PAPER

Sea Scallop Harvest Gear: Engineering for Sustainability

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ABSTRACT
The Atlantic sea scallop is the most important molluscan shellfish species commercially harvested in the United States. The species is sought for the large, white circular adductor muscle (the 'meat') that holds the two valves of the animal together. In North America, the 'meat' is generally the only part of the scallop that is landed and eaten, although the meat only accounts for about a third of the animal's visceral weight. In 2004, U.S. landings of sea scallop meats totaled 29,374 metric tons. The value of the U.S. scallop harvest in 2004 ($321 million) was only exceeded by crabs ($447 million), shrimp ($425 million), and lobster ($344 million). Harvesting problems in the wild capture scallop fishery have a long history of being addressed with technical gear-related solutions. Recent advances include larger rings and twine tops, turtle chain mats, and changes to the drag frame. Management strategies and gear design must work together for sustainable fisheries.

Gear Background

Sea scallops were first harvested commercially in the United States along the coast of Maine in the 1880s using oyster dredges. These dredges had a handle or 'pull-bail' consisting of two iron bars joined together to form a towing eye. The dredge mouth, constructed of flat iron bars, was 1 m wide and 23 cm high. The dredge frame had bored holes to which a 'bag' was attached. The lower side of the bag consisted of iron rings (6-10 cm in diameter) to allow small scallops to escape, while the top and sides of the bag were made of twine netting. The dredge was commonly fished by two men from a small boat under oars or sail.

Dredge size increased during the next half century when motorized vessels outfitted with powered deck equipment entered the fishery. As local scallop beds became depleted, fishing effort was diverted further offshore and to 'hard' bottom areas where fishing operations required heavier and sturdier gear. By the 1940s, the standard New Bedford scallop dredge frame was already 3.3 m wide and 0.3 m high. A pressure plate was added to provide hydrodynamic force to hold the dredge on bottom when being towed at higher speeds. The bag, instead of being fixed to the bottom of the frame, was attached to a sweep chain that was fastened only to the ends of the frame. This modification allowed the sweep to follow the ocean bottom contours resulting in a cleaner, more productive catch.

The predominant gear used in the Northwest Atlantic scallop fishery today is still the steel dredge; sometimes more correctly called a drag or rake. Although there is no 'standard' drag design, two types of drags are generally recognized: the Digby-type dredge (also called rock or tumbler drag) used primarily in inshore waters along the Gulf of Maine and Canadian coast, and the offshore or New Bedford-type dredge (originally called the airplane drag) used by virtually all sea scallop vessels fishing in waters deeper than 40 meters. Construction details of early versions of the New Bedford drag are given in Smolowitz and Serchuk (1988).

The modern offshore New Bedford drag consists of a heavy steel bale welded to a rectangular frame. The bottom of the frame consists of a rectangular steel "cutting bar" which rests on steel-plated shoes. Attached to the top of the frame is a forward-angled pressure

FIGURE 1

The New Bedford drag with component parts.

