SR613_Analysis and suggested modifications for Queen Scallop dredge net_C100

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West Coast Sea Products Ltd

Analysis and suggested modifications for Queen Scallop dredge net

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Introduction

West Coast Sea Products Ltd (WCSP) are a company primarily involved in commercial fishing for scallops off the West Coast of Scotland. This report aims to solve some of the issues WCSP currently have with the collection of the smaller Queen Scallop.

Currently, scallops are collected by dragging a series of metal nets along the sea bed (Fig.3). A series of metal spikes or "tickler" chains at the front of the net flip the scallops out of the sand and into the net (see Fig.1 and Fig. 2)). This method has several very large drawbacks as follows:

1. Environmental damage: The spikes and very heavy net cause a huge amount of damage to the sea bed. It leaves very large areas badly damaged which cause problems for all others sea life in the area.
2. Cobbles: The spikes not only dislodge scallops, but also sand and a large number of cobbles and other debris in its path. Some of the sand escapes, but not all and the cobbles and other debris stay in the net. This makes the net even heavier causing not only more damage to the sea bed but also making the dredge more difficult to tow thus increasing fuel costs dramatically.
3. Net damage: The sea bed is a very harsh and abrasive environment and with the heavy metal nets being constantly ground away, damage is frequent. The nets are very expensive to manufacture and also repair, with each link in the net being welded by hand and then heat treated.

The primary concern of WCSP is the environmental impact that the dredges have. In today's political and environmentally aware climate, fishing is coming under increasing scrutiny to make it both sustainable and to reduce the damage caused by commercial fishing. However, many other commercial issues are also important if WCSP are to remain a viable business.

The aforementioned issues will be dealt with in more detail in the course of this report.

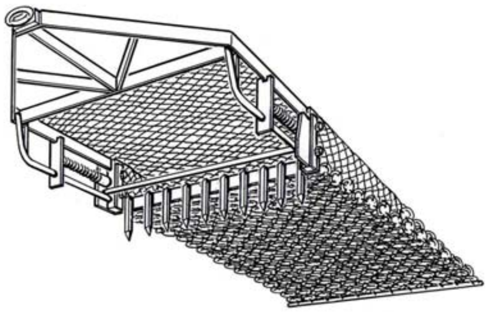

Figure 1: Spike dredge

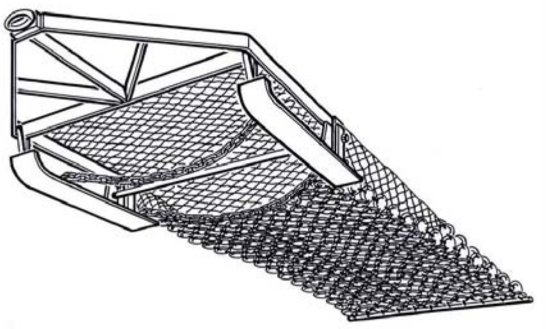

Figure2: Bar dredge

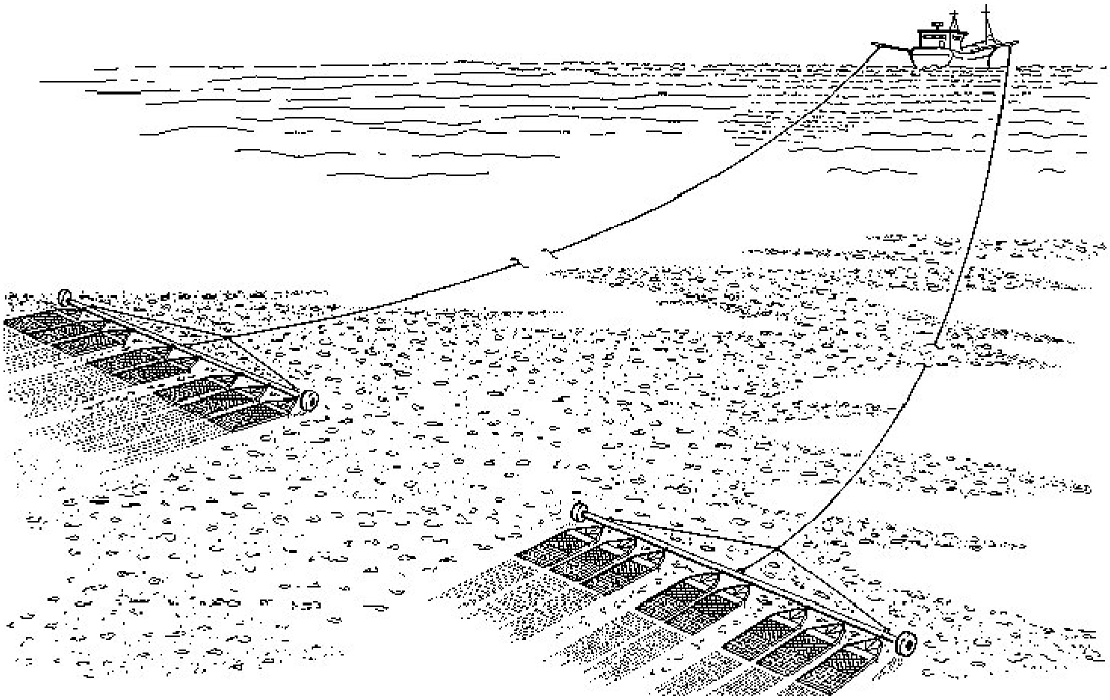

Figure 3: Typical dredge arrangement

Problem Areas

WCSP want to look at two particular problems. The first relates to the method of "flipping" the scallops into the net and the second relates to the design and material used to manufacture the net. Each issue will be discussed separately.

Front Mat

Traditionally, scallops are forced into the net via a series of spikes or a chain strung across the front of the dredge. WCSP have modified their Queen Scallop dredges by fixing a stiff laminated mat across the front. As the mat has a degree of flexibility, this is better than the chain or the spikes. Firstly it leaves cobbles or large stones in situ which reduces the disruption to the sea bed. By only disturbing the sand, silt and scallops, the sea bed recovers much quicker than it would by being raked. Secondly, as less unwanted debris is flipped into the net, net damage is reduced. The weight of the net is reduced which leads to a further reduction on sea bed damage. Also, as the dredge is lighter (without the stones etc.) the fuel consumption of the boat towing the dredge is therefore reduced.

The problem with the mat arises when it has been in service for a few days. Due to the highly abrasive nature of the sea bed, the top layers of the mat begin wearing away, not only exposing the less hard wearing layers underneath (and hence accelerating the wear), but also meaning it loses its rigidity and subsequently skips over the scallops as well as stones etc.

Net Design

The current net is made of thousands of rings linked together, with each ring welded individually. The whole net is then heat treated using a case hardening process. The rings are made from EN8 or 080M40 steel, the specifications of which are listed in Appendix A.

Both the material and method of manufacture make the net very heavy and also very expensive. There are also a number of other disadvantages. Firstly, as the material is case hardened, once the hardened layer has worn away, the material underneath remains relatively soft and as with the mat, the wear is then accelerated. The heat treatment process leads to problems when the net has to be repaired. Since the rest of the net is already heat treated, any repairs would have to be left in the untreated state or the whole net would have to go back in the oven, making even a minor repair very expensive in terms of both transportation and energy usage during the treatment process.

A second disadvantage is in the physical construction of the net. During the dredging process, all sorts of debris is collected, but the main substance is sand. Much of the sand escapes but a large quantity does not and the majority of the weight brought up after each dredge is made up of sand, typically several hundred kilogrammes for a couple of hundred kilogrammes of scallops. This is very wasteful in terms of fuel consumption and also ecologically, as the more sand that can be left where it is, the quicker the sea bed will recover.

This report will cover each issue separately. Firstly, to look at alternative materials and then consider design modifications for the mat. Secondly, it will investigate possible alternative materials and heat treatments for the net and finally, design modifications to the net to capitalise on any advantages these materials may offer.

Alternative Materials for Belt

The current design for the front mat uses sections of conveyor belt, cut to size and drilled with mounting holes. The belt is a laminate as shown in Figure 4, consisting of a woven fabric layer (2) bonded between two layers of vulcanised rubber type material (1).

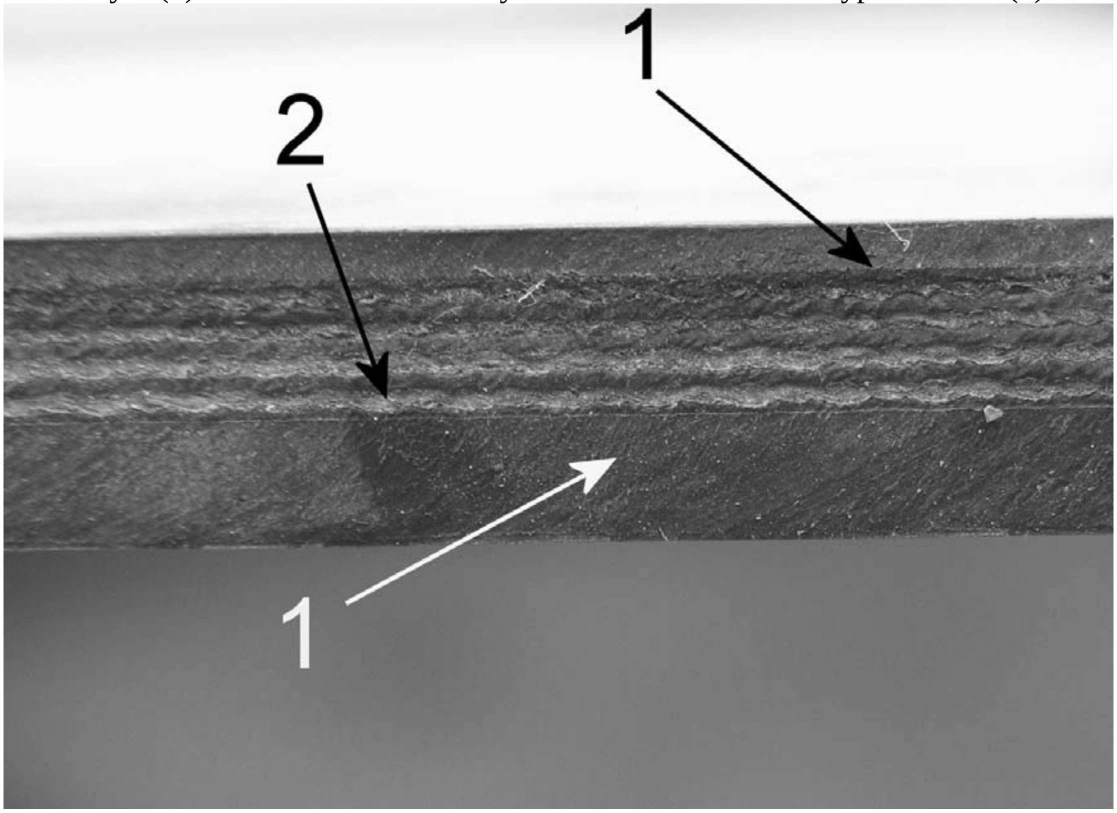

Figure 4: Mat cross section

The mat replaced the traditional bar or chain that is dragged just below the sea bed surface to disturb the scallops and push then into the water from where they are then collected by the following net. This method decimates the sea bed. As such, the mat is used to leave the sea bed relatively unscathed (as it only touches the surface of the sea bed). It also has the advantage of leaving large cobbles unmoved and hence not collected in the net.

The mat is quite rigid when new, however, this rigidity lessens as the layers are worn away. As the rigidity reduces, the effectiveness of the mat to flip the scallops into the net also reduces and they start to slip under the mat as it folds further and further back. The mat wears quickly as it was never intended to be used in this application, and as the structure is broken down and the softer fibers become exposed, the wear rate accelerates.

The patterns observed on existing mats indicate very localised wear, mainly on the outer corners. This local wear does however compromise the rigidity of the whole mat in a progressive manner, starting at the outer edges and working toward the centre.

Alternative types of mat from different manufacturers were investigated, but it is unlikely that there will be any significant prolonging of the belt life as they were never designed to encounter the type of abrasion experienced in this application. Trials could be conducted using sections of belts from other suppliers. Some suppliers details are given in Appendix B.

Another alternative that was considered was to move away from belting and use standard floor matting. This is not as rigid or wear resistant as conveyor belting but it has the advantage of being much cheaper. Trials could be conducted on the understanding that these alternatives will not last as long as the current mat used, but they can be replaced with very little cost. An alternative fixing method may be required if this route is undertaken to allow easier replacement of the mats on the dredges. One such supplier (F. Parr) of industrial matting is given in Appendix B.

Finally, one manufacturer was found that could potentially offer a significantly longer lasting belt. The belt was designed for harsh environments such as sand, gravel and stone conveying and is used in a variety of damaging environments, including cement plants, quarries, timber mills, steelworks and on road building machinery. The product of particular interest is known as ‘Ripstop’. It is a multiple ply polyester/polyamide belt with special abrasion resistant coatings. Although this will undoubtedly be more expensive than standard matting or belting, the potential increase in useable life could make it economical.

No prices were available for the belting but by contacting the companies given in Appendix B, samples will be probably be made available to test. A comparison of longevity against cost can then be made to ascertain the best product for WCSP.

Design Modifications for Belt

An alternative to finding a different material to replace the existing type of mat would be to modify the existing design to prologue the life of the mat. Several different ideas have been considered and will be discussed separately. However, ideas could be combined should trials on each one prove satisfactory. Also, each item could be applied to any alternative belts as discussed above.

It would seem logical that since the rigidity appears to fade as the surface layers wear away, reducing the wear rate on the surface layers would increase the useable life of the belt by maintaining its rigidity. Surface coatings were considered but discounted due in part to the cost, partly due to their environmental impact (many of the metal spray coatings contain heavy metals or environmentally damaging solvent carriers) but mainly due to their ineffectiveness. Surface coatings tend to be very thin layers. If not, they would have an adverse affect on the flexibility of the mat, making it too rigid to be effective, and since they are thin, they would wear quickly and the mat would be left unprotected once more.

An alternative to a full surface coating is based on the skid pads that were once used on F1 cars. The bottom of the car is relatively fragile and since it is very close to the road, any suspension movement would cause the floor to scrape on the road. As such they used small “door stop” size pads of titanium to protect the floor. A similar principle could be employed with the mats. Titanium, while very hard and tough, is very expensive. An alternative would be standard steel bolts. They are very easy to obtain, very cheap, easy to fit and hence easy to replace and are much harder than vulcanised rubber and since they would be placed at intervals, they would not adversely affect the operational rigidity of the mat. An array of nuts and bolts could be used as shown in Figure 5 (shown in green).

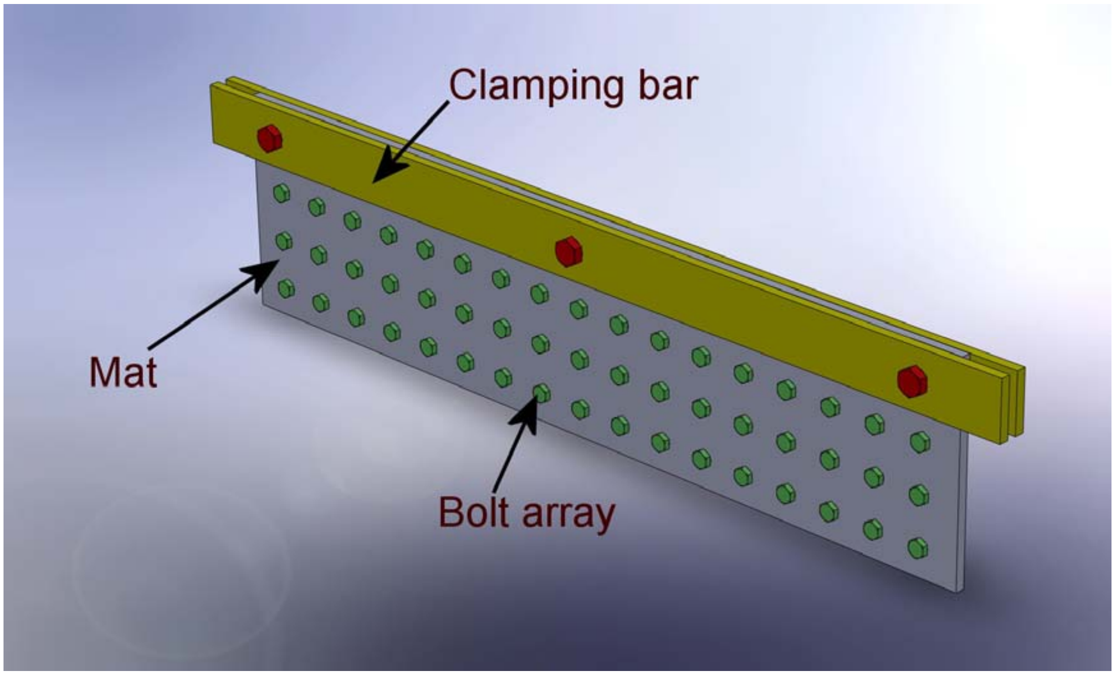

Figure 5: Wear pad arrangement

This will have no impact on the rigidity of the belt but it will protect the surface layers from wear which will prolong the mat life.

Another idea to hopefully reduce the cost of replacing the belt would be by making it in sections. Belts that have been rendered useless have large areas which have little surface wear. If, instead of one continuous belt, the mat was constructed on several smaller sections of belt, firstly, only the excessively worn areas would require replacing and secondly, “collateral wear” would be reduced. The term collateral wear refers to the wear of adjacent sections of belt when the mat goes over a cobble. In a continuous mat, when it flexes, to go over a cobble, the internal fibers in a large section of the mat are worked and eventually, this, coupled with the surface wear, will reduce the rigidity of the mat. Also, the sectioned surrounding the part of the mat going over the cobble, effectively push this section down, increasing the wear even more.

If each area was allowed to flex individually, then each section could ride over the cobbles without affecting adjacent sections. Also large cobbles could be deflected through the gaps between the sections, again reducing the amount of damage these rocks cause. An illustration is shown in Figure 6.

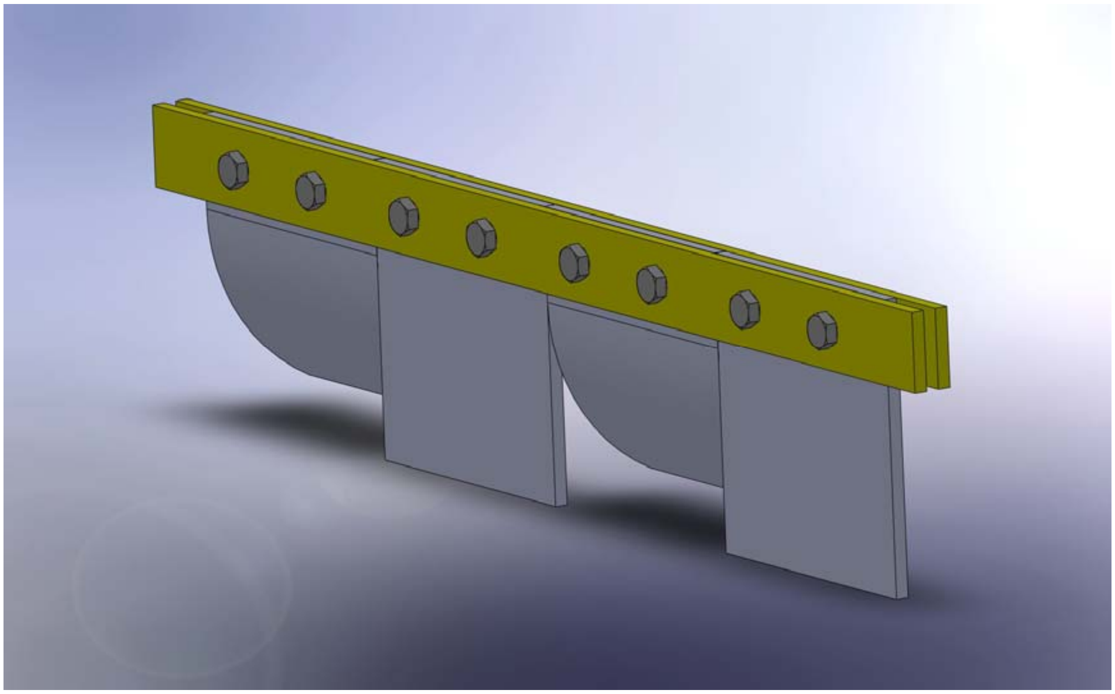

Figure 6: Cut mat arrangment

There is a potential problem with this option. As mentioned above, each area of the mat is pushed down by the surrounding areas and if this is removed by chopping the belt into separate sections, the mat may not be rigid enough to operate effectively. Whether this is a problem or not can only be ascertained by in-situ sea trials. Figure 6 shows the mat cut into four sections though different numbers of sections could be trialed.

