published in the *New Zealand Fisheries Occasional Publication* series.

Edited by C. M. Coffey and G. G. Baird
Set in 10 on 11 English Times
Typeset by Visual Perceptions
Printed by Thames Publications Ltd.

ISBN 0-477-08275-0

Contents

Abstract

Michael, K. P., Olsen, G. P., Hvid, B. T., and Cranfield, H. J. 1990: Design and performance of two hydraulic subtidal clam dredges in New Zealand. *N.Z. Fisheries Technical Report No. 21.* 16 p.

The sandy beaches of New Zealand appear to support large populations of shellfish in their surf zones. Hydraulic dredges offer the best sampling tool to investigate the potential of this surf zone resource. This report describes the design, operation, and performance of two hydraulic dredges: the Olsen dredge, developed during this project, and the Rabbit dredge, developed in Japan.

The Olsen dredge and the Rabbit dredge are lightweight hydraulic dredges which use jets of water to liquefy the seabed and dislodge buried shellfish. The Olsen dredge uses an airlift system to convey the catch to the surface; the Rabbit dredge retains its catch on the seabed. In sheltered waters, where cockles (*Chione stutchburyi*) predominate, the Olsen dredge delivered shellfish to the surface satisfactorily, but in the surf zone it was difficult to handle, and in both situations it blocked frequently. In the surf zone the Rabbit dredge was more effective than the Olsen dredge, and it caught subtidal clams (*Paphies donacina, Spisula aequilateralis, Mactra murchisoni, M. discors, and Dosinia anus*) with a mean efficiency of 65%. The Rabbit dredge appeared to have little effect on the surf zone ecology. Both dredges were most effective when winched at a steady speed of about 6 $m.min^{-1}$.

Introduction

About 1000 km (10%) of New Zealand's coastline consists of long (over 10 km) and exposed sandy beaches which have shallow gradients (Tortell 1981). Beaches similar to these in other parts of the world support large populations of bivalves in their surf zones (McLachlan 1983), and studies suggest this is also the situation in New Zealand. Live shellfish stranded after storms have provided some indication of biomass, size, and species composition of these bivalves (Eggleston and Hickman 1972).

Surf zone bivalves, more commonly known as subtidal clams, are infaunal species (i.e., they live in the seabed). Dredges designed to harvest epifauna, such as scallop and oyster dredges, which skim the top of the seabed, are inadequate for harvesting subtidal clams. Although these dredges can be modified to penetrate deeper into the seabed, they still can not dig deep enough to capture infaunal shellfish efficiently, and they generally damage those shellfish which they do not capture. Therefore, hydraulic dredges have been developed to harvest shellfish buried in the seabed.

Hydraulic dredges use jets of water to liquefy the seabed and dislodge buried shellfish. The resultant slurry is easily penetrated by the dredge bit. The seabed needs to be liquefied to a depth equal to the lower edge of the bit to ensure all shellfish in the dredge path are captured without being damaged. The depth to which the seabed is liquefied is determined by the angle of the digging jets, the water pressure and volume, the seabed density, and the dredge towing speed. The bit combs through the slurry and directs shellfish, debris, and a small amount of sediment into the dredge. All of these materials, except the larger shellfish and debris, are returned to the seabed through the filtration grills in the underside and rear of the dredge; a process assisted by water jets (Smolowitz and Nulk 1982). The captured shellfish are either held in a catch bag or delivered to the surface by airlift.

The efficiency of hydraulic dredges has been shown to range from 80 to 100% (Manning 1965, Pickett 1973, Meyer *et al.* 1981, Smolowitz and Nulk 1982). To achieve this high efficiency, a balance between water supply and towing speed needs to be maintained. (To overcome the effects of depth on water supply, some fishers in the United States use dredges with submersible electric water pumps.) In addition, materials channelled into the dredge by the bit need to be filtered efficiently to prevent the catch bag or delivery chamber becoming choked with sediment.

Hydraulic dredges are used in many countries and in a wide range of environmental conditions, from sheltered muddy estuaries to exposed offshore areas (in depths up to 100 m). Many hydraulic dredge designs have been developed, each for a specific environment and depth range. These designs, which are mostly well documented, include the hydraulic clam rake (Bourne 1967), the hydraulic escalator clam harvester (Manning 1965, Adkins *et al.* 1983), the hydraulic clam dredge (Meyer *et al.* 1981), the electrohydraulic clam dredge (Smolowitz and Nulk 1982), the British cockle dredge (Pickett 1973), and the Rabbit dredge (Nashimoto and Motoya 1985).

In New Zealand most exposed surf beaches are long distances from good launching facilities, and their surf zones can be accessed only by small vessels (7–10 m) which can be launched from the shore. As these vessels can operate only lightweight dredges, many of the dredges which have been developed can not be used for harvesting subtidal clams in New Zealand. To overcome this problem, Olsen proposed the use of a small hydraulic dredge, similar to the British cockle dredge, with a continuous delivery system (pers. comm.). The "Olsen dredge" was built to test the design. While the Olsen dredge was being developed, a North Island processing company imported a lightweight hydraulic dredge from Japan. This dredge, called the Rabbit dredge, was developed to harvest horse mussels (*Atrina pectinata japonica and Pinna atrina japonica*) off Japan in depths of 25–35 m. It was made available for this study so that its effectiveness in the surf zone could be evaluated.

This report describes the design, operation, and performance of the Olsen dredge and the Rabbit dredge. It discusses the catch efficiency of the Rabbit dredge and the immediate effects of dredging on subtidal clams and the surf zone environment. A towing technique for hydraulic dredges operated in shallow waters is described.

Since this study was conducted, the Rabbit dredge has been used to determine subtidal clam resources off the Wellington west coast (MAF Fisheries Greta Point unpublished data); Rabbit Island, Nelson (Michael and Olsen 1988); and Cloudy Bay, Marlborough (Cranfield and Michael 1987).

The Olsen dredge

Design

The Olsen dredge uses jets of high pressure water supplied from the surface to liquefy the seabed, filter the resultant slurry, and wash the catch into the back of the dredge. An airlift system conveys the catch to the surface.

Design specifications for the Olsen dredge are shown in Figure 1. The dredge is made of 4 mm steel and weighs 100 kg. To ensure that water and air flows are not constricted, rigid PVC heliflex hoses are used throughout the dredge. A bridle (2.5 m of 12 mm steel chain) is used to tow the dredge. Steel channel skids, which support the dredge on the surface of the seabed, enable the dredge to be towed at a steady speed and to be kept in continuous contact with the seabed. A skimming plate may be bolted on to the front of the dredge to prevent the entry of surface debris and fauna which can cause blockages. The bit, which is also bolted on to the dredge, is a 6 mm steel plate (400 × 180 mm) in which holes of 20 mm diameter have been drilled 50 mm apart (centre to centre). Bits of different dimensions, depending on the burial depth of the target species, may be bolted on easily.

The two filtration grills are made of 10 × 10 mm steel bars which have been welded 13 mm apart on to two 50 × 10 mm steel bars. The lower grill is shorter (400 × 200 mm) than the upper grill (400 × 400 mm). The digging jet manifold is above the bit, and the front washback manifold is positioned so that its jets spray water down between the bars of the upper filtration grill. The water jet manifolds are made of galvanised pipe. The digging jet manifold and the front washback jet manifold have internal diameters of 25 mm and jet holes of 3 mm diameter. The jet holes are 30 mm apart on the digging jet manifold and 40 mm apart on the front washback jet manifold. The rear washback jet manifold has an internal diameter of 8 mm and jet holes, which are 4 mm in diameter and 40 mm apart. The angle of the digging jet manifold and of the front washback jet manifold may be altered by rotating the manifolds in their clamps. The rear washback jet manifold is mounted at the upper rear of the delivery chamber and its jets are directed downwards.