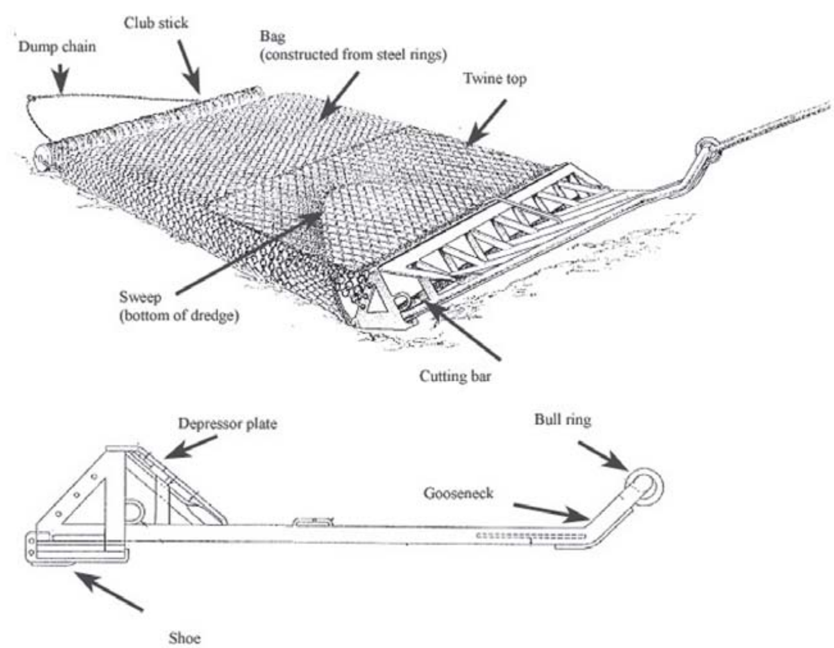


plate that acts as a depressor in keeping the dredge on bottom when being towed. At the bottom of the frame, fastened to the shoes, is the sweep chain. The lower portion of the collecting net (called the chain bag) is attached to the sweep chain. Also attached to the sweep chain are two triangular sections called 'diamonds'. The chain bag and 'diamonds' are all fabricated out of welded steel rings and links. The top of the collecting bag consists of a twine top, followed by a linked ring section called the apron. To the aft end of the net is attached a club stick which holds the bag's shape and facilitates dumping. Drag size, defined by frame width, within the offshore fleet is variable; most vessels use drags between 4 5 m wide.

Operations

Once on the grounds, vessels usually fish around the clock often towing two drags at the same time from hanging blocks suspended in gallows frames on each side of the vessel. Tow duration depends on bottom type and scallop density but most tows are between 30-50 minutes long. Typically, the gear is towed at 4-5 knots using a 3:1 scope (warp length to water depth).

The crew hand-sorts and culls the catch. Scallops and marketable fish are removed from the catch piles created when the drag contents were dumped on the deck. Marketable-sized scallops are placed in baskets and emptied into shucking boxes in the 'shucking houses'. To prevent spoilage, scallops are usually shucked at sea. The muscle meat is separated from the shell and viscera, washed in sea water, packed in 20 kg linen bags, and stored with ice in the hold. Some vessels are packing and freezing the scallops at sea.

There have been many issues associated with commercial fishing gear in recent years as we move towards more sustainable fisheries (Smolowitz, 1983). Important objectives to scallop gear operations include increasing the size of scallops retained in the gear, preventing damage to scallops not ready for harvest, avoiding mortality to unwanted fish species, mitigating any adverse impact to habitat, and reducing risk to threatened and endangered species.

Selectivity

Minimizing the harvest of small sea scallops has always been considered a desired goal for the fishery. Maine fishermen in the late 1880s were known to return small non-marketable scallops to the water if caught and utilized sufficiently large rings in their dredges so that small scallops passed through unharmed (Smith, 1891). As a caveat to developing the Mid-Atlantic fishery, arising from the discovery of prolific scallop beds by the R/V Grampus in 1913, it was stressed that all small scallops be returned to the water (Welsh, 1914). However, prior to the early 1960s the conservation benefits associated with any practices and procedures in the scallop fishery were largely unknown. As such, marketing preferences and anecdotal beliefs about gear performance and resource sustainability were, until mid-century, the most influential factors affecting fishery behavior.

Localized depletion of scallop beds, the successful development of 'savings gear' for groundfish (i.e., increased cod-end mesh sizes, Herrington, 1935) and for lobsters (i.e., widened lath spaces, Wilder, 1949), and frequent evasion of scallop minimum size regulations (Medcof, 1952) prompted research in the 195's and 1960s aimed at eliminating the capture of undersized scallops through gear modification. The most obvious approaches were to evaluate the effects of increased ring sizes and increased ring linkages. Beginning with the Canadian efforts in the early 1950s, ring size selectivity experiments have been conducted for nearly five decades. Over this period, field testing of various combinations of ring sizes (ranging from 67-127 mm inside diameter) and ring linkages (14 links coupling the rings) has been accomplished using both alternate-haul and paired-tow procedures (Posgay, 1958; Bourne, 1960, 1964, 1966; Caddy, 1971; Smolowitz, 1979; Serchuk and Smolowitz, 1980; Smolowitz and Serchuk, 1987; DuPaul et al., 1989) .