The potential loss in rigidity leads onto a further possible solution. Currently, the mat is a large flat spring. An everyday example of a flat spring can be seen in the form of a measuring ruler. If one end is clamped and a force applied to the free end, as long as the force applied does not exceed the elastic limit of the spring, it will return to its original shape when the force is removed. Although using a flat spring would add complexity to the assembly, it would allow the current mat to be replaced with any flexible hard wearing material and as long as the correct spring was selected, it would mimic the current belt material. Since the structural rigidity would be supplied by the spring and not the mat, the assembly would remain useable until the mat had almost worn through. The cost of the spring would be offset (at least in part) by the use of cheaper matting and the spring cost would be a one off initial outlay. Only the mat would wear out and the spring would not require replacing. As the rigidity is provided by the spring, a sectional approach could be employed without the drawbacks mentioned above. A proposed arrangement is given in Figure 7 (Note: two of the mat sections and associated springs are shown deflected).

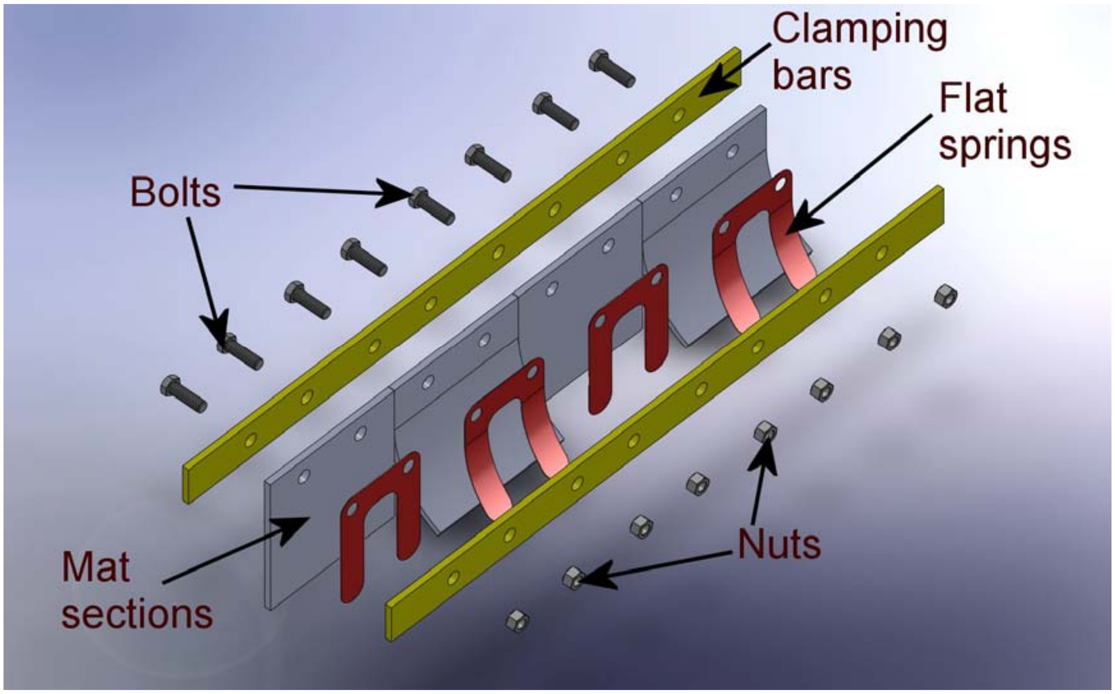

Figure 7: Flat spring stiffener arrangement

Obviously, an appropriate spring would need to be discussed with, and probably selected by, the spring supplier. Several manufacturers are given in Appendix B.

So far it has been assumed that the mat operates effectively due it its flexibility. An alternative is that it is the shape of the mat when under load that creates a “bow wave” which will dislodge the scallops but leave the heavier cobbles still embedded in the sea floor. If this is the case, then an alternative approach can be employed. The shape is dictated by the amount of movement of the bottom of the mat, so by physically limiting the movement of the lower edge of the mat, the correct shape could be achieved using a much less rigid (and hence much cheaper) type of mat. A simple way of doing this would be using a modification to the arrangement shown in Figure 5. By using longer bolts, the ends would restrict the maximum deflection of the mat. This is illustrated by the two views in Figure 8. The bolts used in the illustration are M16 x 110 at a vertical spacing of 50mm (when the mat is flattened) and would give a maximum lateral movement of 82mm. It is unclear if this is the same distance as the mat currently used, however a simple measurement on the dockside would ascertain this and adjustments could be made to the bolt length.

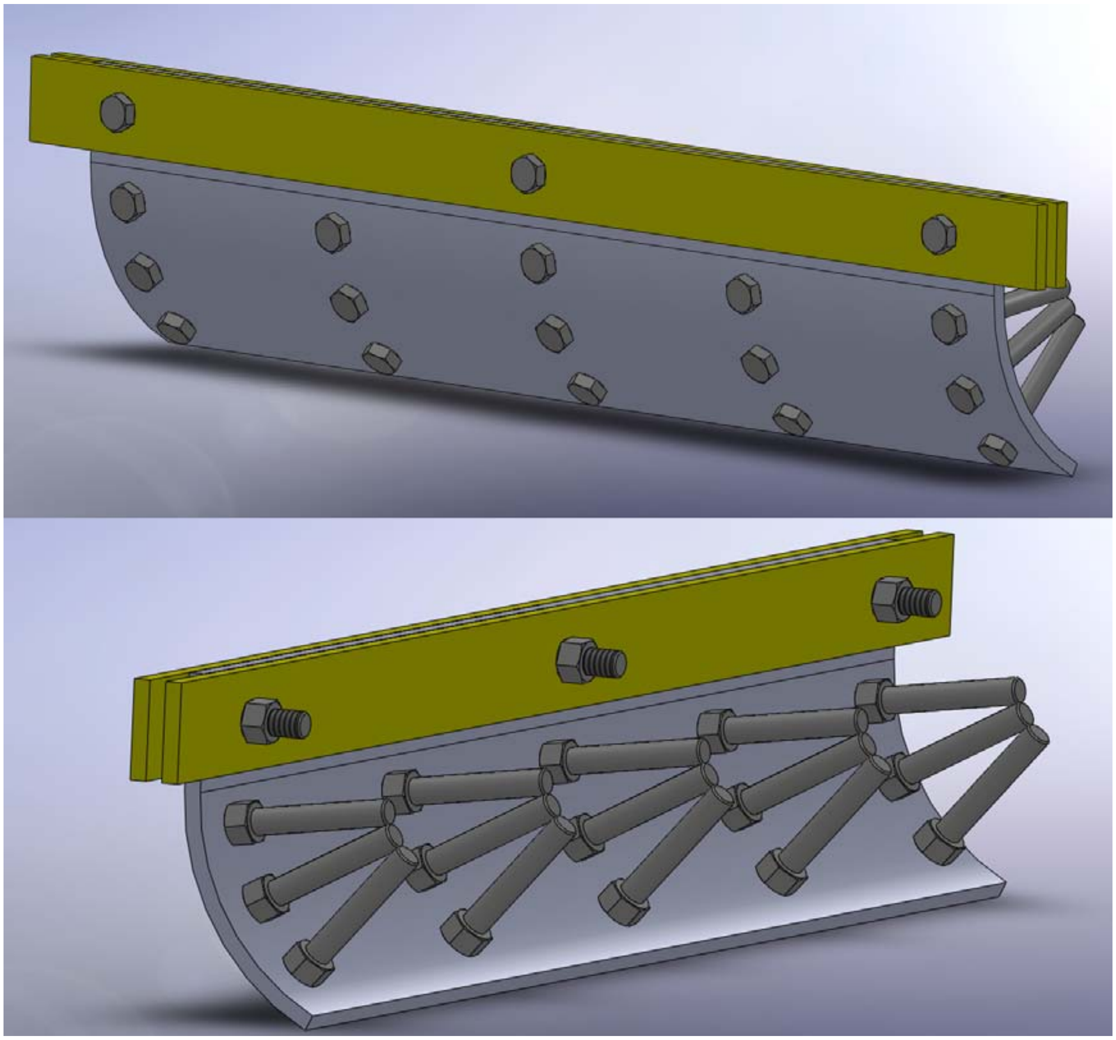

Figure 8: Motion limiting arrangement

This approach is perhaps the easiest to test in sea trials, as it could be employed on existing dredges with very little modification. All that is required is a few nuts and bolts. It could even be employed on worn out mats to see if it rejuvenates their effectiveness. It also has the benefits laid out in the first option discussed above.

A variety of other options were briefly investigated but were discounted quite quickly as being obviously either, ineffective, too expensive, too complex or not robust enough (given the environment it will be working in), shaped plates pivoting on a top bar for example. Other agencies are also working on new dredge designs. Cliff Goudey from Massachusetts Institute of Technology's (MIT) Sea Grant Centre for Fisheries Engineering Research has recently trailed - off the coast of the Isle of Man - a non contact water jet system to dislodge the scallops, with some success. However, this approach was not considered, partly for copyright and intellectual property issues and partly because of time and funding constraints.

The different possible approaches outlined above were suggested for their low cost and that they could be trialed easily without major modifications to existing equipment. Each could be used in conjunction with the another. For example, the wear pads could be used on a sectional mat or the movement limiters could be used with a flat spring etc. However it would be advisable to try each option individually to ascertain its effectiveness. Detailed drawings can be made available, however, several assumptions were made on the size of the assembly (i.e. the only thing that could be measured was a mat) so any drawings would require modification based on accurate measurement of the mounting and towing mechanism on the dredge.

Alternative Materials for Net

This section will deal only with alternatives materials for the net in its current configuration. Modifications to the net design will be dealt with in the next section and any required material modifications based on new designs will be dealt with then.

Currently, the net is manufactured in a chainmail style with large metal rings being individually welded around connecting rings. The construction can be seen in Figure 9 which shows one section at the front of the net.

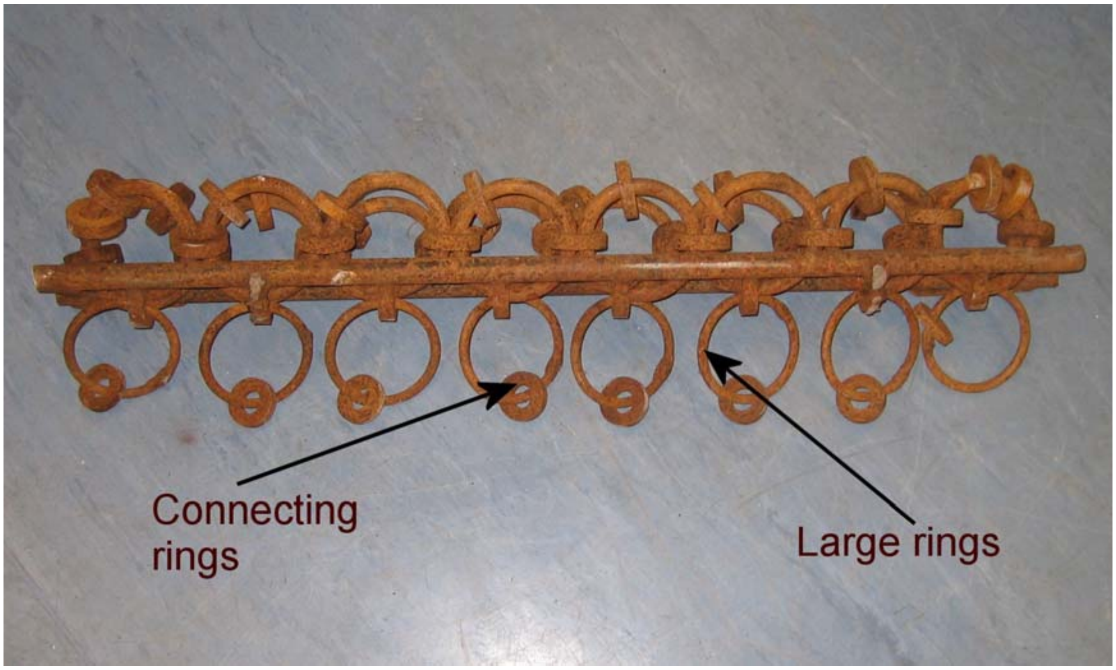

Figure 9: Section of current chain

The net is manufactured from 080M40 (BS 970: 1991) or EN8 (BS970: 1955) which is a medium tensile steel used largely in the automotive industry for axles, spindles etc. but is also used widely in general engineering applications. The material specifications are given in Appendix A. The chain when fabricated, is then case hardened as a complete unit. This immediately brings up two points, both relating to the steel used. Firstly, it is not recommended that steel with a carbon content of above 0.35% is welded unless special precautions are taken (Introduction to Steel Selection Part 1, J. H. E. Fox, 1979, Design Council and BSI). EN8 has a minimum carbon content of 0.36%. This is not a major issue as the carbon content is only just above the recommended value and if the correct preheating (to 100°C using a sulphur free torch) and filler rod (low H_2) are chosen it can be welded satisfactorily. The second issue is a little more puzzling. EN8 is usually considered a through-hardening steel, whilst case hardening is usually applied to lower carbon steels such as 080M15 (EN32C) for example. Case hardening medium carbon steel (such as EN8) could also alter the properties of the core material. It is possible that the case hardening process is nitriding, which is done at a lower temperature below the lower transition temperature which will leave the toughness of the EN8 core intact. However, nitriding usually is a very thin surface layer (typically around 30 microns or 0.03mm) which can be prone to chipping and peeling off. A transition layer of around 0.5mm depth occurs below the very hard layer. This layer goes from the very hard but also brittle outer layer, to the much tougher but not as hard core properties of EN8. This layer is also initially susceptible to impact damage which is exactly the working conditions of the dredge. Oxidation (rusting) will exacerbate this problem and in a very short time, the nitrided layer will have gone altogether.

A more suitable heat treatment would be to through-harden the material. Oil quenching from 830°C and tempering at 500°C will provide a fully hardened material which although may not be as hard as case hardening, will last much longer as the surface will not chip and the material will have improved properties as it wears. It is advised that discussions with a heat treatment service provider be conducted to ascertain the exact details of the best heat treatment (see Appendix B for a list of heat treatment companies).

An alternative to EN8 would be EN9 (070M55) which has similar properties but because of a higher carbon content, is capable of a greater hardness when through-hardened with only a slight decrease in toughness. Material data is given in Appendix A. There is a slight disadvantage in that the pre-weld heating needs to be to a higher temperature (between 100 and 300°C).

There are many other steels that would provide qualities that are desirable in this application, however they are invariably more expensive. Both EN8 and EN9 are readily available and relatively inexpensive steels. As such, given the manufacturing method of the net (other materials suitable for modified designs will be discussed below), EN8 or EN9 through-hardened are recommended.

Polymers and ceramics were also considered. Ceramics can exhibit high hardness and wear resistance, however they tend to be quite brittle and are used where impact is low and in much more precise environments than this application (bearing races etc.). One ceramic is potentially suitable however, it is an aluminium/zirconia/silica (AZS) material specifically designed for heavy impact uses by Saint Gobain Ceramics. Parts are manufactured via a casting process so it is unsuitable for the net in its current form, and it is also likely to be expensive. It may be possible to discuss this materials use directly with Saint Gobain when a suitable redesigned net has been decided upon.

The range of polymers available is as vast as the range of steels. As such, several of the most common engineering polymers were investigated. If polymer net trials are to be conducted, then a more detailed discussion of suitable polymers should be discussed with the suppliers.

The mechanical properties of the polymers discussed here are given in Appendix A. What becomes immediately apparent is just how much weaker and softer the polymers are than the steels discussed. It is obvious that if any of the polymers stated were used, the net would wear very quickly indeed. The belly of the net would be much lighter if made from any of the polymers. The relative density of carbon steel is approximately 7.8. Therefore, the belly would be 6.5 times lighter in polycarbonate and if made from high density polyethylene (HDPE), the belly would actually float. However, if the net weighs 700kg in steel, the equivalent in ABS would weigh a mere 93kg, but at the end of each dredge there is another 700kg of scallops, sand and cobbles (based on approximate figures stated by WCSP). The total net weight of a full dredge in ABS would be approximately 60% that of a steel dredge, the hardness and tensile strength being only 5% that of steel. The wear rate would therefore be significantly higher. The exact accelerated wear rate would depend on many factors other than those stated and would realistically only be determined by sea trials, but given that the mechanical properties are so much lower, sea trials are deemed totally unnecessary.

A logical conclusion can be drawn that if the net is used in its current configuration, polymers are wholly inadequate. Other problems are apparent, for example, finding stock in the correct form to make the net would be difficult and it is likely that tooling would need to be commissioned. The rings would require bonding which, given the working environment, would limit the types of suitable adhesives. Polymers will be discussed in the following pages as they may be more suitable when used in a redesigned net belly.

Given the above discussions, if the net design were to remain unchanged, then the current material or possibly EN9, through-hardened rather than case hardened would be the most suitable material.

Design Modifications for Net

A great deal of research is being conducted into scallop dredges. A joint program with Bangor University and MIT is looking into the use of water jets to dislodge the scallops rather than the traditional chain. MIT's Division of Marine Fisheries have published a paper where they researched the use of acoustics and electric fields to disturb the scallops causing them to start swimming, where they could then be collected with a trawl as they swim into the water column. Fisheries and Oceans Canada have conducted trials using different ring and washer configurations in a standard dredge net design. Copies of the papers published as a result of this research are included in Appendix C. Due to intellectual property issues, the work done in the research will not be considered for this report however it may be possible for WCSP and SEAFISH to arrange a joint research program with these Institutes to progress work already conducted.

Much of the damage caused to the net is caused by the highly abrasive nature of the sand and silt on the seabed as well as impact and abrasion from rocks and cobbles. As with the front mat, sacrificial skid pads could be used to protect the net. Hardened steel pads, welded or bolted on, may help. However, if used on the current net design, they are unlikely to have any appreciable benefit unless a large number are used to help lift a large proportion of the net off the sea bed. An array of supports could be used with skids attached but this would have the same drawbacks as the skids that are used on the A-frames, which are very expensive and wear out quickly.

The wear on the net belly is similar to that of a grinding wheel. If you grind a piece of metal on a bench grinder, the harder you press onto the grindstone, the quicker the metal is ground away. The same applies to sand (which is very similar to the silica used in grindstones) - the harder the net presses into the sea bed, the quicker it gets ground away. If the net belly could be made lighter, then the wear rate would decrease. Polymers could potentially be used to reduce the weight and, as discussed earlier, a 700kg net could be reduced to less than 100kg. However, polymer nets would wear much quicker, so this, combined with the extra cost involved in getting plastics parts manufactured (tooling etc.) means that a polymer net would not be a cost effective alternative.

To reduce weight, the basic construction of the net must be changed. WCSP have trialed one method where a section of the net was replaced with a grid. This is shown in Figure 10. The grid has been demonstrated to show several advantages. It is easy to manufacture, each section can be heat treated separately and it can be attached mechanically rather than welded as with the present link system. It also has the advantage of dispersing sand and silt that has collected in the net. Conventional ring type nets collect several hundred kilogrammes of sand and silt during each dredge. A lot of sand slips through the net but a surprising amount stays in which not only has to be towed, but also lifted out of the sea and separated from the scallops on deck. The grid that was trialed had the main bars running laterally which does not allow the sand to escape as well as if they were longitudinally. Also on the trialed arrangement, it was attached using a welded link. If this were replaced with pinned mechanical joints, then net repair is no longer a specialist job.