Water is supplied to the dredge by a Wallace selfpriming pump (model 95820), which gives a maximum flow rate of 575 $l.min^{-1}$ from a cast iron impeller. The pump is powered by a Suzuki petrol motor (four stroke), which produces a maximum of 2.6 kW (3.5 hp) at 3500 rpm. Water is pumped to the digging jet manifold through a 50 mm diameter hose. This hose splits into two reinforced rubber hoses, which supply the washback jet manifolds.

Compressed air is supplied by a Masport M3 vacuum pump. This "compressor" delivers air at 1870 $l.min^{-1}$ at 135–170 kPa when it is run at 1225 rpm. The compressor is powered by a Kawasaki K100 aircooled petrol motor (single cylinder, four stroke), which produces a maximum of 7.36 kW (10 hp) at 3600 rpm. The compressor and motor are mounted to reduce vibration. For lubrication, compressed air is used to pressurise a sealed oil reservoir, which forces oil into each side of the compressor through two small needle valves (Figure 2).

The air induction chamber consists of a 100–150 mm concentric steel reducer which is attached to the rear of the dredge by a 90° welding elbow of

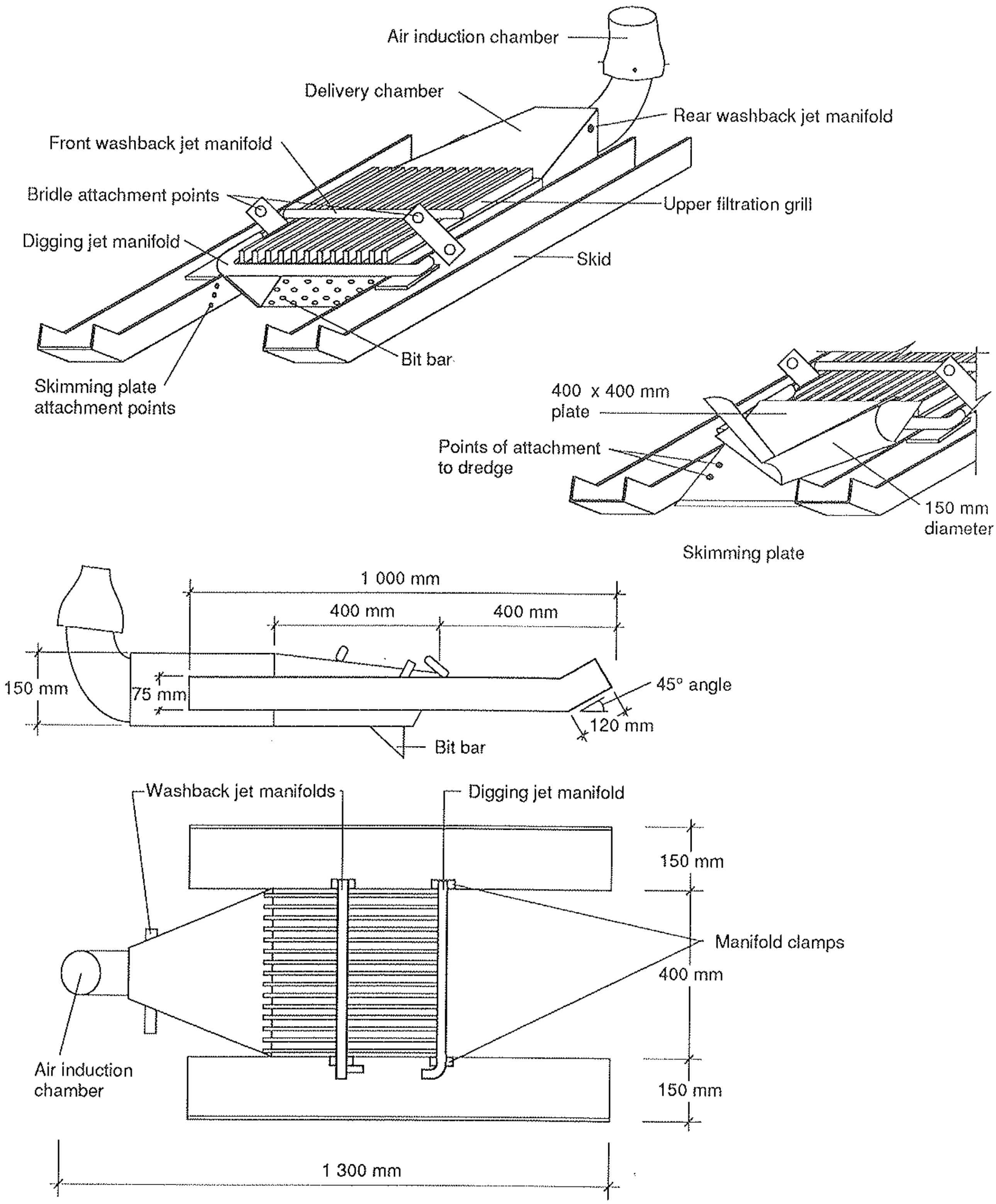


Figure 1: The Olsen dredge design specifications.

100 mm diameter (Figure 3). Air is pumped into the air induction manifold through a 38 mm hose at about 12 kPa for every metre of water depth. The manifold, which is made of galvanised pipe, is 150 mm long and has a diameter of 38 mm. It splits the air into four outlet ports, which are made of 25 mm lengths of galvanised pipe of 25 mm external diameter. The air then passes through the delivery hose to the air induction chamber. The delivery hose (100 mm diameter) is in 2 m lengths which are coupled together and to the induction chamber and delivery chute by camlock fittings. The air draws the catch through the air induction chamber and drives it to the delivery chute on the surface (Figure 4). The delivery chute is composed of 6 mm diameter aluminium rods welded 10 mm apart to form a 450 mm diameter channel,

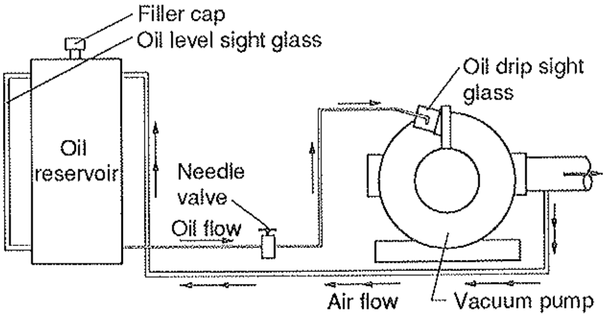


Figure 2: Lubrication system of the Olsen dredge compressor.