In total, the results from these studies have been equivocal; some experiments found virtually no change in selectivity when ring size was increased, while in others, sharp differences in ring-size selectivity were apparent. Such variability is not totally unexpected given the large number of biotic and abiotic factors (apart from gear modifications) that can affect selectivity and gear performance (Pope et al., 1975; Caddy, 1977). As a group, the experiments tend to suggest that selectivity is a course function of ring size and rink-linkage (inter-ring spacing), but that other factors such as bottom type, scallop density, and quality and quantity of trash markedly affect selection as well. Still unclear, however, is when during the tow and in which portion of the dredge most selectivity occurs.

Functionally, mechanical selectivity is thought to be most effective at both the beginning of the tow, prior to trash build-up and during haul-back when scallops are washed out of the ring bag. In truth, depending on where and how the drag is being fished, selection may occur at various places within the drag and at various times between set-out and haul-back. Although underwater camera, scuba diver and submersible observations have enhanced our understanding of drag performance and scallop behavior, much remains unknown about the operational and selectivity characteristics of scallop gear. Given the variable results from the experiments already performed, development of an effective 'savings gear' for scallops may require looking at gear design from scratch.

Improving gear selectivity, by itself, will not insure that harvesters freely adopt *any* changes in technology unless profitability is maintained or increased. Gear designs that reduce the capture of small scallops (particularly when such scallops are landed and sold) without also increasing the catch of largersized scallops will not be readily accepted since significant short-term losses in catch and revenue are normally incurred. While this reaction is understandable, it is regrettable that so much attention was focused on short-term impacts and so little on long-term benefits. In retrospect, the fundamental problem can be the management system in place; for example, a system based on scallop size without controls on overall landings.

Due to the rapid growth rate of sea scallops, catch reductions would be short-lived; the increased escapement of small scallops (< 89 mm) would, within 6-12 months, generate gains in the overall catch of larger-sized scallops. This was well-understood by industry but the specter of eliminating large quantities of small scallops from being caught and sold was too much for a fishery dependent on incoming recruitment. Under conditions of high effort and low cull size with all areas open, it was economic inertia, rather than technological barriers, that constrained fishery acceptance of 'savings gear' designs. This lesson is apt to be as true for finfish and other shellfish fisheries today as it had been for scallops.

However, with the development of scallop rotational area management, with limits on total allowable catch (TAC), a new paradigm has been struck. Scallops are left in closed access area to grow to sizes in excess of 100 mm. When these areas are opened for controlled access trips the scallops present are mostly large and in dense concentrations. Harvest is more constrained by possession limits than by fishing time in most cases so the loss of smaller scallops is not as important to the fisherman's catch as in the past. The 102 mm ring size is now regulation.

Incidental Mortality

Apart from mortality resulting from the actual capture of scallops, it has long been recognized that scalloping operations induce additional mortality to scallops and other species that are either not caught or landed. This non-yield, indirect mortality may result from mechanical processes (ie., injury to species physically encountering the gear during fishing; crushing/damaging species due to dredge passage over animals on the bottom; shell breakage of scallops compressed within the dredge itself) or on-deck handling and culling procedures (i.e., dumping of catch from the dredge; prolonged air exposure on deck during sorting and culling; shoveling of undersized scallops overboard). Also, alterations to the sea bottom by the gear (i.e., churning up sediments; dislodging sand/mud into scallops) may weaken animals making them more susceptible to predation, kill them outright, or reduce the favorableness of the habitat for scallop survival, spat settlement, or reproduction.