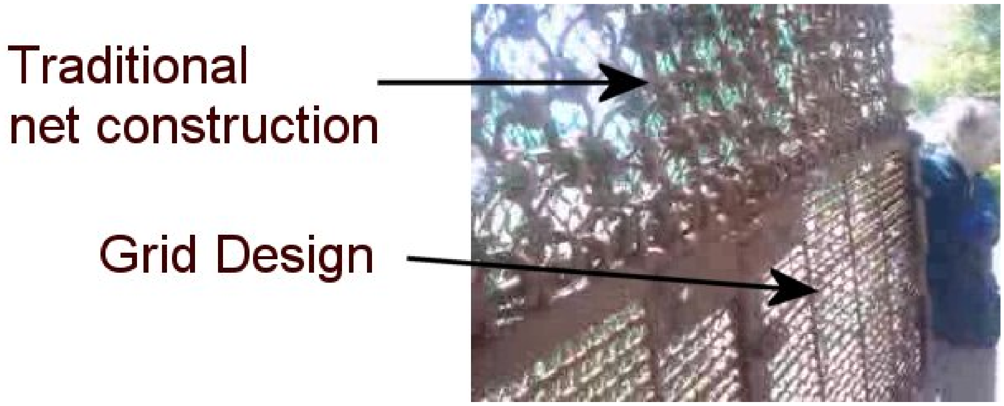

Figure 10: Grid modification in situ

An illustration of a modified grid design is shown in Figure 11. Skid pads could be attached by bolting them on rather than welding, again making maintenance a non-specialist job and as the system would be semi rigid, the number of pads could be reduced when compared to a standard net.

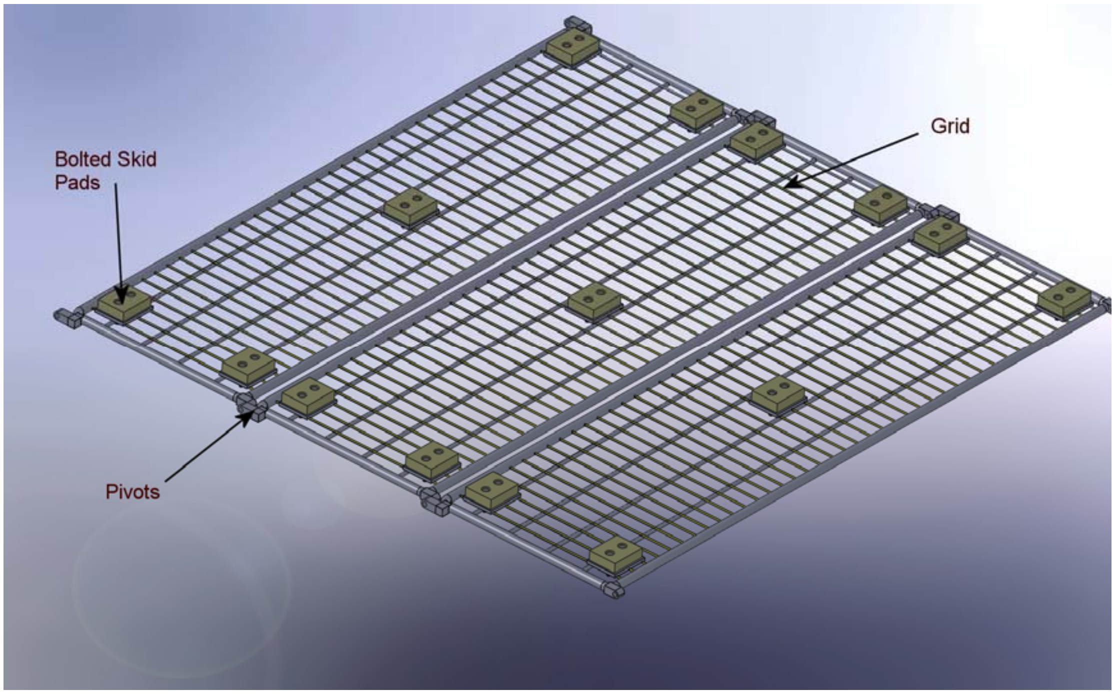

Figure 11: Wear pads bolted to proposed grid

The specific sizes of wire gauge, spacing etc. would need to be determined based on minimum scallop sizes. The larger the gaps between the rods, the more sand, silt and other by-catch will escape. The manufacture of a grid system would be substantially cheaper than the current chain-type design for several reasons. Firstly, the assembly would be fabricated using standard size bar and because it is standard, it is much cheaper and more readily available than manufacturing rings from the same material. Also, because the assembly is sectional, heat treatment of each part is much easier and therefore much cheaper.

The above system does still have the disadvantage of excessive and still relatively heavy contact with the sea bed. One possible way of reducing the load is to use aerofoil sections which would mean that the net was effectively gliding over the sea bed. There are a number of disadvantages to this option: the hydrofoil would be expensive to manufacture and prone to damage; the amount of lift required would be difficult to control; and it would be unlikely that enough lift could be generated to raise the net off the sea bed when full. Further investigation into this option is possible but will not be discussed further in this report.

A much simpler way of generating lift would be to simply attach floats to the net belly. If the net were not touching the seabed then standard nylon fishing net could potentially be used. A nylon rope net would be much lighter than even a polymer dredge net, weighing only a few kilogrammes. The only issue is that the buoyancy would have to balance the weight of the towing frame. The scallops are dislodged with the mat which has to be in contact with the sea bed. As such, the weight of the net and the catch (including sand, cobbles and by-catch) could not be more than the weight of the A-frame assembly. If it does weigh more, then the buoyancy required to lift the full net, would lift the A-frame and the dredge would not work at all. No figures are available for the weight of the A-frame assembly so WCSP will need to calculate the appropriate values to ascertain if this is a possible valid solution.

A modification that has already been trialed by WCSP and shown to work on the A-frame is the use of wheels rather than skids. If this idea were extended to the net belly, then apart from two tracks made by the wheels, the only damage to the sea bed would be from the scraper mat which is only surface damage and which will recover quickly (unlike the chain scraper design used by other dredges that scrape below the sea bed causing much more damage). An illustration of this design is shown in Figure 12. Each section is connected with pivoting rods. Limit pins underneath the connecting rods at the trailing edge of the wheel housing stop the wheel housings simply spinning round and dragging along the sea floor but allow a degree of movement to compensate for the uneven sea bed. Slots in the top of the wheel housing allow the net to fold up in sections so the net emptying mechanism on the boat can still work.

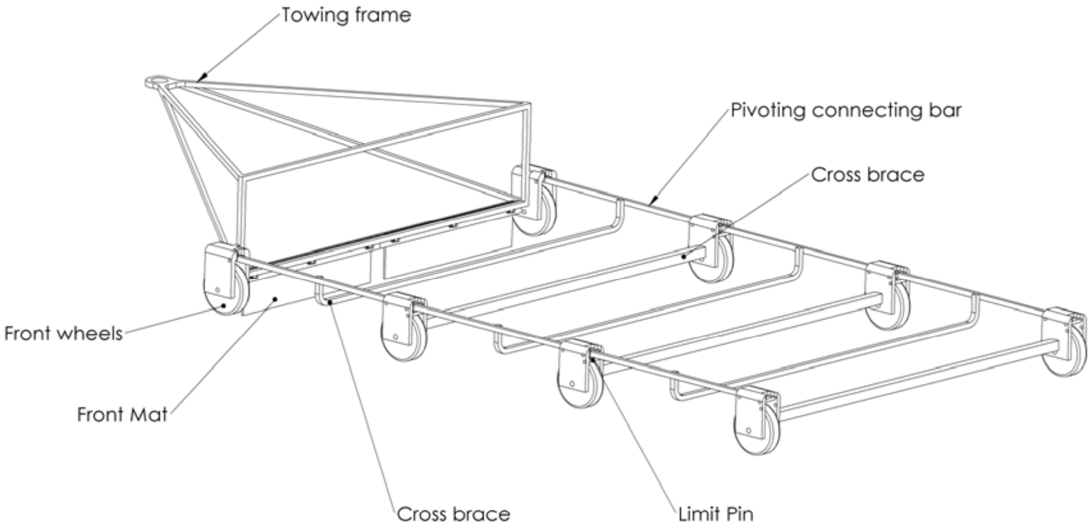

Figure 12: Trolley type dredge proposal

Cross braces would not only make the assembly more rigid but also give supports for the net. The net is not shown on the figure 12 for clarity but since it would not contact the sea bed, it could, as stated earlier, be a simple nylon rope net. The pivot mechanism is illustrated in Figure 13 where it shows the ability to move over uneven ground. The last section is shown raised as it would be when being emptied onboard.

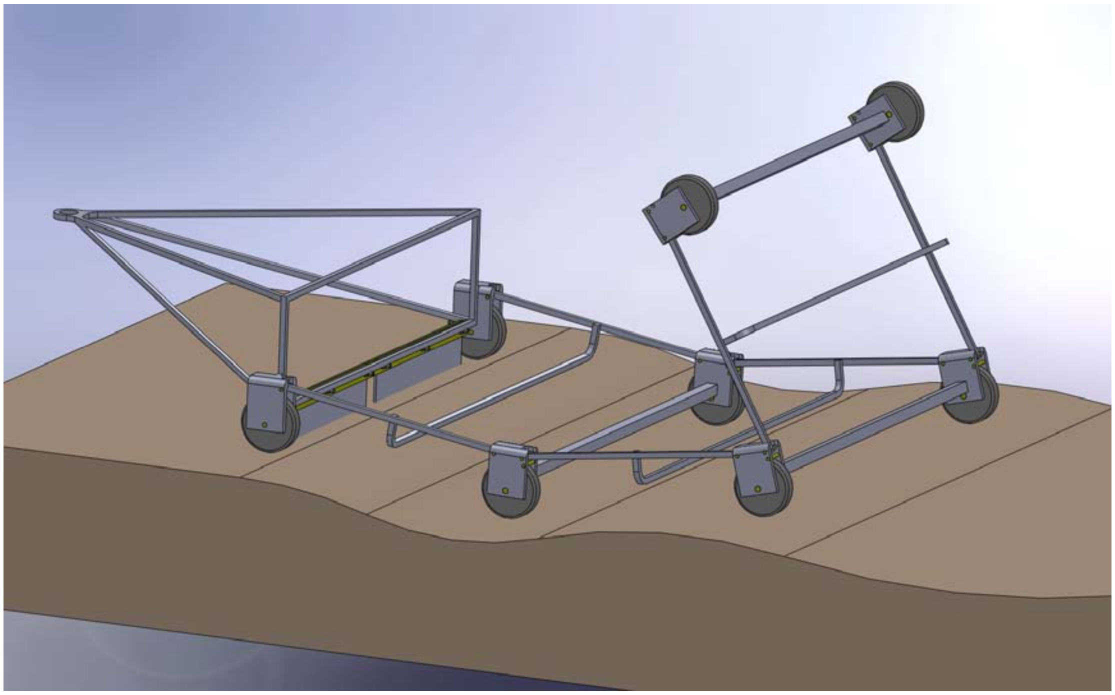

Figure 13: Trolley type dredge un uneven ground

Three sections have been shown for illustration purposes only, but length and number of the connecting bars can be altered to make the assembly more or less flexible as required.

Any of the above ideas could be used in conjunction with others presented. For example, if the grid system showed promise in sea trials, then attaching wheels to each section instead of skids may reduce damage even further to both net and sea bed.

Conclusions

The investigations conducted for this report were split into four sections. With regard to the first area - alternative materials for the mat - it would appear that the currently used mat is likely to be as good as anything similar on the market with the exception of one specialist mat. With this in mind, the second section concentrated on increasing the useable life of the mat in its current form. Several of the options put forward are very easy to trial, with no modifications to the dredge itself being necessary.

The third section, looked at alternative materials and concluded that polymers, while much lighter, are simply not tough enough for this application. The conmination of material properties combined with high tooling costs to make a net belly make them unsuitable in this instance. The only exception is the possible use of AZS, but again, tooling costs will be excessive and the material itself is likely to be prohibitively expensive. Therefore the current material is adequate and probably the most suitable material for the net belly if used in its current form. A different hardening method is advised. The case hardening used at present is an entirely unsuitable process for both the material and the application.

Finally, the net belly design proposals will be more expensive to trial simply because large sections will need to be fabricated. The best solution, both financially and ecologically, would be a hybrid of the grid system with the wheels fitted to lift the whole thing off the ground, although if the wheeled system worked adequately, the grid would be unnecessary and a simple nylon net could be used.

Detail drawings were not produced as part of this investigation. All designs shown are merely for illustrative purposes. When WCSP have decided which ideas they wish to take into sea trials, the designs proposed are simple enough to advance to a manufacturing stage with little extra work.

Appendix A – Material Specifications

080M40 (EN8) BS970: 1991 (1955)

Composition	Carbon	Manganese	Phosphorus	Sulphur
%	0.36-0.44	0.6-1	0.05 max	0.05 max

Mechanical properties	UTS N/mm^2	Yield N/mm^2	Elongation %	Brinell Hardness
Normalised	550	280	16	152-207
Hardened and tempered	625-775	435	12	179-229

070M55 (EN9) BS970: 1991 (1955)

Composition	Carbon	Manganese	Phosphorus	Sulphur
%	0.5-0.6	0.5-0.9	0.05 max	0.05 max

Mechanical properties	UTS N/mm^2	Yield N/mm^2	Elongation %	Brinell Hardness
Normalised	700min	355	12	201-255
Hardened and tempered	850-1000	595	9	248-302

Polymers

Name	UTS N/mm^2	Elongation %	Shore Hardness	Brinell*** Hardness	Relative Density
HDPE	32	55	D69	50	0.94
ABS	38	20	-	-	1.04
Polycarbonate	72	100	D80	60	1.35
Nylon*	79	50	D60	46	1.15
Nylatron**	86	25	85	63	1.16
PEEK	110	20	D85	63	1.31

*Nylon 6-6
**MoS2 filled type 6/6 polyamide
*** Approximation

Appendix B –Supplier Contact Details

Conveyor belt suppliers

Company	Apex Belting Company Ltd.
Address	Boldero Road
	Moreton Hall Industrial Estate
	Bury St. Edmunds
	Suffolk
	IP32 7BS
Telephone	01284 752 486
Email	sales@apexbelting.co.uk
Website	http://www.apexbelting.co.uk

Company	Marathon Belting Ltd
Address	Healey Mill
	Whitworth Road
	Rochdale OL12 0TF
Telephone	1706 657052
Email	sales@marathonbelting.co.uk
Website	www.marathonbelting.co.uk

Company	Sunisha Polymers Ltd
Address	4007, Phool Bhawan Ajmeri Gate
	Delhi
	India
Telephone	+91-011-23211475/23217971
Email	tuffline@hotmail.com
Website	http://www.sunishapolymers.com

Company	Neelkanth Rubber Mills
Address	Kapurthala Road, Varyana
	JALANDHAR
	Punjab
	India
	144002
Contact	Mr. MANAV ARORA
Telephone	0091-181-2651715
Email	manaav@jla.vsnl.net.in
Website	http://www.nkconveyorbelts.com

Industrial Matting Suppliers

Company	F. Parr Ltd
Address	Merse Road

	North Moons Moat
	Redditch
	Worcestershire
	B98 9PL
Telephone	0845 600 7424
Email	customerservice@parrs.co.uk
Website	http://www.parrs.co.uk/category-Industrial-Matting-MATT7.htm

Spring Suppliers

Company	Irvine Spring Co.Ltd
Address	6, Kyle Rd
	Irvine Industrial Estate
	Irvine
	Ayrshire
	KA12 8JS
Telephone	01294 279396
Email	info@irvinesprings.com
Website	http://www.irvinesprings.com

Company	Claridge Springs & Wireforms
Address	11 Boulton Road
	Reading
	Berkshire
	RG2 0NH
Telephone	0118 986 0114
Email	sales@springsandwireforms.co.uk
Website	http://www.springsandwireforms.co.uk

Company	Lion Springs Ltd
Address	Summer Street
	Rochdale
	OL16 1SY
Telephone	01706861352
Email	sales@lionsprings.co.uk
Website	http://www.lionsprings.co.uk

Heat Treatment Companies

Company	Agra Engineering Services
Address	15 Ure Street
	Dundee
	DD1 5JD
Telephone	01382 201600
Email	info@agra-eng.co.uk
Website	http://www.agra-eng.co.uk

Company	TRS Heat Treatment

Address	1 Harebury Avenue Ainsdale Southport PR8 4TA
Telephone	01704 572172
Email	admin@trsheattreatment.co.uk
Website	http://trsheattreatment.co.uk/

Company	Heat Treatments (Northampton) Ltd
Address	Sheaf Close Lodge Farm Industrial Estate Northampton NN5 7UL
Telephone	01604 586920
Website	http://www.heat-treatments.co.uk/

Plastic Suppliers

Company	ICL Tech Ltd
Address	Units A&B 26 Lochburn Road Glasgow G20 9AQ
Telephone	0141 332 1331
Email	sales@icltech.co.uk
Website	http://www.icltech.co.uk

Company	Rossendale Plastics
Address	Station Road Haslingden Lancashire BB4 5HX
Telephone	01706 214652
Email	info@rossendaleplastics.co.uk
Website	http://www.rossendaleplastics.co.uk/

Company	Saint-Gobain Ceramics & Plastics UK P.L.C
Address	Mill Lane Rainford WA11 8LP
Telephone	01744 882 941
Website	http://wearresistantmaterials.com/

Appendix C –Academic Papers

1. Scallop Dredge Selectivity Study: Comparison of different ring washer configurations and dredge configurations; G. Jay Parsons and L. A. Davidson; Aquaculture Science Branch, Fisheries and Oceans Canada
2. Hydrodredge: reducing the negative impacts of scallop dredging; S. Shephard, C. Goudey and M Kaiser; School of Ocean Sciences, Bangor University and Centre for Fisheries Engineering research MIT.
3. Developming a low impact scallop dredge; M. Pol and H. A. Carr, Massachusetts Division of Marine Fisheries

SCALLOP DREDGE SELECTIVITY STUDY: COMPARISON OF DIFFERENT RING WASHERS AND DREDGE CONFIGURATIONS

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ABSTRACT

Parsons, G.J. and L.-A. Davidson. 2004. Scallop Dredge Selectivity Study: Comparison of Different Ring Washers and Dredge Configurations. Can. Tech. Rep. Fish. Aquat. Sci. 2547: iv +20 p.

A study to assess the scallop catch and size selectivity of a dredge with buckets made using 76 mm (3 inch) rings fastened with different types of washers was conducted in the southern Gulf of St. Lawrence. Buckets with rings joined with only steel washers caught less small, undersized (≤76 mm) scallops compared to buckets with other configurations. The buckets with rings joined with steel washers and chaffing pads were the second most efficient at releasing the undersize scallops while buckets with steel and rubber washers were third. The buckets with rings joined with two rubber washers were the least efficient. This was because the effective ring size was larger for the steel washers. The buckets with rings fastened with steel washers had a slightly lower mean number of scallops per tow but a slightly higher mean shell height of scallops >76 mm compared to buckets with other configurations. The net result, for type of buckets, was no difference in catches, based on meat weight of scallops >76 mm in size.

RÉSUMÉ

Parsons, G.J. et L.-A. Davidson. 2004. Etude de sélectivité pour des fins de comparer les différents anneaux et configurations de la drague. Rapp. Tech. Can. Sci. Halieut. Aquat. 2547 iv+ 20 p.