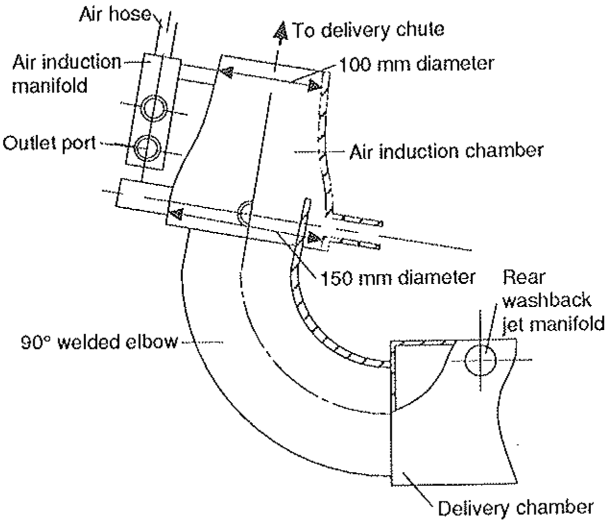


Figure 3: Air induction chamber of the Olsen dredge.

1.5 m long. The front 0.2 m of the chute is curved by 90° into the vessel to allow the catch to be delivered on to the boat. A perspex spray shield can be clipped on to the chute to prevent water and solid material being deflected into the vessel.

Operation

Towing

The Olsen dredge was towed alongside the aft end of the vessel to allow the delivery hose to be attached to the delivery chute and the catch to be delivered on to the vessel. A lifting bridle and warp were used to lower and haul the dredge, and a towing bridle and warp were used to tow the dredge. The angle between the towing warp and the seabed needed to be shallow to prevent the front of the dredge being lifted off the seabed. This angle could be reduced by moving the towing point to the bow. Dredging was most effective when the bridle was attached to the inside of each skid, just forward of the centre of gravity (i.e., 500 mm from the front of the skids). When the bridle was attached too far forward, the front of the dredge lifted and the dredge skipped and gouged out lumps of sediment. This sediment often blocked the delivery chamber. Towing from points too far behind the centre of

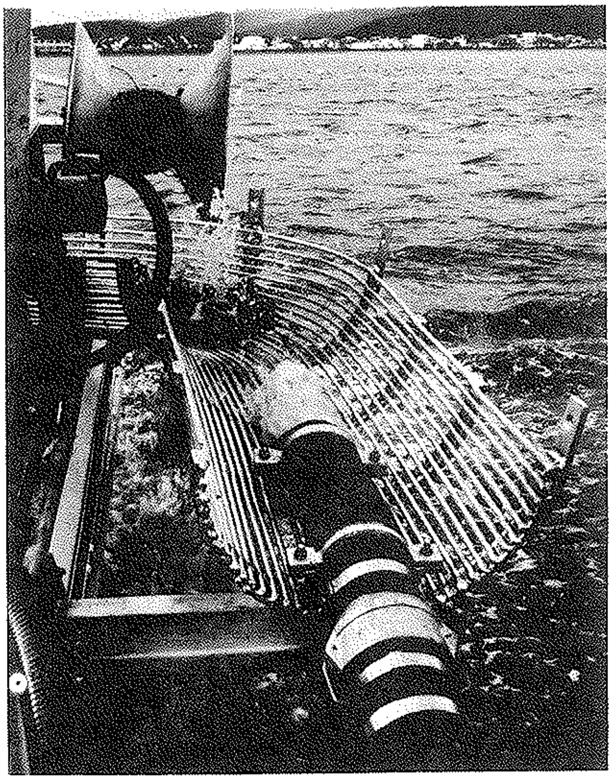


Figure 4: Delivery chute of the Olsen dredge.

gravity caused the rear of the dredge to lift off the seabed.

In deep waters (over 8 m), Japanese fishers achieve a slow steady towing speed by winching the vessel and dredge on a warp attached to a block anchored to the seabed. The winch maintains a steady horizontal pull on the dredge and keeps it in continuous contact with the seabed. Although this technique was effective, resetting the block was time consuming and laborious. However, in this study the dredge was used only in shallow water and the block was not needed, which increased the efficiency of the dredging process without decreasing its effectiveness (Figure 5).

The government research vessel *Torea* (a 6.7 m aluminium jet boat) was used to tow the dredge. A hydraulically driven aluminium winch drum which held 300 m of 6 mm steel warp was bolted to the starboard side of the vessel. The warp was guided from the winch drum to the vessel's bow by two blocks, and it was attached to 2 m of heavy chain and a 15 kg plough anchor. A buoy was attached to the anchor to mark its position. The winch drum speed was set by a variable hydraulic valve, and the time taken to recover a known length of warp was measured to give the winching speed.

Towing speed needed to allow enough time for the water jets to penetrate and liquefy the seabed to the required depth. A towing speed of about 6 $m.min^{-1}$ satisfied this requirement in surf zone and sheltered waters. At a towing speed of 9 $m.min^{-1}$ the water jets did not dig deep enough, and at speeds less than 6 $m.min^{-1}$ the slurry was formed below the lower edge of the bit.

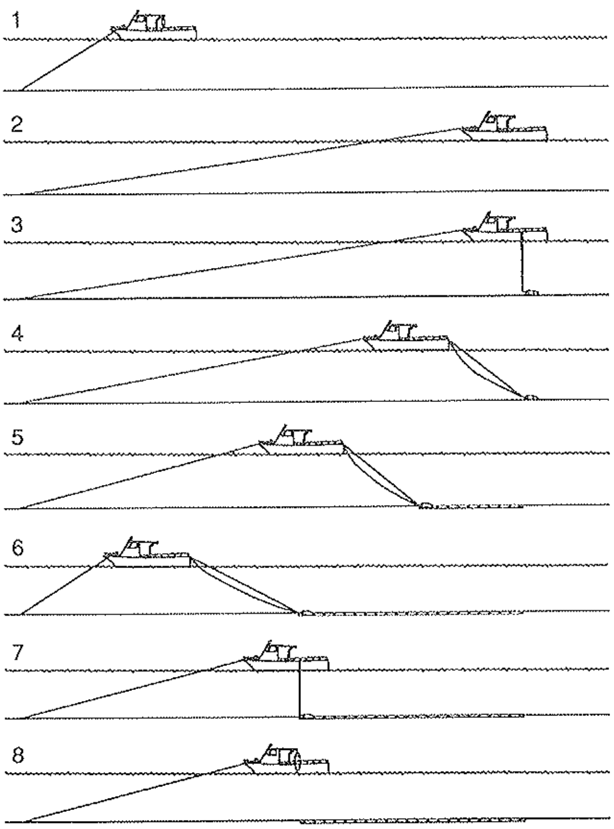


Figure 5: Winching technique for hydraulic dredges. 1, The anchor is set on station; 2, The winching warp is paid out as the vessel moves astern down the tow line; 3, When all of the warp has been paid out, the dredge is lowered to the seabed; 4, The winching warp is slowly winched in and the towing warp is paid out until tight; 5, The water pump (and the compressor for the Olsen dredge) is turned on, and the vessel and dredge are winched together towards the anchor at a slow steady rate; 6, At the end of the tow, winching ceases and the water pump (and compressor) are turned off; 7, The vessel moves astern and the winching warp is paid out until the vessel is directly over the dredge; 8, The dredge is hauled (and emptied if necessary).