From a gear design and conservation perspective, it is essential to quantify the magnitude of these impacts. Less destructive harvesting equipment is critical if the fishery is to survive and prosper. To date, only a few studies have addressed incidental mortality putting it in the range of 5-31% (Caddy, 1973; Naidu, 1988; Murawski and Serchuk, 1989). These studies noted that scallop damage was more frequent on rough bottom than on smooth bottom.

Little has been accomplished in improving scallop gear design to reduce incidental mortality. It is possible that if the belly of the dredge were raised slightly off the bottom that gearinduced mortality of scallops passing under the sweep chain or through the belly meshes would be reduced. This idea merits further consideration. Underwater observations of scallop gear indicate that when the cutting bar of the dredge rides several centimeters above the substrate the sweep chain passes over scallops and inflicts little damage. Research studies have been conducted to redesign the shape of the cutting bar to create sufficient hydrodynamic force to lift scallops from the bottom into the dredge. This type of innovation is attractive because it would increase capture efficiency while reducing incidental mortality.

The early scallop dredges, lacking sweeps, did not normally catch large rocks since the frame opening height limited entrance into the dredge proper. The problem has been addressed effectively by adding rock chains to the dredge gear. By running a series of tickler chains athwart the dredge opening connected by a series of 'up-and-down' chains, the size of the opening between the sweep and the dredge frame is markedly reduced, the captures of rocks lessened, and overall dredge efficiency maintained or even increased. Generically, the entire chain rig is referred to as rock chains.

Habitat Impact

The effects of towed gear on the bottom habitat and its potential for impacting the entire food chain is probably one of the most important issues related to fishing gear, as well as the least understood. It is commonly accepted that habitat impact is related to the substrate type, sediment size, current velocity, the organisms present, and the gear being used. The gear parameters are thought to include gear type, weight, and frequency of use. What is not very well known is the long-term impact on an ecosystem that undergoes continual disruption by towed gear.

There is evidence indicating that fishing can change the species complex in an area, not only by altering the physical habitat, but also by selectively destroying sessile organisms that occupy the habitat. The destruction can be due to harvesting and subsequent removal of sessile species, sediment re-suspension, mechanical contact with the gear, or physical movement of substrate. In most cases, however, it is still difficult to separate out the long-term impacts of fishing from natural processes and other anthropogenic impacts. Insidiously, the act of fishing may keep ecosystem production depressed, but undetectable, by chronic sub-lethal effects on reproduction and feeding.

Scallop drag impact on habitat may have to do with the amount of repeated tows, or fishing effort, to which a particular area may be subject. Areas vulnerable to bottom contact gear may see a change in benthos composition, but to what degree depends on the distribution of fishing effort in the vicinity (Rijnsdorp et al., 1991). Mobile bottom gear may also place into suspension sea bed particles which are moved and re-deposited. How this compares to similar natural processes, such as storms and currents, is still an unanswered question. A significant reduction in potential adverse habitat impact has been achieved by the rotational area management system in that it has resulted in much higher catch rates thus less bottom time.

Fish Bycatch Reduction

Historically, there had been no research conducted on how to decrease fish bycatch in New Bedford-style scallop gear. We do have some underwater video observations of an eight-foot wide New Bedford drag, recording the behavior of several species of fish to the gear, on different bottom types. Based on these observations the best approach might be to deter and guide fish away from the front of the drag. It may be viable to physically block fish entrance into the drag and/or provide means for their escape once in the drag. It must be noted that New Bedford-style scallop drags fish differently depending on bottom type thus extensive testing may be required.

One other important point that should be mentioned is that modifications made to a drag to keep swimming fish from entering, may also decrease the catch of small scallops. Small scallops, under 80 mm in shell height, are active swimmers and have shown flight responses from drags. Modifications to elicit escape responses in fish may therefore improve drag size selectivity for scallops.