Une étude pour des fins d'évaluation des prises de pétoncle et de sélectivité de taille en se servant de différents types de rondelles sur une drague à pétoncle avec des paniers fabriqués avec des anneaux de 76 mm (3 pouces) fut effectuée dans le sud du golfe du Saint-Laurent. Des paniers munis d'anneaux rejoints avec seulement deux rondelles d'acier ont capturé moins de pétoncles de petite taille (≤76 mm) à comparer aux paniers avec autres configurations. Les paniers munis d'anneaux rejoint avec des rondelles d'acier munis de tapis de caoutchouc qui prévient l'usure, sont les deuxième plus efficace à laisser passer les pétoncles de plus petite taille. Les paniers munis d'anneaux rejoints avec des rondelles d'aciers et de caoutchouc étaient les troisièmes. Les paniers munis d'anneaux rejoints avec deux rondelles de caoutchouc étaient les moins efficaces. L'espace effectif des anneaux est plus grand lorsque les anneaux sont reliés avec les rondelles d'acier. Les paniers munis d'anneaux rejoints avec les rondelles d'aciers retenaient un peu moins de pétoncles par trait mais il y avait plus de pétoncles >76 mm à comparer aux paniers avec autres configurations. Dans l'ensemble, pour chaque type de paniers, il n'y avait pas de différence dans la prise (poids de chaise) des pétoncles >76 mm.

1.0. INTRODUCTION

Several studies have examined the selectivity and efficiency of different scallop dredge types over at least the last thirty years (Bourne 1964, 1966, Rolfe 1969, Caddy 1971, 1972, Mason and Chapman 1979, Worms and Lanteigne 1986). More recently, a few studies have examined the effect of ring size and different gear configurations on catch rates (Howell 1983, Robert and Lundy 1988, DuPaul *et al.* 1989, Anon. 1996).

In the southern Gulf of St. Lawrence some fishers are using rubber washers instead of steel washers or along with steel washers to link the rings. They claim that this technique reduces the wear and tear of the rings. Some fishers have kept using only steel washers, but have added rubber pads under the buckets to prevent chaffing.

With a number of scallop populations experiencing low recruitment rates and declining stocks, the need for conservation measures to protect undersize, nonmature (juvenile) scallops is an important objective for the management of the scallop fishery. One approach to protecting undersized scallops is to develop gear that is more selective, retaining larger scallops and leaving the smaller ones on the bottom. With scallop dredges, this could possibly be achieved through the use of a large ring or through the use of washers that do not reduce the effective ring size.

With the interest of all participants in the southern Gulf of St. Lawrence scallop fishing industry (fishers, managers, biologists) in seeking new conservation measures and with the use of many different ring and washers combinations, an experimental study was undertaken to assess scallop catch and size selectivity by using different bucket configurations.

2.0. MATERIALS AND METHODS

The study was conducted on commercial scallop beds in the southern Gulf of St. Lawrence (Figure 1). In general, the scallop beds in the study area have gravel/sand bottoms. The study was conducted in four locations with four different fishing vessels. All trials were conducted between October 13, 1995 and November 28, 1995 (Table 1). There were a total of 99, 111, and 41 tows, respectively, conducted with vessels from P.E.I., N.B., and N.S. for a total of 251 tows.

For this experimental study, a ten bucket Digby dredge was used. Each bucket was a standard width of 0.6 m (2 feet) with teeth and the metal mesh bag was constructed with 76 mm metal rings (3 inches, internal diameter). A configuration of five different types of buckets was used. The first type had rings linked with two steel washers (steel); the second had rings linked with one steel and one rubber washer (rubber and steel); the third had rings with two rubber washers (rubber); the fourth had rings linked with two steel washers and was lined with 13 mm (0.5 inch) black plastic mesh, Vexar™ (steel-lined); and the fifth had rings linked with two steel washers and had external rubber pads (steel-pad) (Annex 1). For the trials, there were two buckets of each type. The order of the buckets were steel, steel and rubber, rubber, steel-lined, steel-pad, steel, steel and rubber, rubber, steel-lined, and steel-pad. Using this design, each bucket type was represented on each half of the tow bar and one of each bucket type was generally on the outside and one on the inside of the tow bar. The initial placement of the buckets was randomly assigned.

For each tow, the fishermen towed the dredges for eight minutes at a speed of about two knots. There was approximately a 3:1 scope on the warp. For each tow, the starting and finishing position (Loran), start and finish time, direction, speed, depth, scope, and bottom type were recorded.

For all tows, the number of scallops per bucket was recorded. Further, for 17, 3, 91 and 7 tows from Cape Bear Reef, P.E.I., Howard's Cove, P.E.I., Cape Tormentine, N.B., and Pictou Island, N.S., respectively, (Table 1) the catch was measured for shell height (hinge to ventral margin) to the nearest mm using Vernier calipers. Field assistants were on board at all times to record the scallop catch information.

The scallop catch data and shell height information were entered into a database and summarized and analyzed for statistical differences among different buckets types with an one-way ANOVA using the SPSS statistical software package. Where there were significant differences among factors, differences among treatments were examined using the *post hoc* Tukey B test.

3.0. RESULTS

Data from Cape Bear Reef, P.E.I. could not be considered in the analysis because fishers did not use all ten buckets on one tow bar.

The highest mean number of scallops per tow was found in buckets with two rubber washers followed by the steel-pad and steel and rubber. The lowest count was in the buckets with only steel washers and steel-lined buckets (Figure 2 and Table 2). However, there was no statistical difference between the mean number of scallops per tow and the different bucket types (Table 2).

In order to compare the mean number of small scallops (≤76 mm) and large scallops (>76 mm) among the different bucket types, the data obtained from the tows in which the scallops were measured were used. The mean total number of scallops per tow (i.e., all sizes) from the measured tows was compared (one-way ANOVA) and presented no significant difference among the buckets (Table 2, Figure 2). However, when the data for scallops >76 mm was compared among the different bucket types, there was a significant difference (Table 2). The bucket with the rubber washers had the highest mean number of large scallops followed by the steel and rubber and steel-pad (Figure 3, Table 2). The steel ring and liner bucket caught significantly fewer scallops than the other buckets ($p<0.05$).

The analysis examining scallops ≤76 mm, revealed that the steel only buckets retained the lowest number of small scallops while the steel-pad bucket retained the second lowest followed by the rubber and steel (Figure 3). As expected the steel-lined bucket retained the largest numbers of small scallops, followed by buckets with rubber washers. These differences, however, were not significant (Table 2).

The mean size of scallops (shell height) was compared for all scallops from the measured tows and there was a significant difference among the buckets (Table 2).

There were also significant differences in the mean shell height of large scallops (>76 mm) among the buckets and significant differences in the mean shell height of the small scallops (≤76 mm) among the bucket types (Table 2). Of the large scallops, the buckets with steel-only washers retained the largest scallops (Figure 4). The second largest were retained by the steel-pad followed by the rubber and steel, and rubber. The steel-lined buckets had the significantly smallest scallops ($P<0.05$). The small scallops, the steel-lined bucket had the significantly smallest mean size scallops ($P<0.05$; Figure 4).

Scallop size frequency distributions showed that the majority of the scallops caught were >76 mm and were primarily in the 77 to 101 mm size range (Figure 5). Overall, 19.4% of the total catch was scallops ≤76 mm (Table 3). A greater proportion of smaller scallops were in the steel-lined and rubber washer buckets (Table 3).

A comparison of the potential catch, in terms of meat weight (total yield of scallops >76 mm) was estimated for each of the different bucket types. A weight-length relationship was derived from data for the Northumberland Strait (Figure 6; Davidson, unpublished data). This catch analysis used the mean shell height and mean number of scallops from tows with scallops >76 mm only and compared the catch (meat yield) for 100 tows (Table 4). The difference in yield was negligible and ranged from 6.8 to 7 kg (15.1 to 15.6 lbs) of meats for the steel, steel-pad, steel and rubber and rubber buckets (Table 4).

4.0. DISCUSSION

The analysis of the total potential catch of scallops for the different bucket configurations resulted in negligible differences among the buckets with steel, steel and rubber, and rubber washers and steel washers with rubber pad. This analysis was based on a weight-length relationship of scallops from the Northumberland Strait. While differences in growth rates can vary throughout the Gulf (Chouinard and Mladenov 1991), the meat weight-length relationship should not have changed during the course of this study.

The findings that the buckets with rubber washers caught more small scallops than the bucket with steel washers is consistent with the finding of Robert and Lundy (1988) who conducted a study in the Bay of Fundy. Robert and Lundy (1988) also found differences in catch rates on different bottom types but they found the same general pattern. For the same ring diameter, buckets linked with rubber washers reduce the inter-ring space compared to buckets with steel washers. This selects scallops of a relatively small size at 70-80 mm shell height. Steel washers buckets retain scallops of a larger size at 100 mm shell height.

Since scallops caught in buckets linked with steel washers had a slightly higher mean shell height, the overall meat yield was the same as buckets with other configurations. Buckets with rubber washers do have lower catch efficiencies however (Robert and Lundy 1988). This suggests that if only steel washers were used, catches of undersize scallops would decline, without impacting the overall yield of harvestable scallops.

A couple of studies have examined the effect of increased ring size on the efficiency and selectivity of scallop dredges on Georges Bank (DuPaul *et al.* 1989, Anon. 1996). These reports conclude that the larger ring size caught fewer small scallops, as would be expected, and that using the large ring size resulted in a net benefit due to increased meat weight yield. Increased ring size could be an additional or alternative conservation measure to be considered for the Gulf of St. Lawrence and a study examining the selectivity of increased ring size using Gulf fishing gear is warranted.

5.0. CONCLUSION

Buckets with steel washers caught less small, undersized (≤76 mm) scallops compared to buckets with other configurations. The steel-pad was the second most efficient at releasing the small scallops followed by the steel and rubber. The buckets with steel washers had a slightly lower mean number of scallops per tow, but a slightly higher mean shell height of scallops >76 mm compared to buckets with other configurations. The net result was no difference in the catch, based on meat weight of scallops >76 mm in size.

6.0. SUMMARY OF FINDINGS

1. Steels washers (two) could be used to link the rings on the scallop buckets as a conservation measure for scallop fishery. These buckets caught less small scallops compared to other bucket configurations and there was no net reduction in catch (as measured in total weight of meats for scallops >76 mm).

2. If for economic reasons, chaffing gear is required, steel washers with rubbers pads or buckets with steel and one rubber washer could be allowed as a second option. However two rubber washers should be avoided.

3. Increasing ring size could be another alternative, but would require further investigation.

7.0. ACKNOWLEDGEMENTS

Thanks to the fishermen (Captains Roger Cormier, Joe Papp, Barry Cooke, and Jack Martin) and field assistants (Bill Cook, Thorold Fitzpatrick, Donna Waltman, John MacIntyre, Robert L. Mackay) who carried out the sampling and to Maurice Maillet (DFO), Dave Gillis (PEI - DAFF), Greg Roach (NS - DF) and François Mondo and Claude Williams (NB - DFA) for their assistance in setting up the study.

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Robert, G. and Lundy, M. J. 1988. Gear performance in the Bay of Fundy scallop fishery. I. Preliminaries. CAFSAC Res. Doc. 88/19 28 pp.

Rolfe, M. S. 1969. The determination of the abundance of escallops and of the efficiency of the Baird escallop dredge. ICES CM 1969/K: 22 8 pp.

Worms, J. and Lanteigne, M. 1986. The selectivity of a sea scallop (*Placopecten magellanicus*) Digby dredge. ICES CM 1986/K: 23 26 pp.

Table 1. Summary of scallop tow locations, dates, and numbers.

Location	**Date**	**Number of Tows**	**Number of Tows Measured**
Cape Bear Reef, P.E.I.	Oct. 13, 1995	21	5
Cape Bear Reef, P.E.I.	Oct. 18, 1995	22	4
Cape Bear Reef, P.E.I.	Oct. 19, 1995	34	5
Cape Bear Reef, P.E.I.	Oct. 20, 1995	15	3
Total Cape Bear Reef, P.E.I.		92	17
Howard's Cove	Oct. 25, 1995	7	3
Total Howard's Cove, P.E.I.		7	3
Cape Tormentine, N.B.	Nov. 7, 1995	25	17
Cape Tormentine N.B.	Nov. 9, 1995	29	25
Cape Tormentine N.B.	Nov. 11, 1995	27	25
Cape Tormentine, N.B.	Nov. 13, 1995	11	10
Cape Tormentine, N.B.	Nov. 14, 1995	19	14
Total Cape Tormentine, N.B.		111	91
Pictou Island, N.S.	Nov. 24, 1995	27	5
Pictou Island, N.S.	Nov. 28, 1995	14	2
Total Pictou Island, N.S.		41	7
Total Study		251	118

Table 2. Summary of mean numbers per tow and mean shell height per tow and results of one-way ANOVAs for each category.

Category	Steel	Steel and Rubber	Rubber	Steel - lined	Steel - pad	F value	P value
			Numbers per Tow				
Mean	7.71	8.28	8.70	7.68	8.46	2.29	0.057
SE	0.29	0.30	0.33	0.28	0.30		
			Numbers per Measured Tows (all sizes)				
Mean	7.73	8.24	8.38	7.19	7.99	1.62	0.17
SE	0.35	0.38	0.42	0.37	0.32		
			Numbers per Measured Tows (>76 mm)				
Mean	6.59	6.84	6.93	5.59	6.77	3.36	0.01
SE	0.30	0.30	0.33	0.30	0.27		
			Numbers per Measured Tows (≤76 mm)				
Mean	1.14	1.40	1.45	1.58	1.21	1.54	0.19
SE	0.11	0.15	0.15	0.17	0.13		
			Shell Heights (mm) - All sizes				
Mean	88.51	87.60	87.17	85.38	88.42	14.48	0.001
SE	0.31	0.30	0.32	0.37	0.31		
			Shell Height (mm) - >76 mm				
Mean	92.53	91.92	91.79	91.42	92.46	3.21	0.01
SE	0.24	0.25	0.25	0.28	0.25		
			Shell Height (mm) - ≤76 mm				
Mean	68.88	69.44	68.49	66.31	69.09	7.89	0.001
SE	0.47	0.37	0.44	0.53	0.45		

Table 3. Overall number of scallops and percent ≤76 mm shell height for the different bucket types.

Bucket Type	No. <76 mm	No. >76 mm	Total No.	% <76 mm
Steel	266	1298	1564	17.0
Steel-pad	279	1334	1613	17.3
Steel and Rubber	320	1345	1664	19.2
Rubber	336	1357	1693	19.8
Steel-liner	349	1102	1451	24.1
Total	1550	6436	7986	19.4

Table 4. Estimated catch (meat weight) for 100 tows by different bucket types.

Bucket Type	Mean Shell Height (mm)	Ave. Meat Wt. (g)[1]	Mean number per tow	Meat Wt. per Tow (g)	Meat Wt. per 100 Tows (kg)	Meat Wt. per 100 Tows (lb.)
Steel	92.53	10.39	6.59	68.47	6.85	15.1
Steel-pad	92.46	10.37	6.77	70.22	7.02	15.5
Steel and Rubber	91.92	10.24	6.84	70.04	7.04	15.4
Rubber	91.79	10.20	6.93	70.67	7.07	15.6
Steel-liner	91.42	10.11	5.59	56.52	5.77	12.5

1. From weight length relationship Ln Weight = 2.2604 Ln Shell Height - 7.8932 (Davidson, unpub. data) (Figure 6).

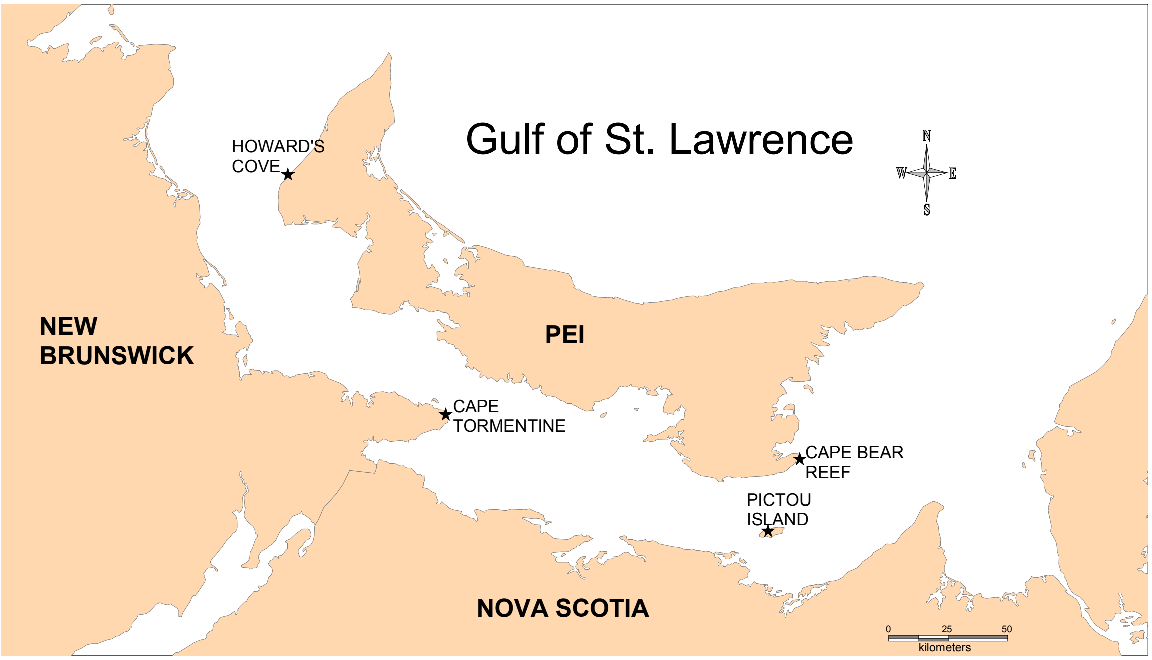


Figure 1. Map of study site.

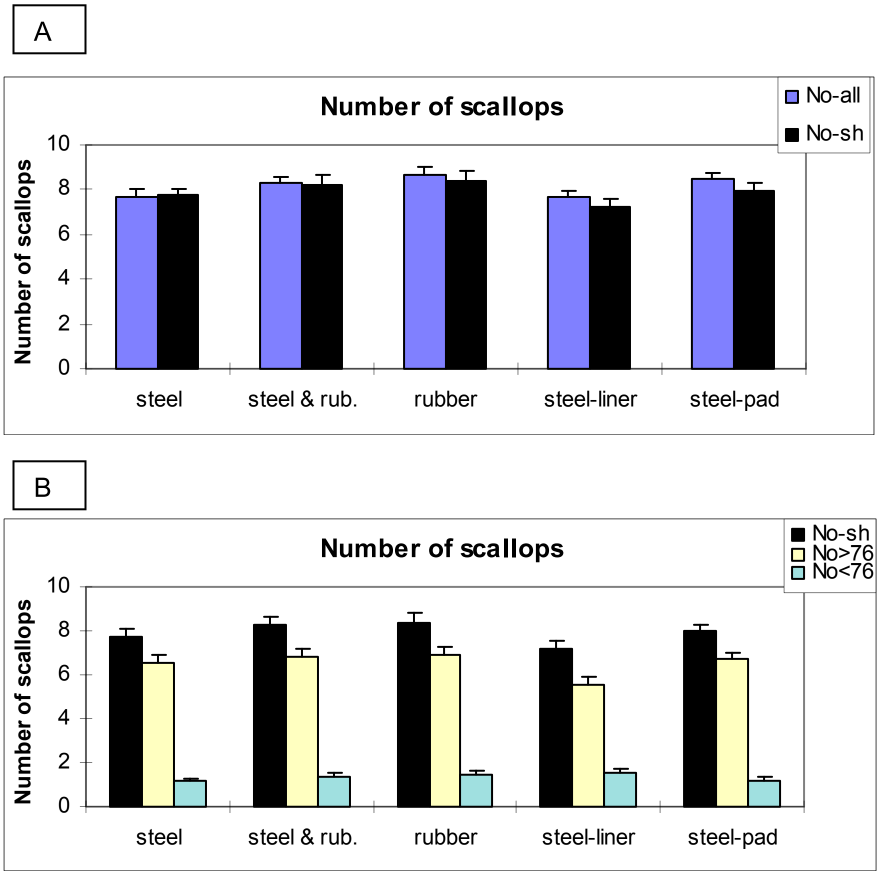


Figure 2. Number of scallops for (A) all tows and for all measured tows and (B) numbers of scallops for measured tows by size.