Dredging

Water supply to the dredge was regulated by the throttle settings of the pump. The pressure and volume of water to each manifold was dependent on the pressure and volume of water from the pump and on the total jet area of each manifold. When the water supply was too high, the seabed beneath the lower edge of the bit was liquefied and shellfish were missed. When the water supply was too low, only a shallow layer of the seabed was liquefied, and many shellfish in the undisturbed sediment were damaged as the bit rode up on the seabed. Dense substrates, such as mud or clay dominated sediments, required a greater water supply to ensure liquefaction. The angle of the digging jet manifold ensured the water jets struck the seabed slightly forward of the bit's leading edge, at 80–85°. At this angle the jets penetrated the seabed to a depth of 150 mm. When the digging jets were angled too far forward, material in front of the dredge was pushed to the sides and out of the dredge path. When the digging jets were angled too far back, the seabed was not penetrated adequately, which resulted in blockages and greater shellfish damage.

The bit was fixed at 45° to the seabed and penetrated to a depth of 150 mm. It channelled shellfish, debris, and sediment in the dredge path into the dredge. Little filtration took place at the bit; most of the material was filtered by the lower filtration grill, with the assistance of the washback jets. The front washback jets moved the remaining material over the grill to the rear of the dredge. The delivery chamber directed the catch into the delivery hose, and the washback jets in the delivery chamber prevented material consolidating and blocking the entry to the airlift system.

Compressed air drove the catch from the delivery chamber to the surface. The compressor ran most efficiently at 1600–2000 rpm, which required the K100 motor to be set at 2700–3000 rpm. At this speed the compressor required an oil flow of at least 30 drops.min^{-1} to ensure that it was adequately lubricated. The needle valves were left fully open for a few seconds before the compressor was shut down to coat the interior of the compressor with oil and inhibit corrosion.

The air induction chamber needed to be 1 m above the maximum pumping depth of the compressor. For the shallow depths worked in this study, the air induction chamber was attached to the base of the delivery hose; however, in deeper water it may be more effective to attach it further up the hose.

Shellfish and debris retained by the dredge, and a suspension of fine sediments, entered the delivery chamber and were lifted through the delivery hose to the vessel-mounted delivery chute. Although a continuous supply of air was needed to prevent shellfish jamming and blocking the delivery hose, an excessive air flow caused many of the shells to break. On exposed surf beaches which have many sand dollars (*Arachnoides zelandiae*) and pieces of driftwood, the delivery chamber frequently became blocked. The addition of the skimming plate was only partially successful in reducing such blockages.

Discussion

In sheltered waters, where cockles (*Chione stutchburyi*) predominate, the dredge delivered shellfish to the surface satisfactorily, though blockages of the delivery chamber and hose were frequent. The blockages mainly occurred when the dredge encountered dense aggregations of shellfish, which congested the entrance to the delivery chamber. When the water was deep the airlift system was more efficient and there were fewer blockages. Subtidal clams in deep water could have their distribution boundaries mapped more precisely than clams in shallow water because they are usually distributed in dense patches and the catch is delivered continuously by the airlift system.

In the surf zone it was difficult to handle the dredge and to keep it in firm contact with the seabed. As the water was shallow, the airlift system was not efficient and the delivery chamber and hose frequently became blocked with sediment, epifauna, and debris. Consequently, the Olsen dredge was not further developed for use in the surf zone.

The Rabbit dredge

Design

The Rabbit dredge (Figure 6) is a lightweight (87 kg) hydraulic dredge which uses surface-supplied water to liquefy the seabed. The catch is filtered and retained on the seabed by the dredge.

Pressurised water is supplied to the dredge by a single-stage turbine pump (Rabbit pump, model P404) made by Fuji Robin Industries, Japan. It is driven by an aircooled petrol motor (two stroke). The turbine pump is selfpriming and uses a four-blade eccentric-rotary vacuum pump to produce a vacuum head of 9 m (640 mm Hg). The 75 mm pump inlet is coupled to a PVC hose which has a cane filter. The discharge rate is $1 m^3.min^{-1}$ ($1000 l.min^{-1}$) at 4350 rpm. The pump gives a water pressure of 11.6 kPa from a 25.5 mm diameter nozzle and 16.8 kPa from a 19.0 mm nozzle.

The Rabbit dredge is made of stainless steel. It is composed of a single slotted panel, which forms the filtration grill and bit, a digging jet manifold, and a washback jet manifold (Figure 7). The components are mounted between two stainless steel sides (without skids) and are braced by stainless steel rods. A catch bag is attached to the rear of the dredge.

The filtration grill and bit consists of a 0.53 × 1.3 m grill which has been made by welding stainless steel rods (5 mm diameter and 25 × 5 mm) 18 mm apart on to a frame. The front 200 mm section is bent 45° towards the seabed to form the bit. The grill and bit panel pivots at the rear of the dredge, and one of three points of attachment determines the level of bit penetration. A removable 1.3 × 0.4 m frame at the top rear of the dredge prevents the catch being washed over the top of the dredge. The frame is made of 15 mm diameter stainless steel rod and is covered in 30 mm trawl mesh. A 1.3 × 0.8 m catch bag of 30 mm mesh is lashed on to a similar rod frame at the rear of the dredge. The dredge is attached to the towing warp by a 2 m steel chain bridle (12 mm thickness), which has three attachment points at the top front of the dredge.

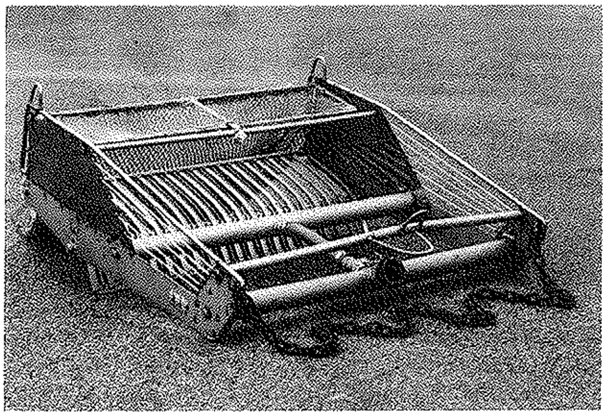


Figure 6: The Rabbit dredge.

The digging and washback manifolds are sealed units which bolt on to the dredge (Figure 8). The angle of the water jets can be adjusted by rotating the manifolds on slotted tabs. The digging jet manifold has a female brass coupling to the supply hose and a plastic hose with an outlet tap to the washback jet manifold. The digging jet manifold has 15 plastic nozzles which spray narrow fans of water. The nozzles are attached to the manifold by two Allen bolts and are sealed with rubber O-rings. The washback jet manifold has 13 nozzles. Water is supplied to the digging jet manifold through a 100 mm diameter reinforced "lay-flat" canvas hose. The hose is divided into 10 and 20 m lengths which are coupled by swivelling clip-on brass fittings to prevent kinks.

Operation

Towing

The Rabbit dredge was towed by the winching technique used for the Olsen dredge (*see* Figure 5). A towing warp length three times the water depth fished was used to keep the angle of the towing warp shallow and the dredge in full contact with the seabed. As the Rabbit dredge is lighter than the Olsen dredge, the angle of the towing warp needed to be shallower. The towing warp was shackled to the bridle and secured to the stern of the vessel.

Dredging

Water supply to the manifolds was regulated by the throttle settings on the pump and a discharge tap on the pump outlet. Another tap between the digging jet manifold and the washback jet manifold was used to regulate the amount of water to each manifold.

The digging water jets were angled to strike the seabed at 50° and 60 cm in front of the bit. Although the angle between the water jets and the seabed was small, high water pressure ensured the seabed was penetrated to 180 mm. The bit was at an angle of 45° to the seabed and also penetrated to a depth of 180 mm.