Fish bycatch reduction in scallop drags has been a major focus of study by Coonamessett Farm and Virginia Institute of Marine Science Sea Grant Program (VIMS) with input from the Massachusetts Institute of Technology Sea Grant Program, from 1994 to the present. Gear modification designs and fabrication were carried out in consultation with experienced scalloping captains and other knowledgeable members of the fishery.

Field trials during 1996-97 tested 254 mm diamond-mesh twine tops and 203 mm square-mesh twine tops against the then standard 140 mm diamond-mesh twine top in use by the fishery. These larger twine tops produced strong to highly significant reductions of Yellowtail Flounder (26-62%) and similar reductions on other fish bycatch species with only a minor loss of sea scallops. By 2005, the managers of the scallop resource required 254 mm twine tops on all scallop drags in all areas.

During 1999, field trials tested a number of drag modifications, including fish sweeps and blocking mesh, provided positive bycatch reduction results and experience on gear modification techniques. Before this work could be further developed, a sea turtle interaction problem arose and gear development efforts were re-directed.

Sea Turtle-Scallop Drag Interaction

Until 2000, there was very little concern that there were interactions between scallop drags and loggerhead sea turtles. In December, 2000, a NOAA Fisheries informal Endangered Species Act Section 7 Consultation concluded that "...there was little overlap between the scallop fishery and foraging turtles due to the difference in depth and water temperature preferred by sea turtles and scallops. However, during the summer of 2000 scallop captains started to report that they were seeing loggerhead sea turtles where they had rarely, if ever, seen them before and that some were coming up to the sea surface inside or on top of the scallop drags.

Loggerhead sea turtles are distributed around the globe in temperate and subtropical areas and there are thousands of sightings from the Mid-Atlantic shelf area in the depth range where the sea scallop fishery historically operates. Most of the scallop fishing takes place in depths deeper than 40 m while most of the turtle sightings were in areas with depths of 22-49 m (Shoop and Kenney, 1992). Our general knowledge of turtle biology and behavior would indicate that loggerhead turtles prefer temperatures found in the warmer surface waters, not in the colder bottom waters where the scallop drags operate.

During 2001, the NMFS observers recorded 11 encounters between sea scallop vessels and loggerhead sea turtles in the Mid-Atlantic (5286 observed hauls). The observed take, when expanded to appropriate fleet effort, provided an estimate of 95 turtles taken. In comparison, high observer coverage in recent years on Georges Bank has not recorded any loggerhead turtle interactions. In 2002, over 20 turtle takes were reported for 72 observed trips into the Hudson Canyon Closed Area located in the Mid-Atlantic region. In 2003 similar take rates were observed in other areas of the Mid-Atlantic as well resulting in a take estimate for the entire scallop fishery of 749 animals (Murray, 2004).

Clearly, loggerhead turtles and scallop drags were starting to have significant interactions. The uncertainty was how and why. Sea sampling reports that had been made public indicated that the turtles had been found wedged into forward parts of the drag frame or in the bag where they had been damaged by rocks and/or the drag frame. In addition, the turtle takes were being observed in a very limited geographical area when compared to the range of the sea scallop fishery. There were all sorts of theories on where the interactions were occurring in the water column.

Immediate attention was focused on how to reduce the bycatch mortality. There are three generally accepted methodologies for reducing bycatch-related mortality; gear design and operational changes, improve handling of the bycatch species, and separating the species of concern in time and space from the gear (fishery).

A gear change that the industry thought would work well was to increase the number of up and down and tickler chains between the sweep and drag frame. This turtle chain mat, designed by Coonamessett Farm, has the effect of preventing turtles from entering the bag while fishing on the bottom or during hauling and setting; an opportune time to catch anything big in the water column. A series of fifteen experimental cruises were carried out during the summer and early fall of 2003 on the continental shelf waters of the Mid-Atlantic Bight. These cruises demonstrated that the turtle chain mat can be effective in eliminating the incidence of turtle bycatch without substantial reductions in scallop catch (Dupaul, Rudders, and Smolowitz, 2004).