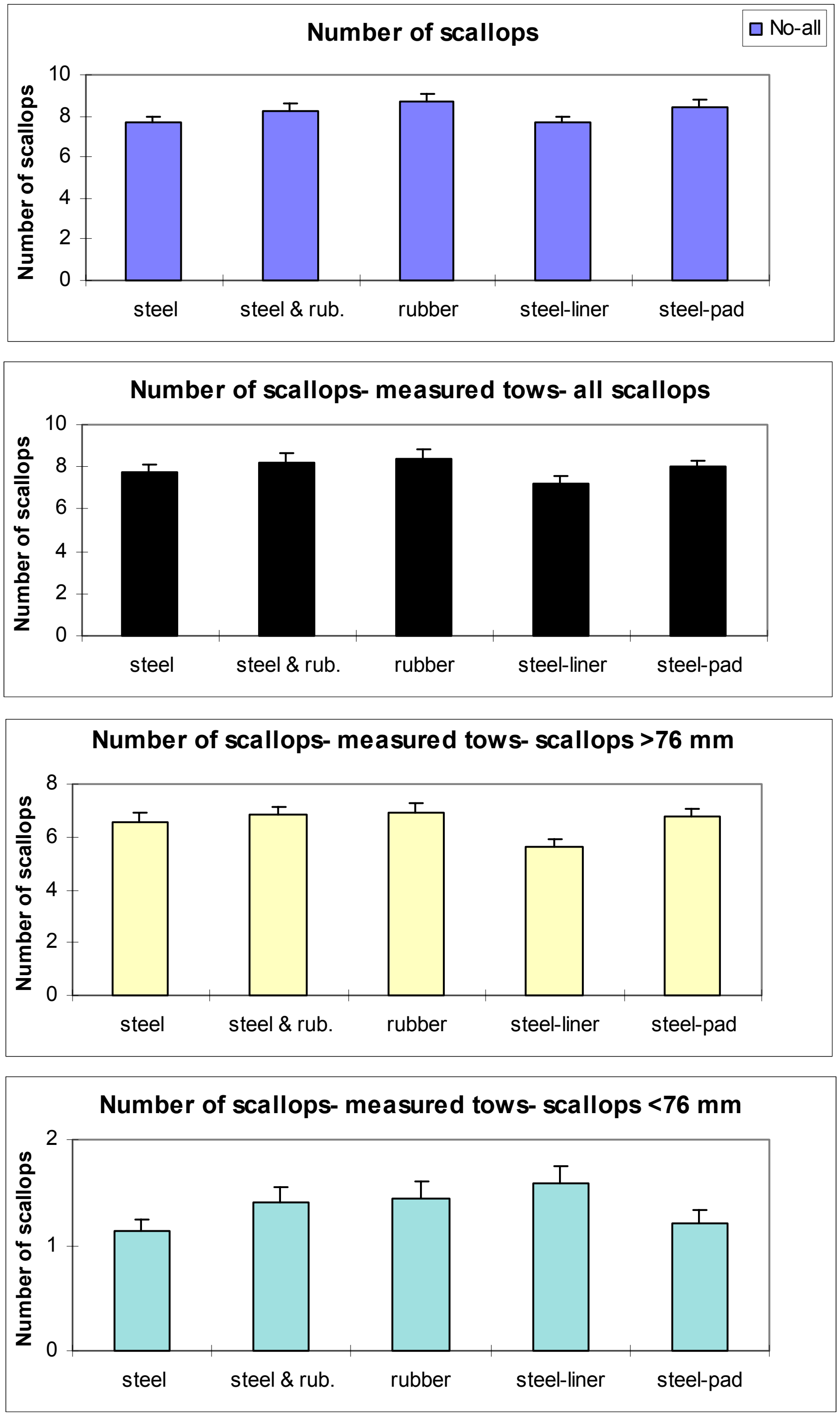


Figure 3. Mean number of scallops for measured tows by scallop size.

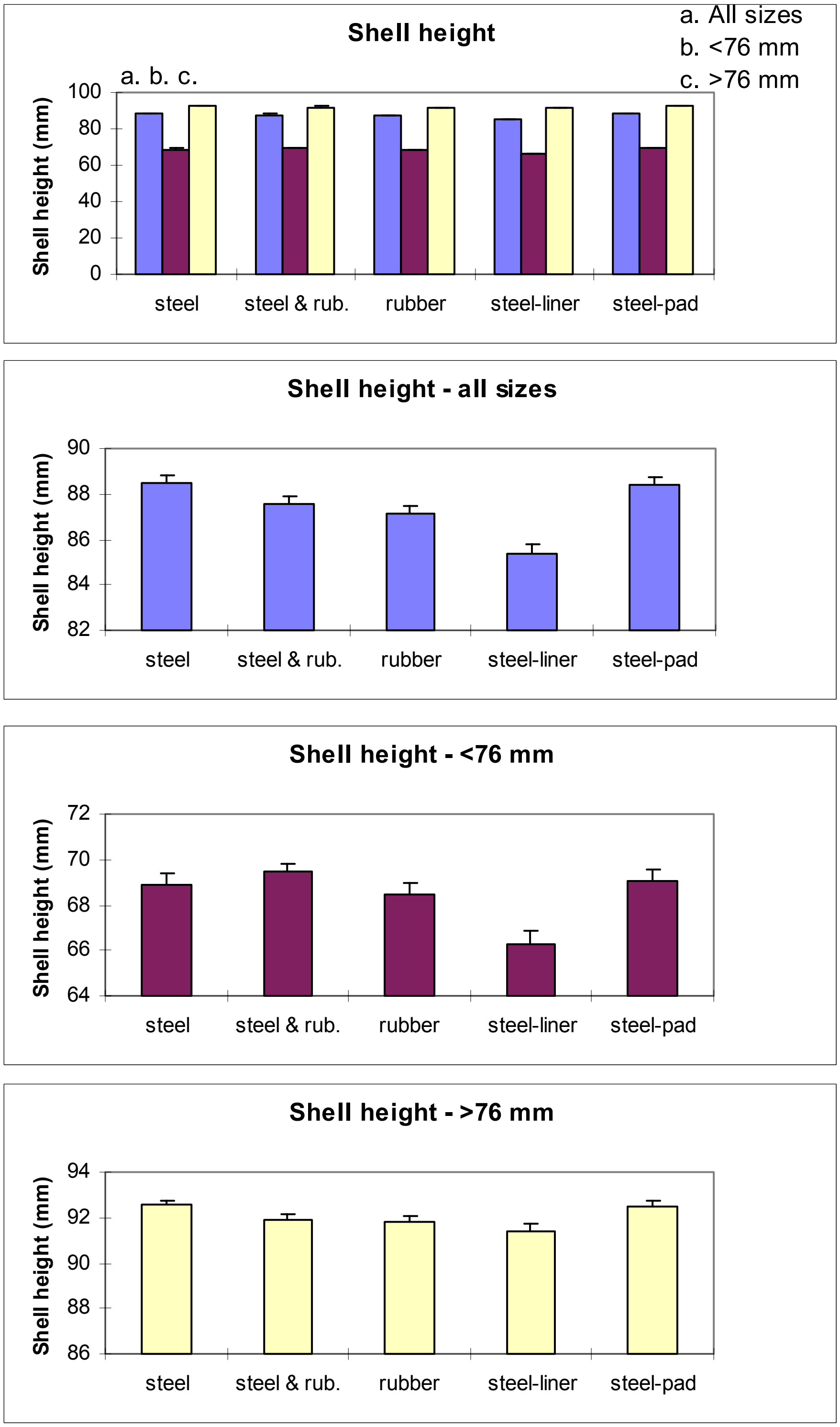


Figure 4. Mean shell height for scallops from measured tows by different scallop size.

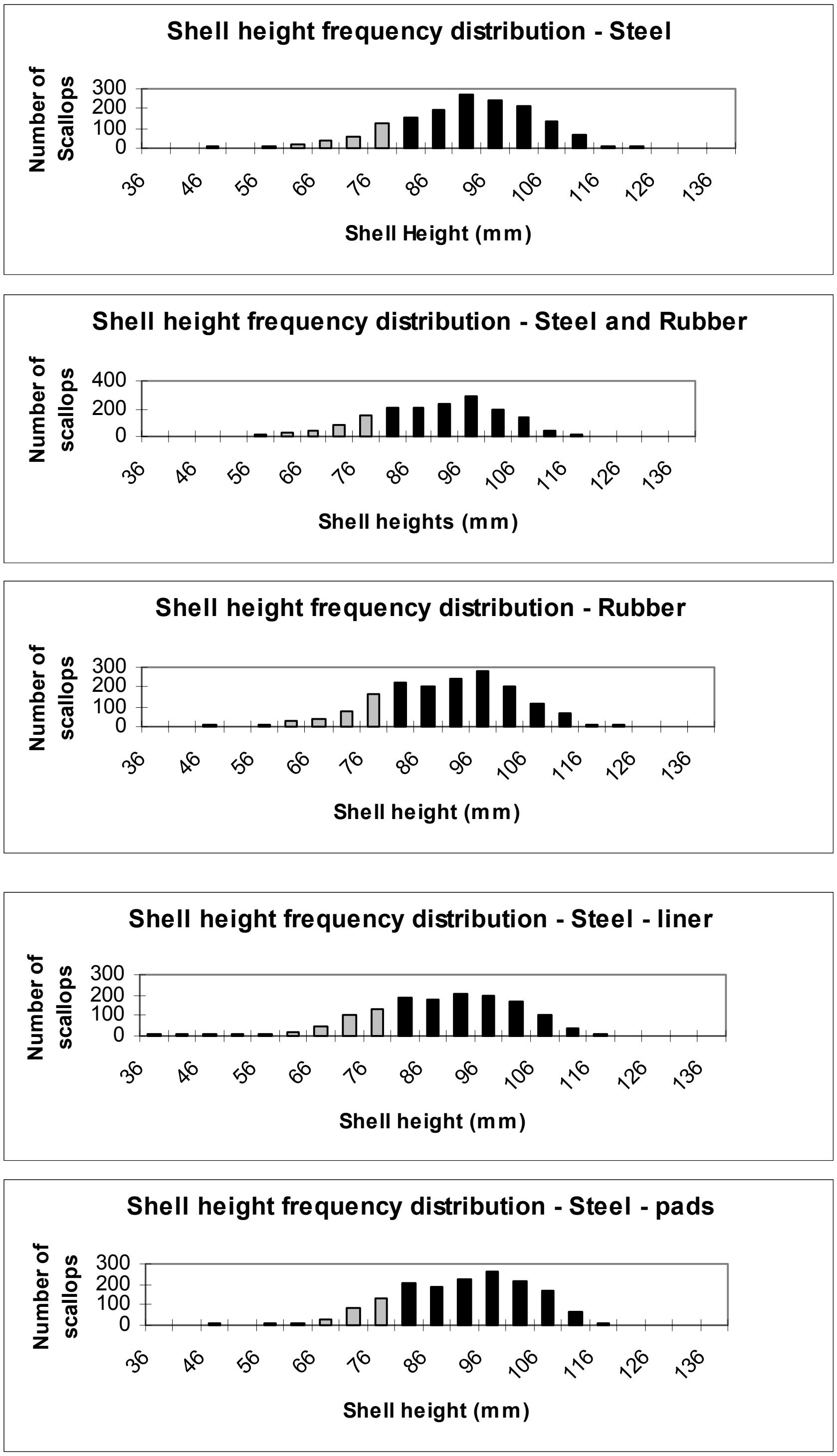


Figure 5. Shell height frequency distribution for all measured tows for each bucket type.

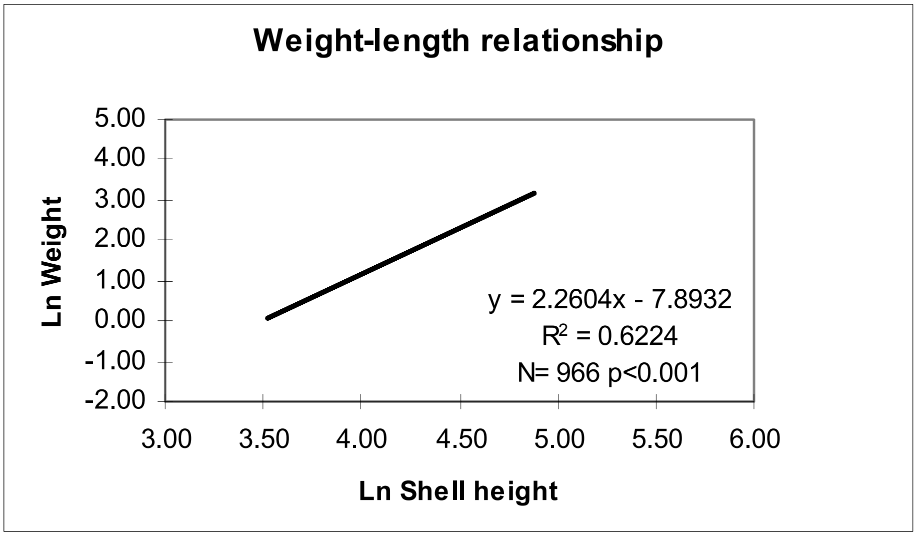
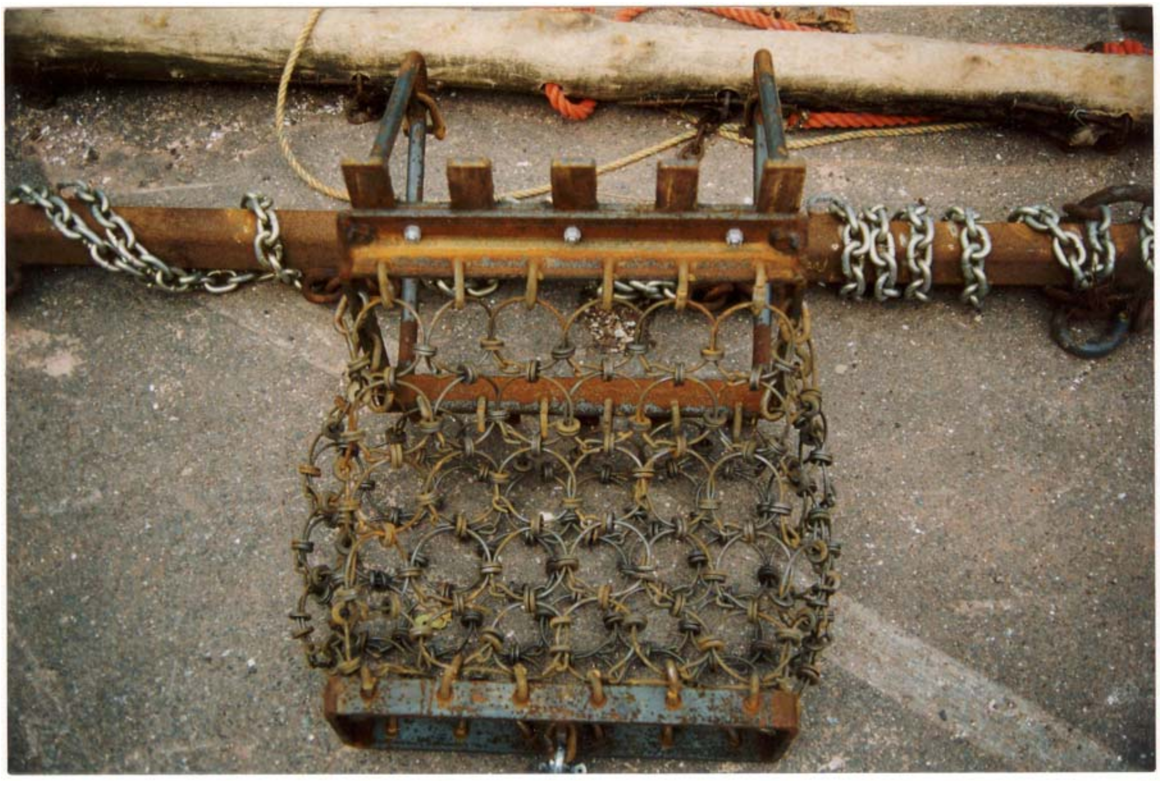


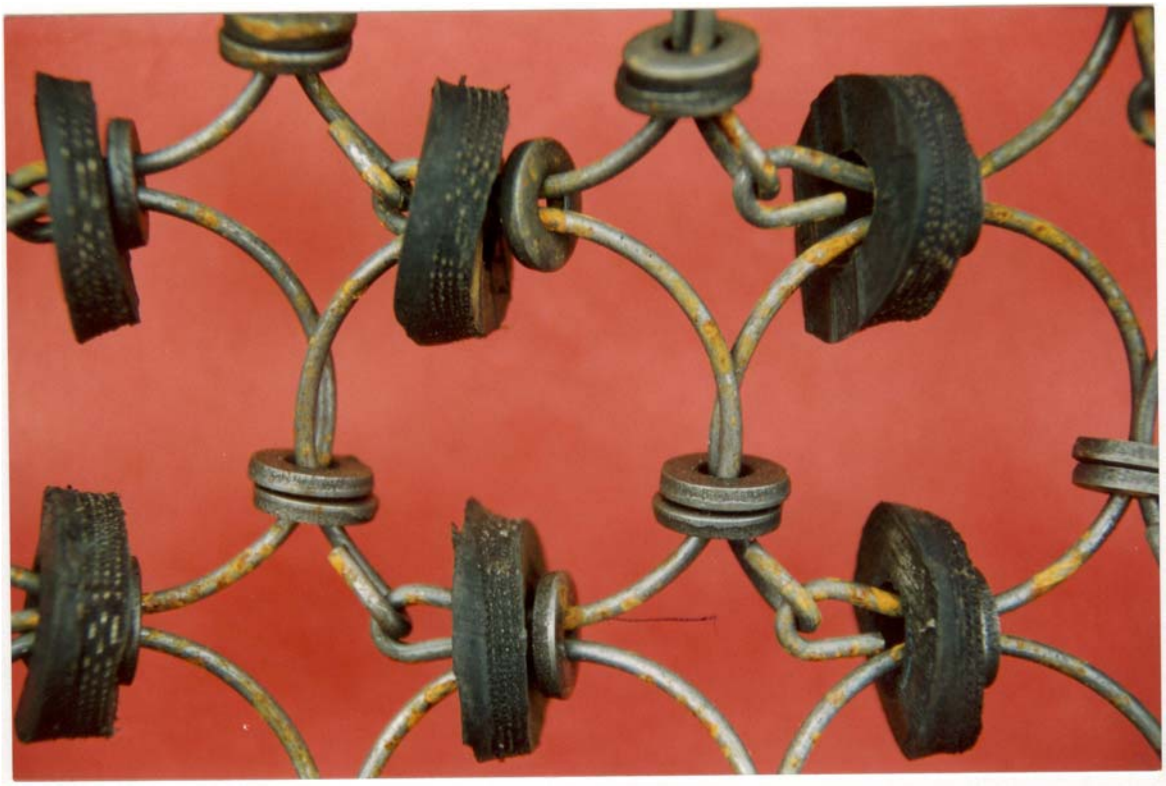
Figure 6. Weight-length relationship for scallops from Northumberland Strait.