On sandy substrates the slurry was almost entirely filtered by the bit. Materials channelled into the dredge needed to be filtered efficiently to prevent the catch bag becoming choked with sediment. The tap which regulated the water supply to the washback manifold was left fully open to assist in filtration through the grill. If the washback jets failed, the catch bag clogged. The catch bag provided additional filtration, and it retained only shellfish and debris greater than 20 mm in length. At faster towing speeds more filtration by the catch bag was needed. Some fishers in the United States provide this extra filtration by using heavy steel barred cages instead of catch bags (Smolowitz and Nulk 1982). Although similar modifications could be

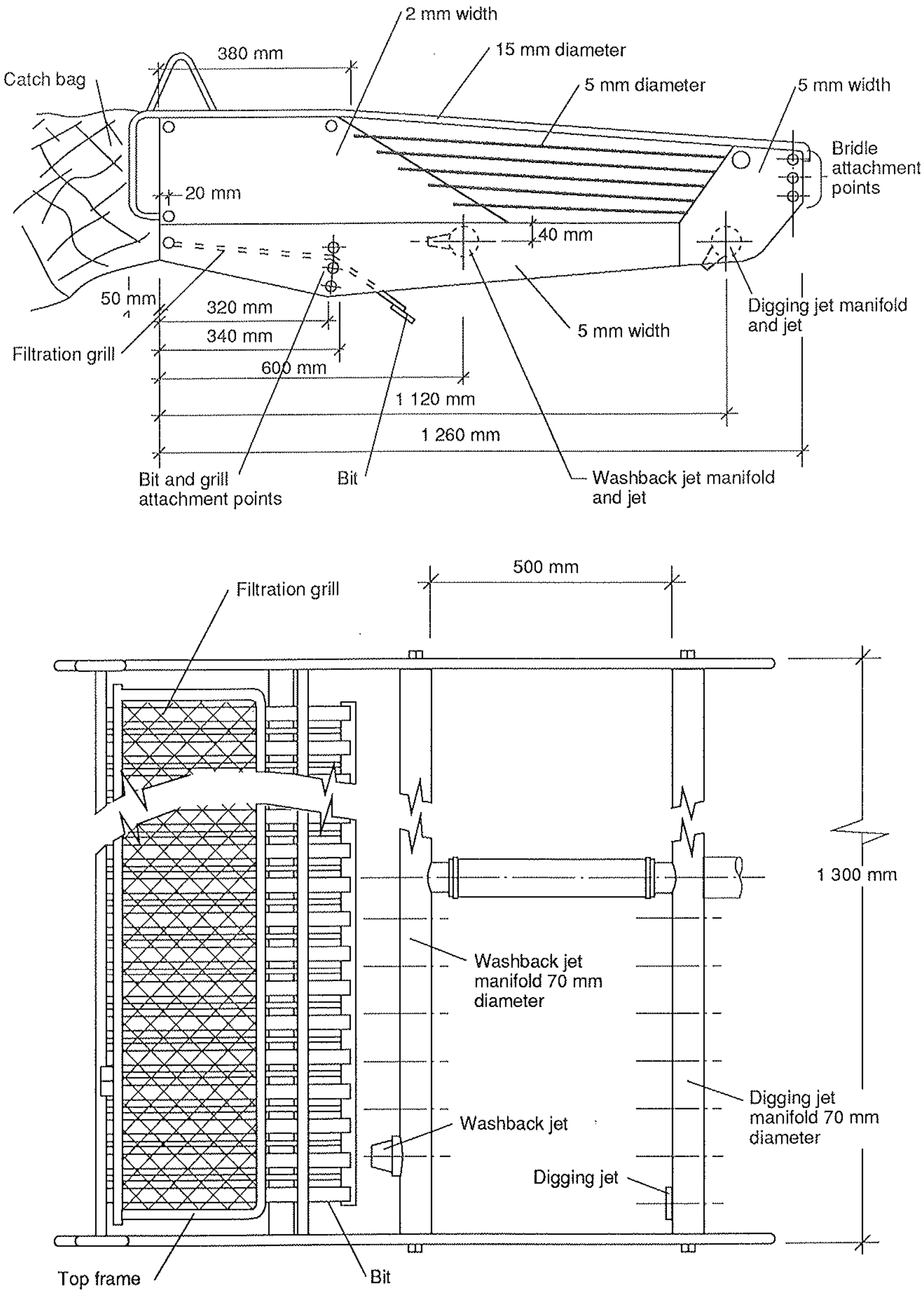
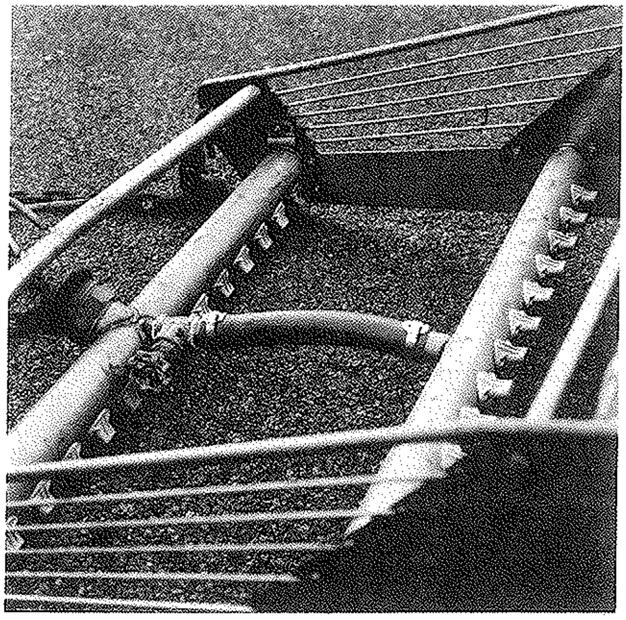


Figure 7: The Rabbit dredge design specifications.



made to the Rabbit dredge to allow it to be towed faster or to be used in fine sediments, heavier lifting and handling gear would then have to be used.

Discussion

The Rabbit dredge operated effectively in sheltered waters and in the surf zone; it was less affected by swells than the Olsen dredge. It was light and compact enough to be used on small vessels which have limited space and lifting gear, and it required only one pump, for water, and one set of hoses. As the Rabbit dredge is wider (130 cm) than the Olsen dredge (40 cm), it dredged a much larger area for the same length of tow.

Figure 8: Digging and washback jet manifolds of the Rabbit dredge.

Catch efficiency of the Rabbit dredge

The catch efficiency of the Rabbit dredge was investigated to establish whether it could be used for commercial harvesting and to enable estimation of the biomass of subtidal clams in the surf zones of New Zealand beaches.

Methods

The catch efficiency trials were conducted on the Wellington west coast off Pekapeka, 15 and 16 June 1986 (Figure 9). The beach dredged had a low gradient and fine sand (0.063–0.125 mm), and it was dissipative and accreting (*see* Gibb 1978, Short and Wright 1983 for more information on beach characteristics).

Environmental variables, such as seabed type and firmness, tidal current strength, weather, and sea conditions can greatly influence the catch efficiency of a dredge (Smolowitz and Nulk 1982). Therefore, the investigation was carried out in calm weather and sea conditions and in a fairly uniform area. No attempts were made to assess the individual impact of each of these factors on the catch efficiency of the dredge.

Airlift sampling

A diver-operated airlift sampler was used to collect samples of subtidal clams from the study area. The sampler consisted of an air induction chamber (*see* Figure 3) which was supported over a 1 m^2 quadrat of seabed by a weighted steel frame. A 1.5 m reinforced PVC hose (100 mm diameter) was attached below the air induction chamber, and a 0.5 m reinforced rubber suction hose (100 mm diameter) was attached above the chamber. A short heliflex hose (38 mm diameter) was attached to the air induction port, which was

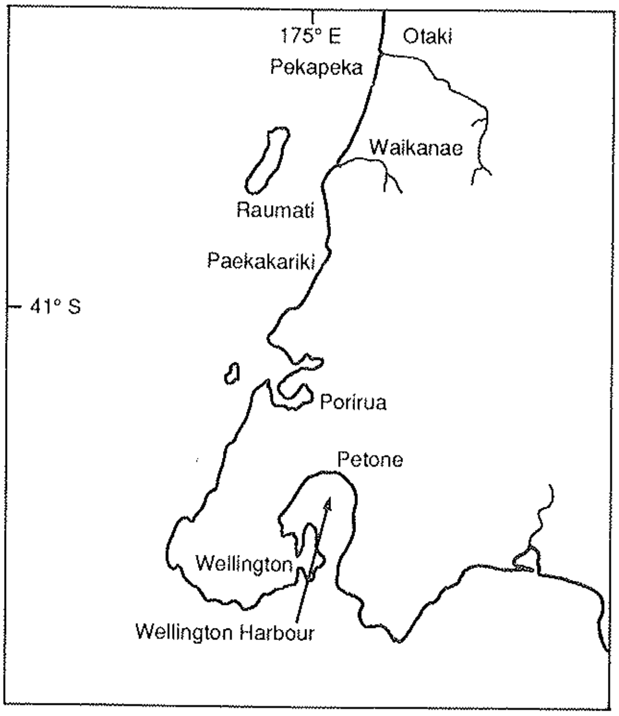


Figure 9: The Wellington west coast, showing areas where the catch efficiency trials of the Rabbit dredge were conducted.

welded to the side of the chamber. Camlock fittings were used to attach the suction hose and the heliflex hose.

The Olsen dredge compressor and its air and delivery hoses were used to operate the sampler. The delivery hose was supported by two "polyform" buoys (100 cm diameter). A catch bag (80 × 25 cm) of 15 mm mesh was lashed to the end of the delivery hose to retain the sample. The catch bag readily filtered the catch, and all material greater than 5 mm in length was retained. The airlift sampler required at least 1 m of water above the air induction chamber to develop adequate suction for sampling. The heavy weight of the sampler (50 kg) and the low tension of the air hose ensured the sampling frame was not moved by wave action. In shallow water the compressor was run at full throttle to enable the sampler to develop enough suction to dig out the sample and deliver it to the surface.

Airlift samples were taken along two transects, which were about 200 m long, 30 m apart, and parallel to the shore. Ten quadrats (about 200 mm deep) were randomly chosen along each transect, and the substrate was sampled until no subtidal clams could be found within the quadrat. After the sample had been taken, the delivery hose was checked to ensure there were no clams jammed in it and the sample bag was removed. Every second quadrat was marked with a weighted buoy line to show the transect line. After each quadrat was sampled the clams were identified and measured.

Dredge sampling

Samples were also taken by dredging the area between the buoyed lines along two 250 m transects. The warp was laid parallel to the shore and down wind, and three random tows were made along each transect. At the beginning of each tow a weighted buoy line was placed at the rear of the dredge to mark the start of the dredge track and to anchor a measuring tape. The dredge was then towed, and a diver swam alongside to observe the dredging operation and feed the tape out. At the end of the tow the winch and the water pump were turned off and the tow length was recorded. After 2 min, when the water visibility had cleared to about 0.7 m, the diver swam back over the dredge track to observe and count the subtidal clams exposed by the dredge. The dredge was then hauled and the water depth and the number of each subtidal clam species was recorded. The vessel was winched forward about 10 m and the dredge was reset for the next tow.

Catch efficiency calculation

The mean catch efficiency of the dredge was calculated as follows:

$$\text{Mean catch efficiency} = \frac{\varrho\ (\text{dredge}) \times 100}{\varrho\ (\text{airlift})}$$

where ϱ (dredge) = mean number of subtidal clams per square metre as determined by dredging; ϱ (airlift) = mean number of subtidal clams per square metre (quadrat) as determined by airlift sampling. For airlift samples confidence intervals of 95% were calculated and the difference between paired transects (inshore and offshore) was tested by two sample t-tests ($P < 0.05$).

Size selectivity

The length frequency distributions of subtidal clams sampled by dredge and of those sampled by airlift were compared to determine whether dredging of subtidal clams is size selective. Measurements were taken from all airlift samples and from random subsamples of 200 subtidal clams from each dredge catch of tows 1, 2, 3, 5, and 6. The length frequency data were compared for each species by the Kolmogorov-Smirnov test.

Results and discussion

The mean density of subtidal clams as determined by airlift sampling was 58.3 ± 5.2 clams per square metre in the inshore transect and 57.9 ± 7.8 clams per square metre in the offshore transect (Table 1). Density measurements did not differ significantly between the transects ($P < 0.05$). When the transects were combined, the mean density was 58.1 clams per square metre, and 95% confidence intervals gave between 48.6 and 67.6 clams per square metre. The mean density of subtidal clams as determined by dredging was 37.8 clams per square metre (Table 2). Therefore, the mean catch efficiency of the dredge was 65.1% (37.8/58.1 × 100).

Divers found few subtidal clams on the surface of the dredge tracks and none displaced to the sides. The number of subtidal clams left behind on the dredge tracks compared with the number caught by the dredge suggested that the dredge efficiency was about 99%. It was not possible to quantitatively sample the dredge tracks for buried subtidal clams or to use the airlift sampler to examine the dredge tracks, because the tracks became indiscernible too quickly. Therefore, divers examined the dredge tracks immediately after the dredge had passed. Areas of about 0.25 m² were excavated by hand, and enough subtidal clams were found to suggest that most clams not retained by the dredge were reburied in the dredge track.

Table 1: Subtidal clam density per square metre as determined by airlift sampling

	Quadrat sampled										
Transect	1	2	3	4	5	6	7	8	9	10	Mean
Inshore*	48	79	48	41	33	86	57	68	61	62	58.3±5.2
Offshore†	69	39	31	92	71	36	92	79	30	47	57.9±7.8

* 2.0–2.6 m below chart datum.
† 2.8–3.0 m below chart datum.

Table 2: Mean subtidal clam density per square metre estimated from each dredge tow

Tow No.	Tow length (m)	Tow speed (m.min⁻¹)	Density	No. of subtidal clams left on dredge track
1	33.5	*	24	†
2	55.0	*	41	†
3	45.0	*	41	†
4	28.5	7.0	42	5
5	32.0	8.0	37	10
6	27.5	3.5	42	12

* Tow speed not measured.
† Not counted.

During dredging the water jets of the digging manifold appeared to turn the subtidal clams end-on (an orientation of least resistance to the water flow), which allowed some of the smaller specimens of the narrow-shelled species *P. donacina* and *D. anus* to pass through the filtration grill. The largest *P. donacina* and *P. subtriangulata* that would pass through the grill were 48–53 mm long. (Most of the specimens of these species sampled by airlift were larger.) The Rabbit dredge could probably be made more efficient for New Zealand subtidal clam species by reducing the dimensions of the gaps in the bit and filtration grill.