Annex 1

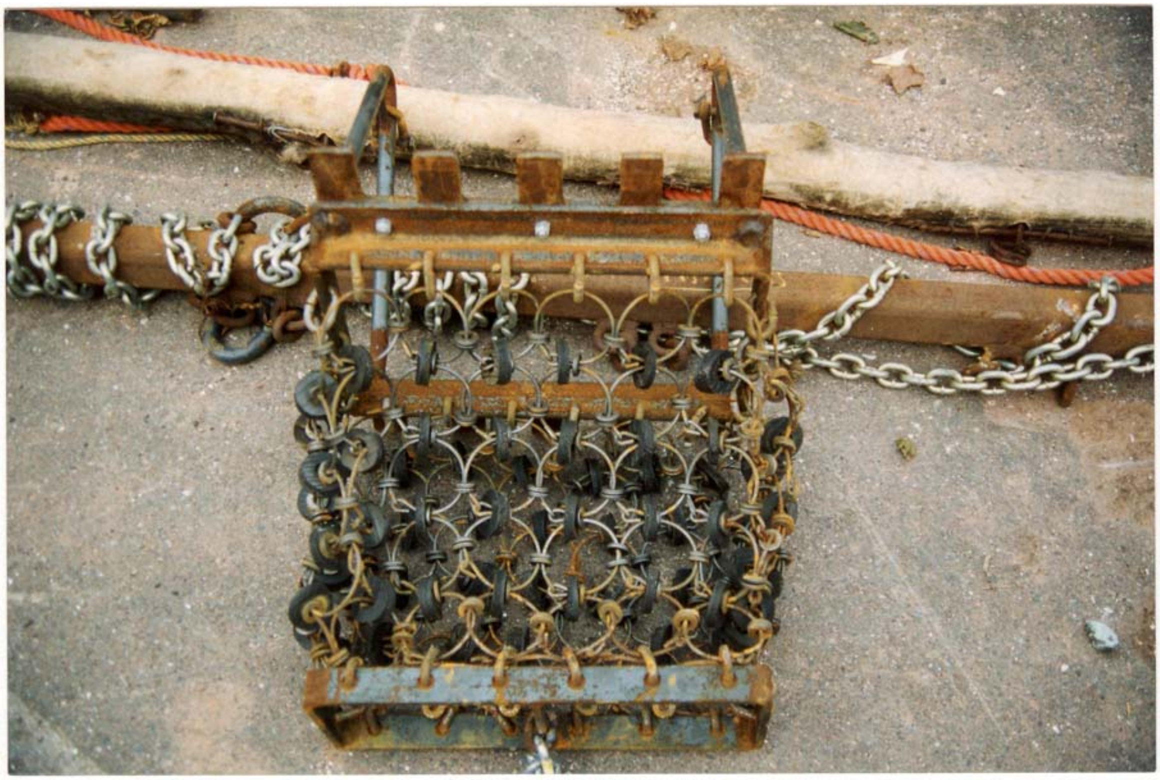
Photographs to illustrate the different bucket configurations, the Vexar and the sampling sheets.

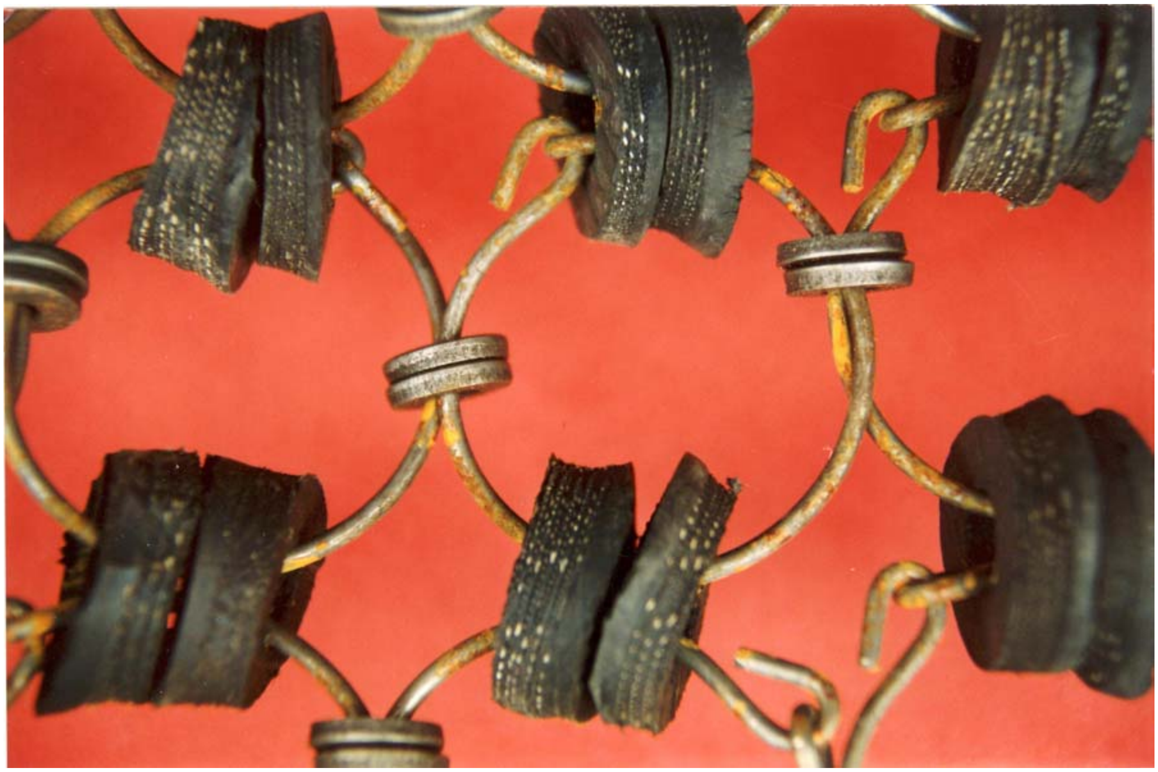
Scallop bucket made with 76 mm (3 inch) rings and steel washers (steel).



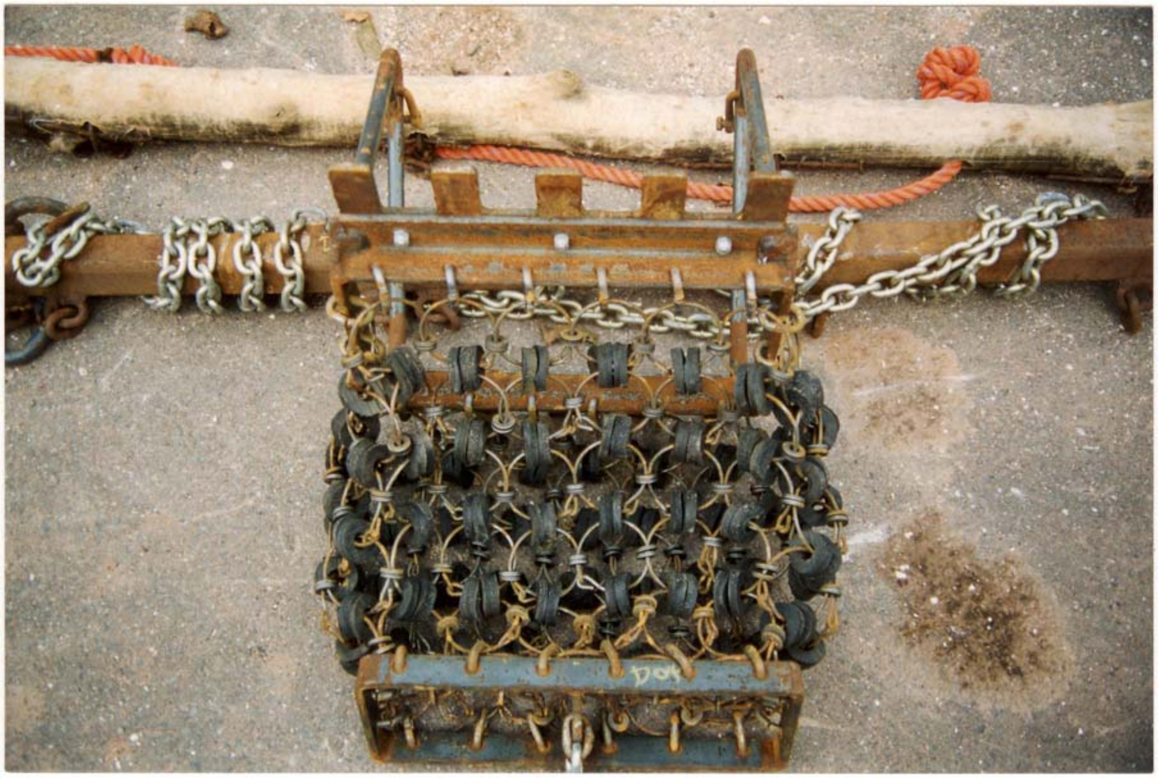


Scallop bucket made with 76 mm (3 inch) rings and steel and rubber washers (rubber and steel).

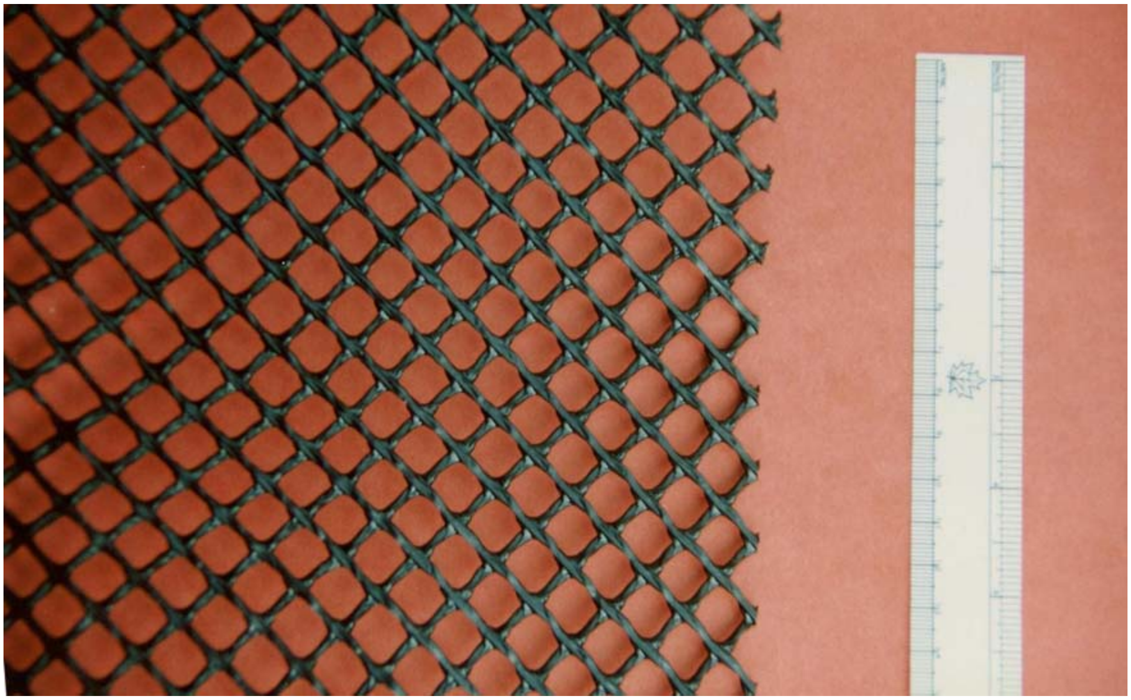




Scallop bucket made with 76 mm (3 inch) rings and rubber washers (rubber).



Scallop bucket made with 76 mm (3 inch) rings and steel washers and rubber pads (steel-pad).



Vexar used to line two buckets made with 76 mm (3 inch) rings and steel washers

Data sheets used by field assistants to collect information (below).

Hydrodredge: reducing the negative impacts of scallop dredging

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Abstract

Scallop dredges typically use teeth or a cutting bar to dig though the sediment and are associated with detrimental impacts on marine benthos. A low-impact ‘Hydrodredge’ was tested that uses ‘cups’ to deflect water downward in a turbulent wave sufficient to lift scallops from the seabed. Trials took place in the Isle of Man fishery for great scallop (*Pecten maximus*) with the hydrodredge and a gang of local ‘Newhaven’ dredges towed simultaneously either side of a commercial scallop dredge vessel. When fished over three different ground types (smooth, medium, hard) and two tow-speeds (2.5kt, 4.0kt), the proportion of dead scallops and bycatch in the Hydrodredge was significantly less that for the Newhaven dredges. This result highlighted the role of the teeth on the tooth-bar in exerting severe (fatal) damage to the catch and bycatch. Rates of non-fatal damage to scallops and bycatch did not differ between gears, suggesting that such damage occurs as a result of contact with other parts of the gears such as the chain-bag. The hydrodredge was less efficient at catching great scallops compared with the Newhaven dredges (~40%). For great scallops, the cups did not significantly increase catch relative to the hydrodredge fished without cups, which contrasts with results for other surface dwelling scallop species. Importantly, the Hydrodredge was designed in the New England fishery for giant scallop (*Placopecten magellanicus*), a species typically lighter and less embedded than *Pecten* and thus potentially more vulnerable to the flow patterns of the Hydrodredge.

Introduction

Scallops form a valuable component of commercial catch for several important fishing nations. In the UK, great scallop *Pecten maximus* now represents the third most valuable fishery (after *Nephrops* and Mackerel), and was worth over £34 Million (value at the point of first sale) in 2005. A large percentage of scallops are caught using various designs of dredge. This type of fishing gear can have detrimental impacts on the marine benthos, and is associated with changes in the physical structure of the seabed (Currie and Parry, 1999), community structure (Kaiser et al., 2000; Bradshaw et al., 2002) and scavenging activity (Ramsey et al., 1998), direct damage to captured and non-captured bycatch species (Veale et al., 2001; Jenkins et al., 2001) and reduced predator escape response in discarded juvenile scallops (Jenkins and Brand, 2001). Such ecological effects are largely related to the invasive dredge teeth or cutting bar used to dig scallops from the sediment, although the degree of impact may vary subject to various environmental variables (Fifas and Berthou, 1999).

A novel 'Hydrodredge' designed at the Massachusetts Institute of Technology (MIT) fir use in the New England fishery for giant scallop *Placopecten magellanicus* has the potential to exert far less damaging effects on the seabed and its biota (Goudey, 2006). Instead of mechanical means, the new gear uses precisely oriented 'cups' that deflect water into a downward jet and creates large-scale vorticity, a combination that exerts sufficient force on the seabed to lift scallops into the water column whereupon they can be captured by the trailing net/chain bag. Following successful tow tank and video trials in the U.S. by MIT, this prototype gear underwent a preliminary evaluation in the Isle of Man (U.K.) great scallop fishery in April 2007. Both research and commercial vessels were used with direct involvement of fishermen in the trials. The results were encouraging, and led to a more thorough evaluation of the Hydrodredge in the Isle of Man fishery during August 2007, being the subject of this report.

Methods

Sampling

A commercial scallop dredger configured with over-the-side beams was used for all experiments (FV De Bounty CT 73, 54.25GT, l.o.a. 19.05 m, 272.4 Kw). The hydrodredge was fished on one beam, while three x 75 cm wide Newhaven dredges were fished simultaneously on the other. This meant that the overall mouth width of the Hydrodredge was about 91% of the Newhaven dredges and a corresponding correction factor had to be made to catch rates. Due to the difficulty of rigging dredges at sea, gears could not be switched between sides of the vessel during the trials, but were interchanged between trials. We devised an experiment to compare the performance of the two gears when fished over different grounds (smooth, medium and hard) and at different speeds (slow 2.5kt and fast 4.0kt). At each fishing site, five replicate tows (approximately 15 min duration) were made for each treatment. The slower speed is typical for fishing the Newhaven gear, while the faster speed was intended to optimise the performance of the hydrodredge by increasing water flow around the cups. For all catches, scallops were measured (width, mm) and assigned a damage score (1-4) according to Veale et al.

(2001). A suite of 10 common bycatch species also were enumerated and assigned a damage score (Veale et al., 2001).

An additional set of tows at each speed but on a single ground type (medium) were made, for which the hydrodredge cups were removed for alternate groups of 2-3 tows (comparison of ‘cups’ versus ‘no cups’) . This allowed assessment of the contribution of the cups to gear function and efficiency.

Analysis

Relative numbers of each of scallops and bycatch species were compared separately using full factorial Type III ANOVA, with Ground, Gear and Speed as fixed effects, and corrected number (allowing for differing mouth widths of gear) of scallops or bycatch respectively were the dependent variables. Tukey post-hoc multiple comparison tests for ground type were conducted. Comparison of scallops and bycatch damage scores by gear used the same analysis, but were based on Ln (n+1) transformed percentages by damage score. Comparisons of Hydrodredge catch of scallops between tows with and without cups (evaluating a ‘cup effect’) were conducted using t-tests on each of a) all data combined, b) with and c) without cups, using scallop catch in the Hydrodredge as a percentage of catch in the Newhaven dredges by tow as the response variable. The dependent variables were checked that they met the appropriate assumptions prior to using the parametric statistics outlined above. Significance was assumed at $P \leq 0.05$ for all tests.

Results

The Newhaven dredges consistently caught more scallops than the Hydrodredge (Table 1; Fig. 1). There was some interaction between gear and ground (Table 1). A significantly greater percentage of scallops (ANOVA $F_{1,48} = 18.352$, $P<0.0001$) in the Newhaven dredges were dead (damage score 4) (Fig. 2) while there was no significant difference in percentage of scallops that had other damage scores. A significantly greater percentage of individuals of bycatch species (ANOVA $F_{1,47} = 14.028$, $P<0.0001$) in the Newhaven dredges also were dead (Fig. 3) while there was no significant difference in percentage of bycatch that had other damage scores. These results imply that the tooth-bar on the Newhaven dredge is primarily responsible for the fatal/severe injuries sustained by scallops and bycatch species, while other components of the gear or the catching process account for the less severe physical damage that occurs.

In the trials to examine the ‘cup’ versus ‘no-cup’ effect at different speeds, the analysis indicated that there was no significant difference in scallop catch in the Hydrodredge when fished with ($t_2 = -1.190$, $P = 0.1781$) or without ($t_4 = -0.616$, $P = 0.2861$) the cups, although the cups appeared to perform better when towed ‘fast’ (Fig. 4).

Discussion and Conclusions

Scallop dredging exerts a negative impact on the benthic environment and on discarded and non-captured scallops and bycatch organisms. By avoiding the use of teeth/cutting bar, the hydrodredge has potential to reduce such damage. Encouragingly, during these trials, the hydrodredge significantly reduced the proportion of dead scallops and bycatch. This emphasizes the likely role of the dredge teeth in exerting fatal damage and highlights the potential of non-toothed dredge designs in reducing the ecological impacts of dredging. It also presents potentially useful results from a longer term perspective on the sustainability of this sector. Interestingly, there was no difference between gears in the incidence of non-fatal damage to captured organisms. This suggests that most of such damage occurs in the chain bag common to both the Hydrodredge and Newhaven dredges. Modifications to the chain bag also could yield important conservation benefits for both target and non-target species.

In the trials around the Isle of Man, the Hydrodredge was significantly less efficient than an equivalent team of Newhaven dredges, and caught between 10-40% as many *P. maximus*. This is a much lower relative catch rate than suggested by preliminary trials of the Hydrodredge in the U. S., when targeting *P. magellanicus*. Notably, the North American species is thinner shelled than *P. maximus*, and typically more active and lives directly on (rather than recessed into) the seabed. These characteristics may render *P. magellanicus* more susceptible to the water flows generated by the hydro cups, and hence more likely to be lifted into the water column and caught. The same issue probably explains the lack of 'cup effect' observed in the Isle of Man trials. The hydro cups seem to be relatively ineffective at lifting the heavy and well recessed *P. maximus*, so many of the scallops that were retained could have been caught simply because of the action of the belly chain. Despite these findings, if targeted at appropriate scallops species (*P. magellanicus* or *Aequipecten opercularis*), the Hydrodredge offers an exciting potential to reduce the environmental impacts in fisheries for these species, particularly the cumulative effect of sub-lethal damage on the benthos. The Hydrodredge is therefore worthy of further field trials specifically targeted at these species.

Acknowledgements

This study was funded by the Department of Agriculture, Fisheries and Forestry, Isle of Man Government and by a grant from Seafish. The authors thank the skipper and crew of the FV De Bounty for their support in this work and the members of the Manx Fish Producers Organization for comments and support during the research.