The length frequencies of the subtidal clams sampled by airlift and of those subsampled from dredge catches are shown in Figure 10. The Kolmogorov-Smirnov test showed that for the length frequency distributions of *P. donacina, P. subtriangulata*, and *D. anus* there was no significant difference between the dredged and the airlifted samples (Table 3). However, for *S. aequilateralis* there was a significant difference, which was caused by the airlift sampler retaining many *S. aequilateralis* spat.

Although it appeared that mostly small *P. donacina, P. subtriangulata,* and *D. anus* were passing through the filtration grill, their length frequency distributions suggested that the loss was not size dependent and was probably the result of the clams passing under the bit.

Catch rates of some species have been improved by increasing the distance between the digging jet manifold and the bit of the dredge used (Smolowitz and Nulk 1982). A similar modification may improve the efficiency of the Rabbit dredge.

Table 3: Results of the Kolmogorov-Smirnov test

Species	N_1*	N_2†	Length range (mm)	$D_{0.1}$	D‡
S. aequilateralis	73	42	15–39.9	0.3151	0.7368
P. donacina	920	878	50–54.9	0.0768	0.0395
P. subtriangulata	36	78	40–44.9	0.3279	0.2479
D. anus	95	107	35–39.9	0.2294	0.0697

* Number of airlift-caught subtidal clams measured.

† Number of dredge-caught subtidal clams measured.

‡ D greater than the critical value ($D_{0.1}$) shows a significant difference.

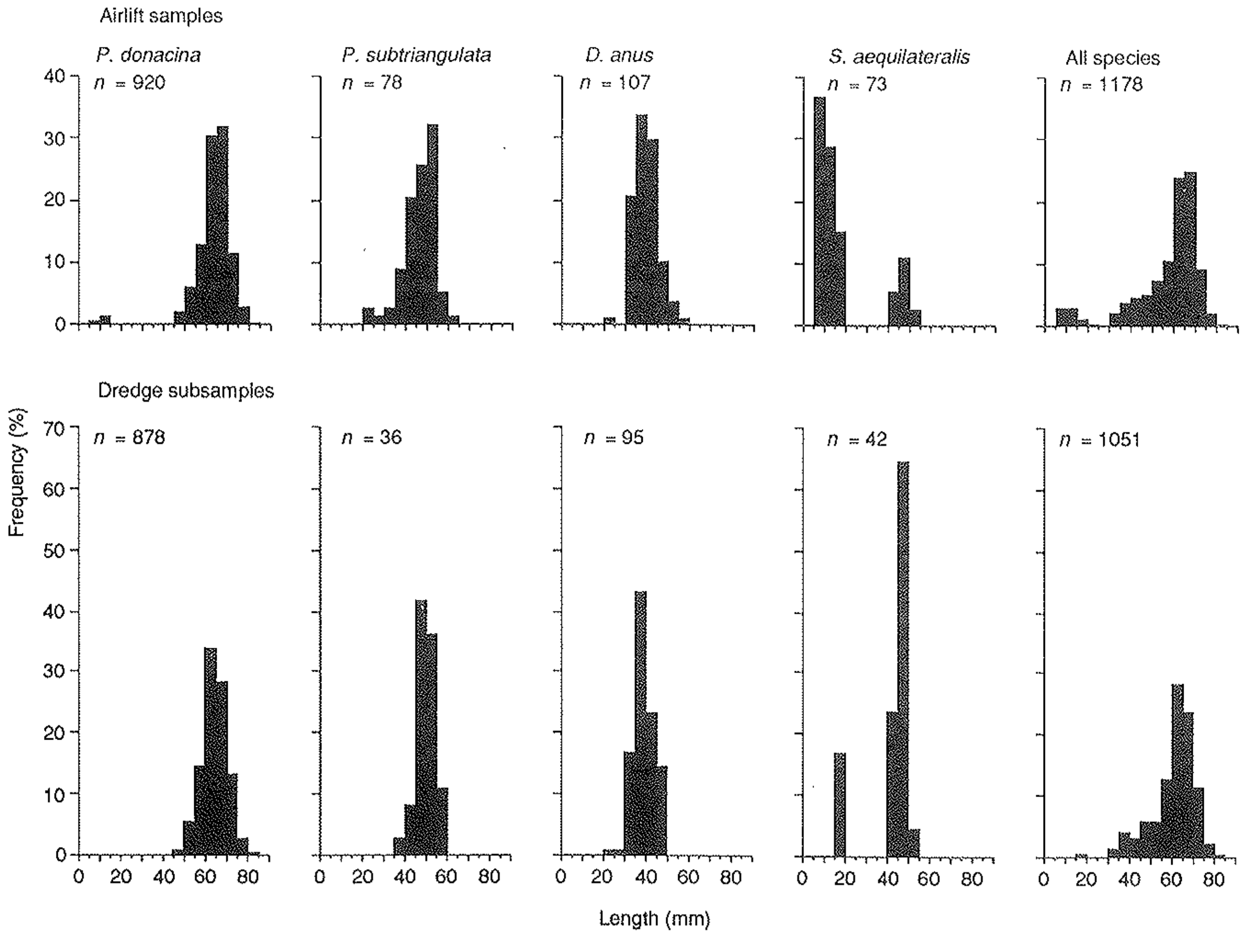


Figure 10: Length frequency distributions, by species, of subtidal clams subsampled from dredge tows 1, 2, 3, 5, and 6 and of subtidal clams sampled by airlift.

Effects of hydraulic dredging on the surf zone

The surf zone of a sandy beach is a dynamic environment marked by high sand mobility. High turbulence leaves little fine sediment on the seabed and oxygenates the substrate to substantial depths (Chapman 1983, Eagle 1983, Pugh 1983, Swart 1983). The fauna of the surf zone adapts to this frequent movement of sediment (McLachlan 1983).

A preliminary assessment of the effects of hydraulic dredging (by the Rabbit dredge) on the subtidal zone was made by evaluating the damage to shells caused by the dredge, the ability of dislodged subtidal clams to rebury, and the immediate effects of hydraulic dredging on the substrate.

Effects on subtidal clams

One hundred subtidal clams of each genus (*Paphies, Mactra, Spisula, and Dosinia*) were randomly sampled from dredge catches and examined for damage. No subtidal clams caught by the dredge had damaged shells, though some (38%) had severed, or partly severed, feet. Those with damaged feet comprised 21% *Paphies*, 12% *Mactra*, and 5% *Spisula* (no *Dosinia* were damaged). Other studies have also found that hydraulic dredging damages a small amount of the catch (Manning 1965, Meyer *et al.* 1981, Smolowitz and Nulk 1982).