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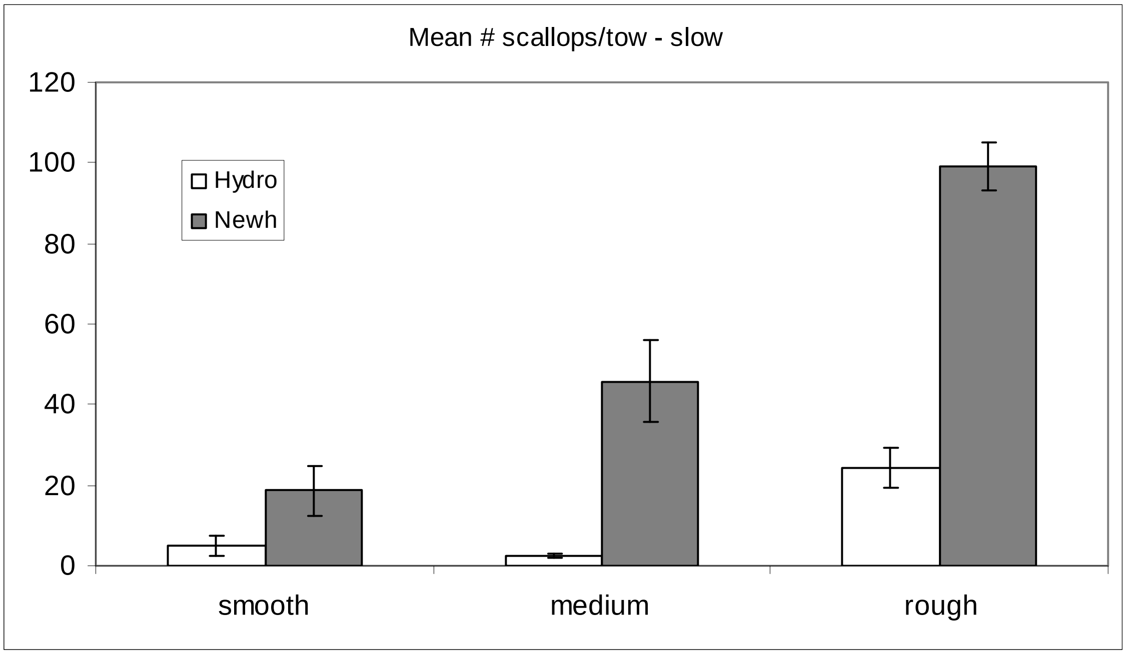
Tables

Table 1. Results from full factorial Type III ANOVA, with Ground, Gear and Speed as fixed effects, and corrected number (allowing for differing mouth widths of Hydrodredge and Newhaven gear) of scallops being the dependent variable.

Source	Type SS	dfs	MS	F	*P*
Corrected model	69805.189	11	6345.926	18.438	0.000
Intercept	73146.227	1	73146.227	212.526	0.000
Gear	24117.744	1	24117.744	70.074	0.000
Ground	35983.181	2	17991.590	52.274	0.000
Speed	329.848	1	329.848	0.958	0.333
Gear*Ground	8426.112	2	4213.056	12.241	0.000
Gear*Speed	221.645	1	221.645	0.644	0.426
Ground*Speed	702.684	2	351.342	1.021	0.368
Gear*Ground*Speed	23.975	2	11.988	0.035	0.966
Error	16520.423	48	344.175		
Total	159471.839	60			
Corrected Total	86325.612	59			

Figures


Mean # scallops/tow - slow
120
100
80
60
40
20
0
Hydro
Newh
smooth
medium
rough

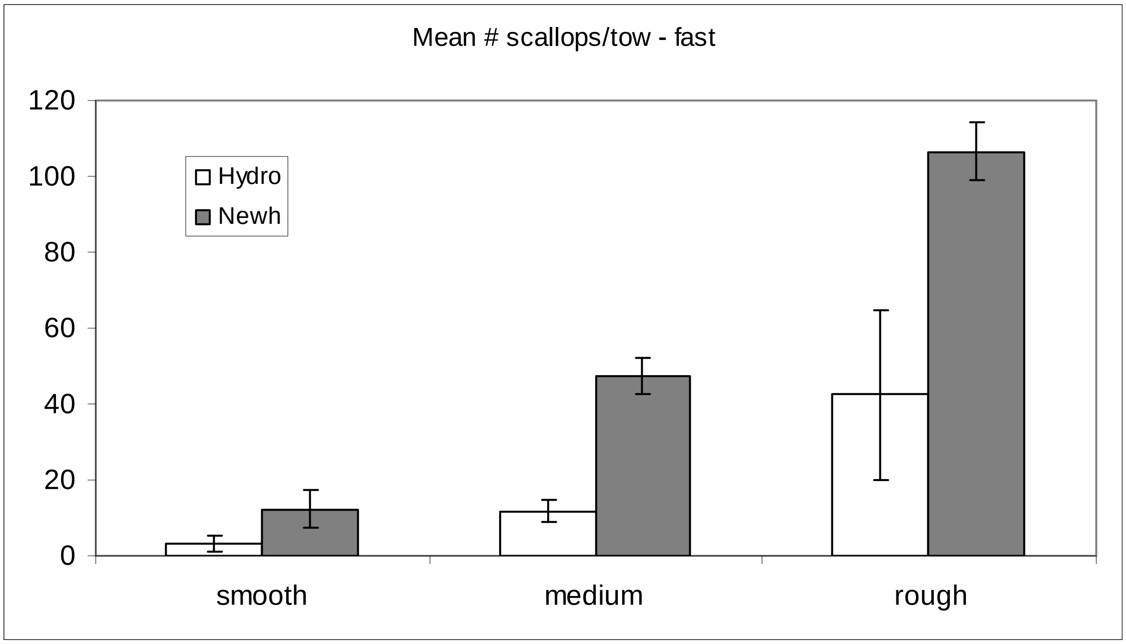


Figure 1. Scallop catch (±SE) in each of Hydro- and Newhaven dredges for three ground types (smooth, medium and hard) at each of slow (2.5kn) and fast (4.0kn) towing speeds.

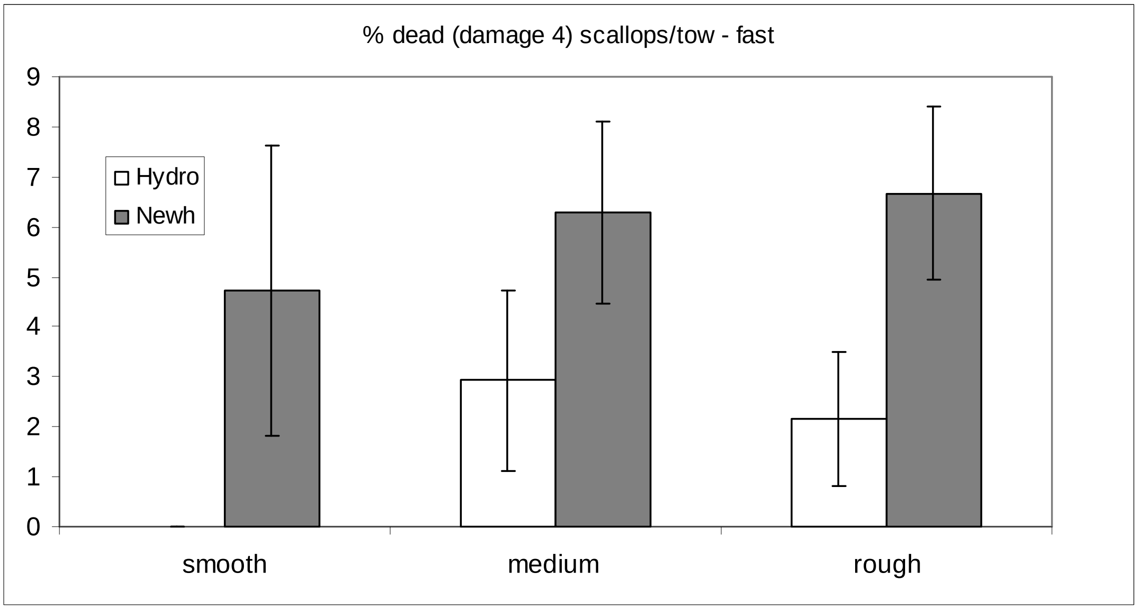
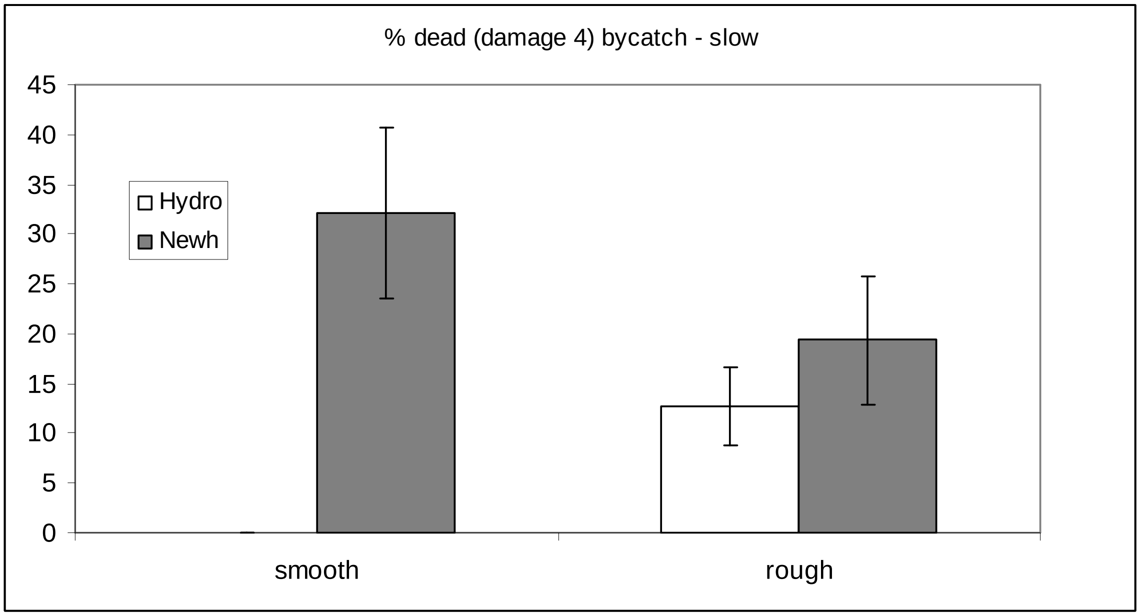


Figure 2. Percentage of scallops (±SE) showing damage score 4 (dead) in each of Hydro- and Newhaven dredges for three ground types (smooth, medium and hard) at each of slow (2.5kn) and fast (4.0kn) speeds.



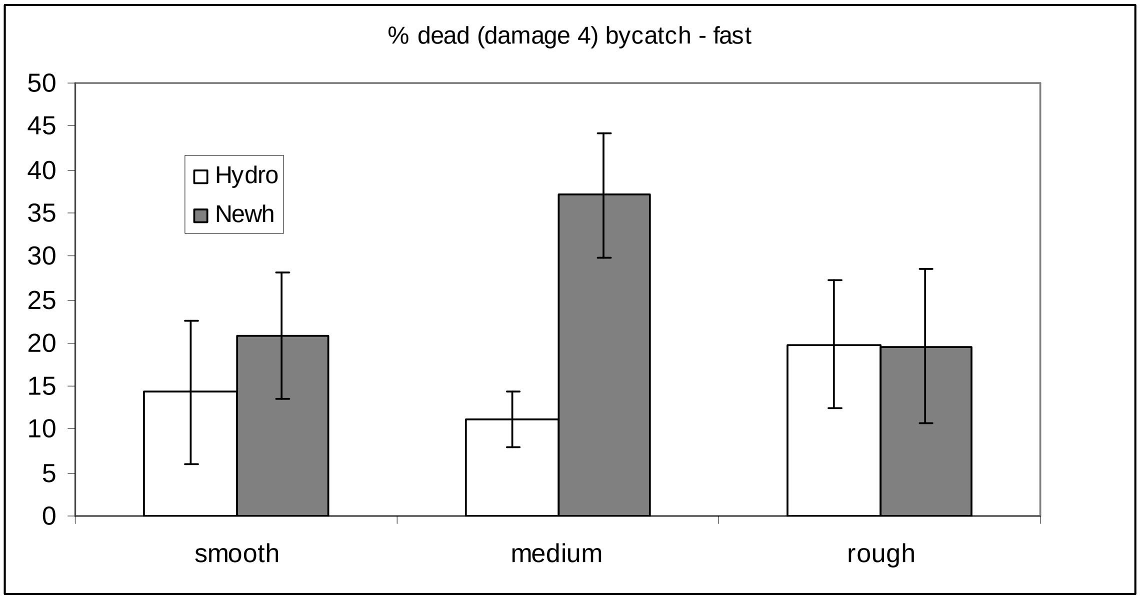


Figure 3. Percentage of bycatch showing damage score 4 (dead) in each of Hydro- and Newhaven dredges for three ground types (smooth, medium and hard) at each of slow (2.5kn) and fast (4.0kn) towing speeds.

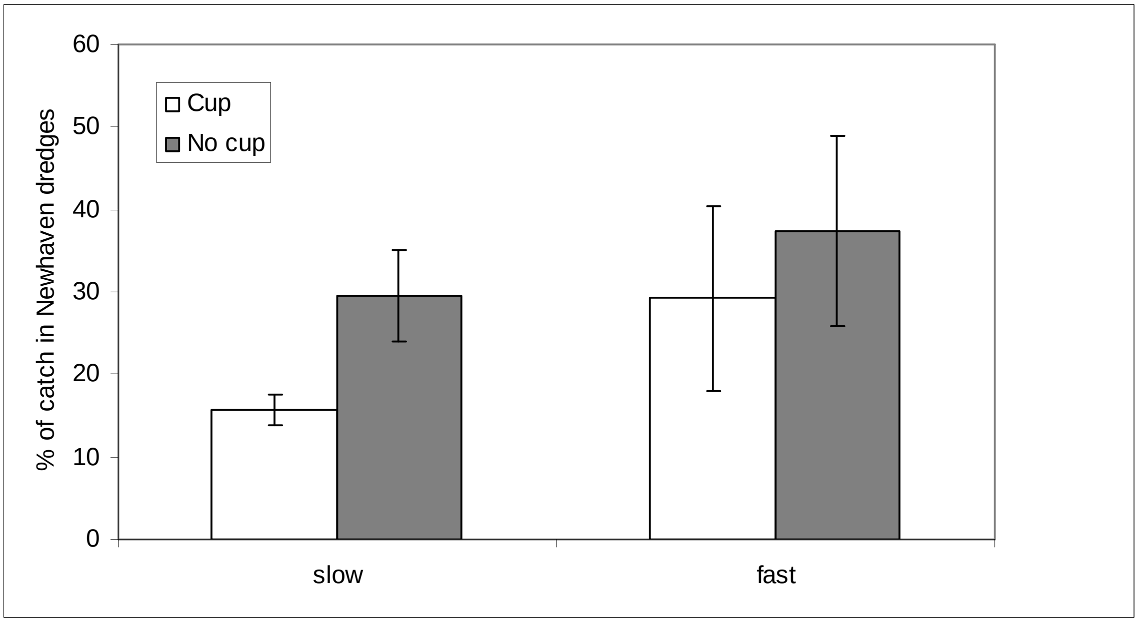


Figure 4. Number of scallops (±SE) caught in Hydrodredge when fished on medium Ground*Speed with and without cups.

Developing a Low Impact Sea Scallop Dredge

NOAA/NMFS Saltonstall-Kennedy Program NA96FD0072, 99-NER-045

Final Report

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Period Covered:	1 June 1999 - 30 April 2002
Start/End Dates:	1 June 2001 - 28 February 2002
Date Prepared:	29 July 2002

II. Executive Summary

The sea floor habitat impact of "New Bedford"-style dredges fishing for sea scallops *Placopecten magellanicus* is generally presumed to be high, especially in sand and gravel substrates. At the same time, sea scallops are highly prized as food, providing ex-vessel income that typically exceeds $70 million per year to the Commonwealth of Massachusetts alone. We sought to develop a dredge with lower impact to habitat that maintains current catch rates.

Bay scallops *Argopecten irradians* were observed swimming up into the water column following the passage of a boat with an outboard engine. Bay scallops and sea scallops were exposed to frequencies selected from engine noise recordings, recordings of engines, and the original engine. This testing resulted in less reaction than historically viewed; subsequent efforts with DC electric pulses showed some indication of a possible future research direction.

III. Purpose of the Project

New Bedford-style dredges are the primary means used to harvest sea scallops *Placopecten magellanicus* from Georges Bank and in the Mid-Atlantic region (NREFHSC 2002). The value of this fishery to the Commonwealth of Massachusetts typically exceeds $70 million (pers. comm., National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD). Dredges are constructed of heavy-gauge steel tubing, welded into a triangular shape, with a bag hung from one side made of steel rings with twine mesh on the upper side. The dredge is towed from the apex of the triangle, and rides along the sea floor on "shoes": steel plates welded to the dredge at the corners of the triangle where the bag is attached.

The actual capture mechanism for sea scallops is theorized to be initiated when scallops swim up vertically in reaction to, or are lifted vertically by, the hydrodynamic effect of the "cutting bar". The 15 ft long (usually) cutting bar rides at or just above the sea floor perpendicular to the direction of the dredge, and connects two corners of the triangle. The leading edge of the ring bag passes beneath the scallops when they rise, and thus the scallops fall into the bag and are captured, unless they are smaller than the inside diameter of the rings (currently mandated at 3.5 in) that comprise the bag and pass through.

The shoes and the bottom half of the bag are the primary contacts of the dredge with the sea floor. The turbulence behind the cutting bar also results in suspension of sediment and some smoothing of irregularities. Other physical impacts relating to setting out and hauling of the dredge occur but are minor in comparison to the shoes, bag and cutting bar.

The overall weight of a New Bedford-style scallop dredge can exceed 1 MT in air (R. Smolowitz, pers. comm.). This weight, amongst other considerations, led to a suspicion that the use of scallop dredges may impact the sea bottom (Dorsey and Pederson 1998). While the severity and consequences of this impact are unknown, it is suspected that some impact occurrs (Collie et al. 1997; Kendall 1998). Underwater observations using side-scan sonar (pers. obs.) show that the passage of a dredge left notable marks on the sea floor. A recent synthesis of fishing gear effects on marine habitats in the Northwest Atlantic concluded that scallop dredges can frequently and strongly impact sand and gravel dominated sea floors (NREFHSC 2002). National Research Council (2002) cited four generalities describing dredge impact including reduction of habitat complexity, changes to benthic communities, reduction of benthic productivity, and increased vulnerability of some fauna. While the questions of the effects of fishing are not likely to be quantified or fully answered in the near future (National Research Council 2002), it is clear that investigation of possible alternative dredge designs or harvest methods should be undertaken in advance of definitive determination of dredge impact.

While developing potential dredge alternatives, field observations were recalled where bay scallops *Argopecten irradians* responded to the passing of an outboard engine by swimming up vertically (A. Carr, unpub. data). The exhaust noise appeared to irritate the scallops. On four separate occasions in four separate embayments, this behavior was observed by a diver swimming behind a boat. These observations were made in shallow water and the response by the bay scallops seemed to be limited to an arc just behind the moving engine. Bivalves do not have a sensory organ for hearing, but it was surmised that mechanoreceptors could be sensitive to the pressure caused by different sound frequencies (Charles 1966).

It was further theorized that these observations could be repeated further offshore, with sea scallops *Placopecten magellanicus*. The motility of the sea scallop has long been recognized, and they have been considered one of the ablest swimmers among lamellibranchs (Drew 1906). Drew (1906) considered the whole structure of the animal as modified for this purpose. Belding (1931) observed that swimming is frequently a diversion of the scallop, which, after lying quietly on the bottom, suddenly takes a slant shooting through the water. We theorized that if *P. magellanicus* reacted the same way as *A. irradians*, the response might be exploited to catch scallops with a re-engineered lighter sea scallop dredge.

The use of sound in finding and enumerating fish is common (Urick 1983). The reaction of fish to sound is a primary component in some commercial fishing methods (Cetinic 2002) and is thought to initiate the capture process for trawl nets (Fridman 1973; Wardle 1993). The use of sound to capture shellfish is not known.

Our initial objectives were:
a) To determine what frequencies stimulate a response in bay scallops and sea scallops.
b) To then apply this knowledge *in situ* using a sea scalloper and underwater observation systems.
c) And to construct or modify a sea scallop dredge that would use acoustics in the capture process to determine effectiveness in the targeted catch and reduction of finfish bycatch.