Most of the subtidal clams missed by the dredge, and those which were flushed through the dredge, were reburied in the dredge track. To investigate the reburial ability of dislodged subtidal clams, divers hand-dug subtidal clams of each species, laid them on the seabed, and recorded the speed of their reburial. The clams did not attempt to rebury sooner than 10 min after being exposed. Within 20 min most of the *Paphies donacina* had actively reburied. *Spisula aequilateralis*, *Dosinia anus*, *Mactra discors*, and *M. murchisoni* were reburied within the same time, though passively by wave action scouring the sand from under them. Reburial reflexes do not appear to be as well developed in subtidal species as in intertidal species such as *Paphies subtriangulata* and *P. ventricosa* (Redfearn 1974). The ability to rebury may relate to the distribution of each species within the surf zone. *P. donacina*, which appeared to have the best reburial ability, occupy the most shallow and turbulent parts of the surf zone, and the *Mactra* species, which appeared to have the poorest reburial ability, occupy less turbulent deepwater areas. Meyer *et al.* (1981) found that 80% of the *Spisula solidissima* dislodged by hydraulic dredges in depths of 20–30 m reburied within 2 h.

Predation of exposed subtidal clams was not seen in this study. Many paddle crabs (*Ovalipes catharus*) were found along the dredge track, but though they inspected some of the larger subtidal clams exposed by the dredge, they fed mainly on the minute food particles suspended by dredging (probably small crustaceans). However, predation of subtidal clams has been seen in other studies. Meyer *et al.* (1981) found that all of the damaged clams on the dredge track and 3% of the undamaged clams were eaten by predators. Wear and Haddon (1987) have found that *O. catharus* eats only small subtidal clams between 3 and 4 mm long.

Effects on the substrate

Divers observed the Rabbit dredge in operation and examined the dredge tracks immediately after towing and between 1 and 24 h later to determine the rate of infill.

The water jets of the Rabbit dredge cut into the substrate and left ribbons of sediment which collapsed rapidly into the slurry. Most of the slurry picked up by the dredge passed directly through the bit and was deposited on to the dredge track, though some passed through the lower filtration grill. The lighter sediment was blown through the rear of the lower filtration grill by the washback jets; the finest grades of sediment were carried through in suspension and became dispersed in the water column. As the sediments on the seabed were already deeply oxygenated, no anaerobic material was disturbed by the dredge. The redeposition of sediment on to the dredge track graded the sediments according to size (large particles (fine gravel) at the bottom and fine sediments at the top). Although the sediment that passed through the dredge was returned immediately to the dredge track, a trench remained after the dredge had passed. The trench had clean cut sides and was 130 cm wide and 12–15 cm deep. The dredge tracks began to collapse and fill in immediately, and after 20 min they were difficult to define. Within 24 h the tracks were indistinguishable.

Conclusions

Hydraulic dredging in the surf zone does not appear to have any immediate deleterious effects; the disturbance caused by dredging is probably no greater than that caused by the passage of several large waves. Subtidal clams dominated the macrofauna of the surf zone, and their removal was the only obvious effect of dredging.

Acknowledgments

We thank Paul Breen and Peter Redfearn for their critical reviews of the manuscript and Ian Doonan and Paul Breen for their assistance with statistical examination of the dredge efficiency data. We also thank Jim Williscroft of Ocean Products, Whitianga for the loan of the Rabbit dredge; Ray Maulder and the workshop staff at MAF Fisheries Greta Point; Bill McQueen and Dick Nicholl on the Victoria University of Wellington research vessel *Tirohia* for their assistance during the development trials of the Olsen dredge; and Wayne Phelphs for his assistance during the Rabbit dredge efficiency trials.

References

Adkins, B. E., Harbo, R. M., and Bourne, N. 1983: An evaluation and management considerations of the use of a hydraulic escalator clam harvester on intertidal clam populations in British Columbia. *Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1716.* 31 p.

Bourne, N. 1967: Digging efficiency trials with a hydraulic clam rake. *Fisheries Research Board of Canada Technical Report No. 15.* 31 p.

Chapman, D. M. 1983: Sediment reworking on sandy beaches. *In* McLachlan, A. and Erasmus, T. (Eds.), "Sandy beaches as ecosystems", pp. 45-61. Dr W. Junk, The Hague.

Cranfield, H. J. and Michael, K. P. 1987: Surf clam resource, Cloudy Bay, Marlborough. Fisheries Research Centre Internal Report No. 75. 11 p. (Draft report held in MAF Fisheries Greta Point library, Wellington.)

Eagle, G. A. 1983: The chemistry of sandy beach ecosystems — a review. *In* McLachlan, A. and Erasmus, T. (Eds.), "Sandy beaches as ecosystems", pp. 203-224. Dr W. Junk, The Hague.

Eggleston, D. and Hickman, R. W. 1972: Mass stranding of molluscs at Te Waewae Bay, Southland, New Zealand. *N.Z. Journal of Marine and Freshwater Research 6*: 379-382.

Gibb, J. G. 1978: Rates of coastal erosion and accretion in New Zealand. *N.Z. Journal of Marine and Freshwater Research 12*: 429-456.

McLachlan, A. 1983: Sandy beach ecology — a review. *In* McLachlan, A. and Erasmus, T. (Eds.), "Sandy beaches as ecosystems", pp. 321-380. Dr W. Junk, The Hague.

Manning, J. H. 1965: The Maryland soft shell clam industry and its effects on tidewater resources. *Chesapeake Biological Laboratory Resource Study Report No. 11.* 25 p.

Meyer, T. L., Cooper, R. A., and Pecci, K. J. 1981: The performance and environmental effects of a hydraulic clam dredge. *Marine Fisheries Review 43(9)*: 14-22.

Michael, K. P. and Olsen, G. P. 1988: Surf clam resource, Rabbit Island, Nelson. Fisheries Research Centre Internal Report No. 84. 17 p. (Draft report held in MAF Fisheries Greta Point library, Wellington.)

Nashimoto, K. and Motoya, S. 1985: The selectivity of great northern tellin hydraulic jet dredge. *Bulletin of the Japanese Society of Scientific Fisheries No. 51*: 1781-1788.

Pickett, G. 1973: The impact of mechanical harvesting on the Thames estuary cockle fishery. *Ministry of Agriculture, Fisheries and Food Laboratory Leaflet (New Series) No. 29.* 20 p.

Pugh, K. B. 1983: Nutrient cycling in sandy beaches. *In* McLachlan, A. and Erasmus, T. (Eds.), "Sandy beaches as ecosystems", pp. 225-233. Dr W. Junk, The Hague.

Redfearn, P. 1974: Biology and distribution of the toheroa, *Paphies (Mesodesma) ventricosa* (Gray). *Fisheries Research Bulletin No. 11.* 51 p.

Short, A. D. and Wright, L. D. 1983: Physical variability of sandy beaches. *In* McLachlan, A. and Erasmus, T. (Eds.), "Sandy beaches as ecosystems", pp. 133-144. Dr W. Junk, The Hague.

Smolowitz, R. J. and Nulk, V. E. 1982: The design of an electrohydraulic dredge for clam surveys. *Marine Fisheries Review 44(4)*: 1-18.

Swart, D. H. 1983: Physical aspects of sandy beaches — a review. *In* McLachlan, A. and Erasmus, T. (Eds.), "Sandy beaches as ecosystems", pp. 5-44. Dr W. Junk, The Hague.

Tortell, P. (Ed.) 1981: "New Zealand atlas of coastal resources". Government Printer, Wellington. 28 p, 15 maps.

Wear, R. G. and Haddon, M. 1987: Natural diet of the crab *Ovalipes catharus* (Crustacea, Portunidae) around central and northern New Zealand. *Marine Ecology Progress Series 35*: 39-49.

Printed by Thames Publications Ltd. under the authority of
V. R. WARD, GOVERNMENT PRINTER, WELLINGTON, NEW ZEALAND—1990