Following initial efforts, the assessment of the effectiveness of an acoustic dredge was repeated using DC electricity. Electricity is known to induce responses in fish (Fridman 1973), and is widely used to sample fish in freshwater research (Reynolds 1983). In salt water, electricity has also been used for benthic sampling (Phillips and Scolaro 1980) and commercial fishing. For example, an ongoing study in Europe funded by the Dutch government and fishing groups is developing an electrified beam trawl for use in a sole fishery (pers. comm., B. Van Marlen).

IV. Methods

Acoustics

Determination of Frequencies

We attempted to determine if specific predominant frequencies within the range of outboard motor output could be identified and reproduced over bay scallop beds. To uncover these frequencies, outboard engine sound output was recorded underwater in three ways. Initially, an interference frequency analyzer with a hydrophone was used to identify dominant frequencies directly by visiting marinas and boat launching sites. In some cases, recordings were made opportunistically with cooperation of private boat owners; some recordings were made of Division of Marine Fisheries (DMF) engines. Essentially, this equipment allowed the user to step through the sound spectrum and record the intensity at each wavelength.

The second and third methods took a slightly different approach: engine sound was recorded and later analyzed for peak intensities. The second method used a digital minidisk recorder with a stereo microphone inside a waterproof dive housing. This arrangement allowed the collection of sound onto a high quality medium simply and inexpensively. Following concerns over the muting effect of the dive housing, further sound was collected using a transducer/hydrophone system that was initially purchased for the production of sound. This system allowed the recording of engine noise without the use of a housing, and therefore avoided the potential muting or elimination of portions of the sound spectrum.

In all cases, the manufacturer, model and age of engines were recorded to identify specific frequency ranges produced by each engine, including the engine which produced the original phenomenon, a one-cylinder British Seagull outboard boat engine. Where possible, engines were recorded at a range of RPMs.

Sound Analysis

Peak frequencies were either identified with the frequency analyzer, or through graphical analysis using a computer program (Horne 2000). The program produced sonograms (frequency (Hz/100) v. intensity (dB) plots). Dominant frequencies were selected by examining peaks in the decibel output of the engines. Peak frequencies were compared across engine types to select candidate frequencies for broadcast to scallops.

Sound Broadcast

Sounds were broadcast to both bay and sea scallops in both laboratory and field settings. Two laboratory facilities were used: the Marine Resource Center (MRC) at the Marine Biological Laboratory in Woods Hole, MA and DMF's Lobster Hatchery on Martha's Vineyard, MA. Both facilities maintain flow-through systems and have experience culturing scallops. Field observations were conducted in several places in the general vicinity of Pocasset, MA.

Sounds were broadcast using two different speaker systems: a University Sound UW-30 and a DRS-8 speaker from Ocean Engineering Enterprises. In addition, sound was broadcast to scallops in the field using the original sound source that produced the upward movement, the British Seagull outboard engine.

Two different types of sound were broadcast. Recorded engine noise was played to bay and sea scallops; also, pure tones of frequencies selected from sound analysis were broadcast using sound generators. Recorded sounds were initially played back from the minidisk recorder via a 60-watt amplifier; later, a public address system was added to increase sound output.

Electricity

Reaction Testing

Pulsed DC voltage supplied by a fish barrier pulsator was acquired based on advice from engineers familiar with the use of electricity to attract fish. The pulsator inverts 110 V AC current from a portable 2.5 KW gasoline generator to various DC voltages and waveforms. The pulses of DC voltage are attenuated in a spherical energy wave between a positive current anode and negative current cathode. To test scallop response, two electrodes were constructed out of steel threaded rod and placed on a frame made of PVC pipe that was placed on the sea floor at a depth of approx. 5 ft. A diver observed the reaction of the scallops to the stimuli.

Tests were conducted with this apparatus on bay and sea scallops in the field and at the Lobster Hatchery and MRC. A bed of bay scallops was found and subjected to electricity. Some of these scallops were collected for subsequent testing in the Lobster Hatchery. Sea scallops were acquired from a commercial scallop dredge vessel and tested in the MRC. A subset of these scallops were transferred for field testing. Field and laboratory testing methods were similar.

Distance between the electrodes was varied between 12 inches and three feet. Variables in the composition of the electric field were wavelength, voltage, amperage and frequency. Pulses were released between electrodes placed directly on and slightly above (6 in) the sea or aquarium bottom. Frequencies of 1 to 30 Hertz and wavelengths of 2 to 10 milliseconds (ms) were tested between 28 and 150 V at amperages of between 24 and 148 A.

Field Trials

An 8-ft New Bedford-type scallop dredge was fitted with electrodes and connected to 400 ft of six-gauge submersible stranded 2-conductor supply line. This length allowed us to dredge to a maximum depth of 70 feet. Connections between the supply cable and the electrodes were made watertight to prevent leakage of electricity. Electrodes were constructed from 3/8 inch diameter steel tow wire and connected to the dredge with conventional shackles, isolated from the dredge using rings cut from tires. Three electrodes were used. One acted as the anode and two as cathodes, producing an area of exposure equal to approximately 6 feet in width extending from the trailing edge of the cutting bar to the chain sweep. Rock and tickler chains were left in place. The dredge was tested by lowering it into the water and placing a lobster between the electrodes.

The dredge was then towed over sandy bottom during a two-day period. Paired tows were carried out by applying current during the first or second tow of the pair and leaving it off for the corresponding tow over the same grounds. Electrodes remained on the dredge for all tows. Tows were conducted on an inshore commercial scallop vessel, the F/V *Bantry Bay*, 300 HP, < 40 ft, homeported in Gloucester, MA.

Underwater Filming

Underwater footage of a scallop dredge was collected for several purposes: to capture the behavior of sea scallops and other species during pursuit by the dredge; to establish some understanding of the bottom impact of a standard dredge for comparison to experimental dredges; to investigate the attitude of the dredge during fishing. Footage was collected from an inshore 42-ft commercial scallop vessel, the F/V *Petrel*, homeported in Sandwich, MA.

V. Results and Discussion

Acoustics

Determination of Frequencies

Underwater engine noise was recorded on several dates between 27 January 2000 and 1 August 2001. A variety of manufacturers was sampled, including Evinrude, Honda, Johnson, Mariner, Mercury, Mercruiser, Seagull and Yamaha. Engine horsepowers ranged from < 10 to 225.

Attempts to identify common frequencies among engines were unsuccessful. Sonograms varied widely between manufacturers and changed based on engine RPM (Figure 1). Table 2 lists identified peak frequencies for thirteen different sound samples. These peaks ranged from 100 to 3700 Hz.

Sound Broadcasts

Bay and sea scallops were exposed to sound on ten different occasions, from 25 April 2000 to May 2001. Bay scallops and sea scallops were variously exposed to engine noise, recorded engine noise, and specific frequencies chosen from recorded samples. (Table 3). Reactions of scallops of both species never matched the intensity or frequency of the original reported reaction. Some scallops swam after being exposed to sound, but scallops were also observed swimming during periods of no exposure. Shell closings were frequently observed in apparent reaction to sound; some observations indicated that the frequency of shell closings was related to the broadcast volume. These observations are consistent with the hypothesis that mechanoreceptors in the scallops would be sensitive to a pressure wave produced by high volume.

Equipment was upgraded several times in order to increase the accuracy of sound reproduction. Also, the original outboard engine was used in areas of high bay scallop concentration. These attempts resulted in the same approximate level of reaction by scallops. None of the levels of reaction to any of the acoustic stimuli was sufficient to suggest that scallop dredges should be altered to exploit them.

The failure of bay scallops to react in the way that was previously viewed was puzzling. We duplicated the circumstances as much as possible, even using the same engine. It is possible that ambient sound levels are higher now than with the initial phenomenon was observed, and that bay scallops have developed less sensitivity to this type of disturbance. Long-term effects of exposure to noise have not been thoroughly investigated for fish, much less shellfish (Scholik and Yan 2001) although long-term exposure to sound can result in reduced sensitivity thresholds in fathead minnows *Pimephales promelas* (Scholik and Yan 2002).

Electricity

Reaction Testing

Height of the electrodes above bottom did not appear to cause any clear differences in scallop response (Table 4). An apparent difference was observed in the response time and type at different combinations of the four variables (wavelength, voltage, amperage and frequency). A combination of higher voltage and higher amperage resulted in more scallops (of both species) exhibiting a response. Administering of shocks held in the laboratories frequently resulted in clapping reactions from approximately 40% of scallops present. "Clapping" was defined as repeated opening of the scallop to full extension and closing. Testing in the field with previously unshocked scallops yielded similar results with both species.

Field Trials

The test lobster responded on all attempts. We interpreted this reaction as evidence of satisfactory function by the electrode array.

Four pairs of alternate tows were conducted on 4-5 April 2002 near Gloucester MA. Voltage was set at 88 VDC at 112 A in 0.2 MS intervals at 30 Hz. No difference was observed in the mean catch rates (electricity off: 232 lb/hr; on: 240 lb/hr). While these data do not show any improvement in dredge efficiency, the results should be viewed as inconclusive. These sample sizes were small due to the limitations of funding, and tows were conducted over identical grounds. A fully developed plan of testing would require more tows and could include the requirement that tows be conducted each time over new grounds. The tows that were conducted show an effect based on the order of tows. Of the four pairs of tows, all four of the first tows had higher catch rates.

Underwater Filming

Underwater footage of a New Bedford-style sea scallop dredge was recorded on 7 September 2000. Analysis of four hours of video indicates that sea scallops are not readily seen passing over the cutting bar; other species can be seen contacting the bar. Also, dredges appeared to ride heavily over sandy bottom, flattening humps and reworking sand into small ridges, and suspending sediment. The attitude of the bail of the dredge was angled off the bottom, so that the cutting bar and shoes provided the initial contact. However, the attitude of the bail was sensitive to engine speed, and could easily be altered.

Summary

Select frequencies, recorded engine noise and actual engine noise could not be used to recreate the original phenomenon that motivated this study. Reaction to noise was observed in both species of scallops, but at lower levels of intensity. The cause of the original, strong reaction remains unknown and unrepeated.

Direct electrical current caused reactions in scallops that were stronger than reaction to acoustics.

The technical aspects of rigging the dredge were solved and the use of electricity can be safe and practical. The effect on catch rates or efficiency of the use of electricity remains unresolved.

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VI. Products

This report is # 12 of the DMF technical report series. A redacted version is planned for publication in the DMF newsletter, distributed to thousands of recipients by mail and Internet. The video footage collected during this study is archived at DMF offices.

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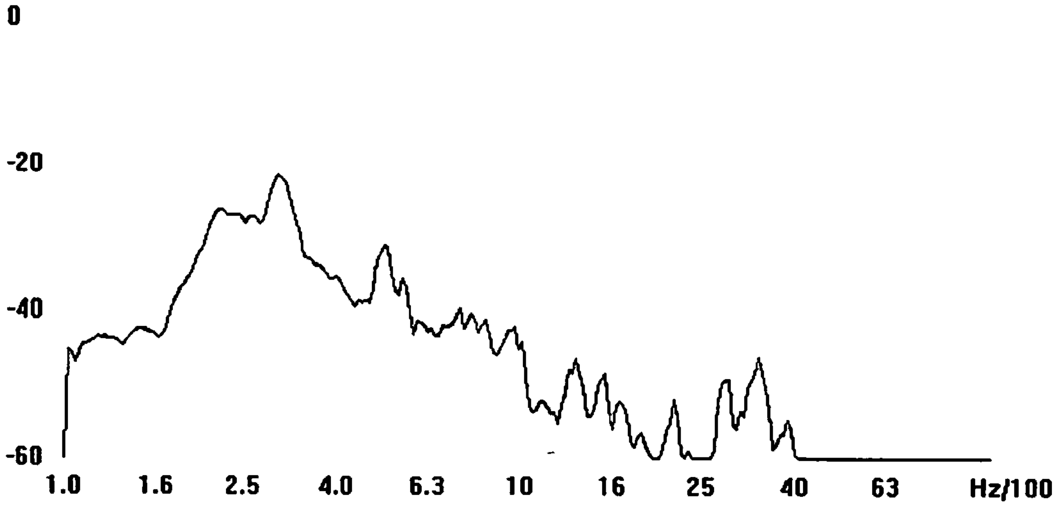
VIII. Key words: sea scallop; bay scallop; acoustics; electricity; impact reduction.



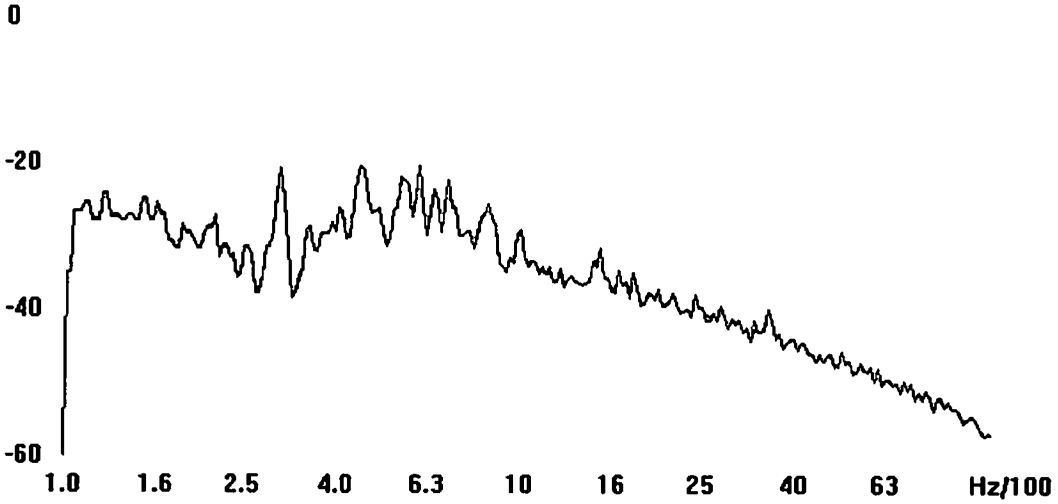


Figure 1: Two sonograms of outboard engine noise: the engine originally observed causing the movement of bay scallops (Seagull, above); and a Mercury outboard recorded opportunistically (below).

Table 2: Peak frequencies identified for thirteen different sound samples. Horsepowers are nominal.

Engine Type	Horsepower	Peak Frequencies (Hz)
Honda (twin)	90	111, 120, 156, 193, 226, 336, 426, 472, 503, 663, 811, 1012, 1238, 2034, 2489, 2937
Johnson (twin)	120	120, 135, 156, 279, 389, 532, 826, 2189
Evinrude	75	128, 171, 385, 434, 512, 811, 1021
Evinrude	75	112, 123, 171, 290, 395, 438, 527, 797, 819, 1021
Yamaha	115	117, 140, 167, 204, 279, 312, 365, 442, 494, 522, 616, 713, 804, 873, 1012
Mercury	90	102, 123, 183, 214, 245, 274, 309, 339, 368, 396, 430, 485, 727, 857, 1692, 3465
Mercury	200	102, 151, 176, 216, 267, 330, 389, 480, 639, 881, 1021, 1296,1602
Mercury (twin)	225	107, 162, 392, 489, 761, 857, 1012, 1308, 1692
Evinrude	225	113, 123, 151, 216, 301, 455, 557, 605, 651, 700, 857, 1012, 1502, 1788, 3529
Evinrude	225	102, 129, 210, 234, 274, 411, 541, 651, 811, 984, 10470, 1602
Mariner	150	106, 123, 216, 290, 336, 512, 811, 1012, 1383, 1631, 2937, 3465
Mariner	150	123, 161, 190, 241, 342, 467, 522, 639, 782, 842, 975, 1273, 1631, 3529
Seagull	?	147, 220, 295, 508, 552, 740, 975, 1333, 1544, 2189, 2857, 3340, 3869
Seagull	?	143, 195, 248, 389, 476, 639, 1408, 1631, 1890, 2356, 2779, 3340, 3798

Table 3: Summary of date, duration, location, species and type of sounds for acoustic exposure experiments.

Date	Days	Location	Species	Type of Sound
Apr-2000	1	Lobster Hatchery	Bay scallops	Rec. engine noise
May-2000	2	Marine Resources Center	Sea scallops	Rec. engine noise
Sep-2000	4	Lobster Hatchery	Bay scallops	Rec. engine noise and frequency generated
Sep-2000	1	Lagoon Pond	Bay scallops	Rec. engine noise, live engine noise, and frequency generated
May-2001	4	Lobster Hatchery	Bay scallops	Rec. engine noise and frequency generated

Table 4: Reactions of bay and sea scallops to electrical stimulation.

November Bay Scallop Lab and Field tests on Martha's Vineyard
1-2 minute respite between trials**

TRIAL #	Ht off bottom (in)	Separation (in)	Voltage Begin	Voltage End	Amperage Begin	Amperage End	Freq. (Hz)	Wave-length (ms)	Response	Species
1 aquaria	0	34"	56	46	54	44	4	2	30% of scallops clapping during duration of the exposure	bay
2 aquaria	0	34"	56	46	54	44	4	2	30% of scallops clapping during duration of the exposure	bay
3 aquaria	0	21"	56	46	54	44	4	2	same response	bay
4 aquaria	0	21"	56	46	54	44	4	2	80% clapping 5% swimming	bay
5 aquaria	0	21"	82	68	80	66	4	2	80-90% spinning and clapping	bay
6 aquaria	0	10"	82	68	80	66	4	2	80-90% spinning and clapping	bay
7 aquaria	0	10"	82	68	80	66	15	7	decrease in activity to 20% moving, weakly	bay
1 field	6	21"	56	46	54	44	4	2	30% spinning 5% swimming	bay
2 field	6	21"	56	46	54	44	4	2	30% spinning 5% swimming	bay
3 field	6	21"	56	46	54	44	4	2	30-40% spinning	bay
4 field	6	21"	56	46	54	44	4	2	same response	bay
5 field	6	21"	82	68	80	66	4	2	40-50% clapping	bay
6 field	0	21"	82	68	80	66	4	2	80-90% clapping 10%moved slightly vert. And about 8" horiz.	bay
7 field	0	21"	82	68	80	66	15	7	80-90% clapping 10%moved slightly vert. And about 8" horiz.	bay

December Sea Scallop Lab and Field tests in Woods Hole and Pocasset
3 minute respite between trials**

TRIAL #	Ht off bottom (in)	Separation (in)	Voltage Begin	Voltage End	Amperage Begin	Amperage End	Freq. (Hz)	Wave-length (ms)	Response	Species
1 aquaria	0	21"	128	126	64	62	5	6	40% clapping every 2-3 seconds	both
2 aquaria	0	21"	78	76	44	42	15	4	20% clapping	both
3 aquaria	0	21"	128	126	64	62	15	5	20%clapping	both
4 aquaria	0	21"	78	76	44	42	20	5	same response	both
5 aquaria	0	21"	128	126	64	62	20	4	10% clap in a weaker fashion	both
6 aquaria	0	21"	78	76	44	42	30	5	same response as above	both
7 aquaria	0	21"	128	126	64	62	1	5	weakening	both
8 aquaria	0	21"	128	126	64	62	30	5	overexposure??	both
9 aquaria	0	21"	128	126	64	62	1	10	lazily clap every 10 seconds	both
1 field	0	21"	128	126	64	62	5	6	40% clapping every 2-3 seconds	both
2 field	0	21"	78	76	44	42	15	4	40% clapping every 2-3 seconds	both
3 field	0	21"	128	126	64	62	15	5	40% clapping every 2-3 seconds	both
4 field	0	21"	78	76	44	42	20	5	40% clapping every 2-3 seconds	both
5 field	0	21"	128	126	64	62	20	4	40% clapping every 2-3 seconds	both
6 field	0	21"	78	76	44	42	30	5	40% clapping every 2-3 seconds	both
7 field	0	21"	128	126	64	62	1	5	two individuals swim one meter away and 40% of the others clap	both
8 field	0	21"	128	126	64	62	30	5	slower reponse and 20% respond	both
9 field	0	21"	128	126	64	62	1	10	same as last treatment	both