While turtle chain mats have been shown to be effective in reducing the take of turtles, there are still unanswered questions on how or why turtles might be interacting with sea scallop drags during a tow. It is not known if turtles are still encountering chain-equipped drags or whether the noise of the chains is creating an avoidance behavior. Since turtles have not been observed on top of chained drags, a typical mode of encounter, the avoidance theory has merit.

There is very little data on the actual precise geographic location of the turtles in real-time and little understanding of their bottom foraging capabilities on sea scallop grounds (temperature and turtle species behavior are key). Some turtles continue to migrate through the interaction area as the season progresses; others seem to remain in one area for the season. These factors indicate that to maintain scallop fleet/turtle separation would require a fast action notification system with full participation of the scallop fleet/observers. This is costly as a regulatory system and would be a least preferred approach to control bycatch.

Another unanswered question is the frequency of encounters with drags with or without chains. Scallop fishermen reported very few encounters with turtles until recent years and then the turtles were there in numbers.

The explanation of why there may be such a sudden increase in encounters must go beyond the possibility of a steady increase in turtle populations to some other factor. A change in distribution due to oceanographic conditions does not seem to be the answer. One hypothesis is that it is related to the density of scallops and the act of scallop fishing. A vessel fishing on a dense bed of scallops does not move around much thus its discharge of scallop viscera remains concentrated in the relatively small area the vessel is fishing. This may attract turtles.

Turtle Chains

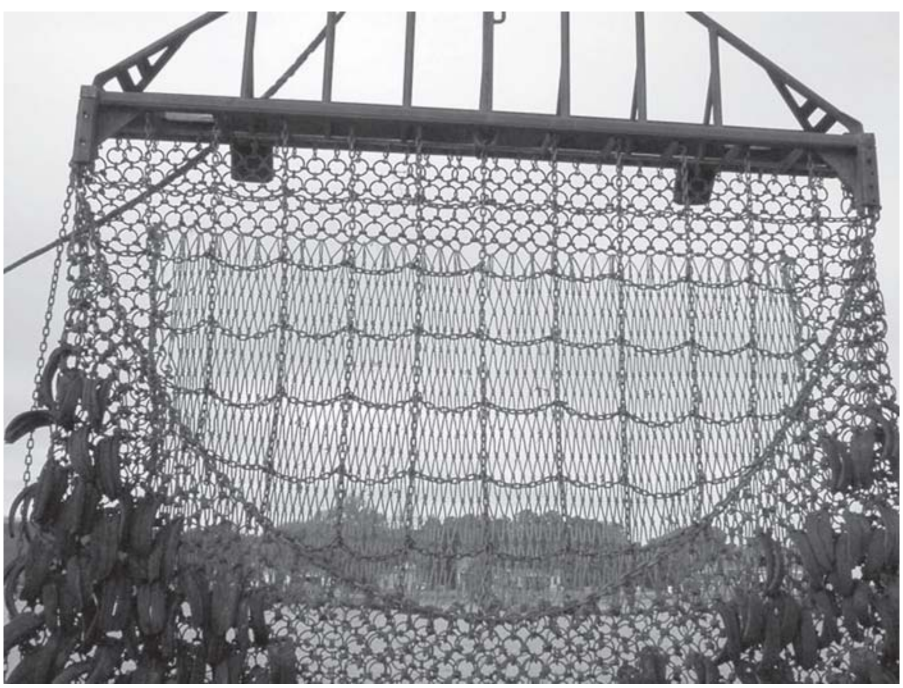
The scallop fishing industry has been very proactive in trying to solve the sea turtle interaction problem. The industry has worked with Coonamessett Farm and VIMS to develop vessel placards describing how to reduce interactions, procedures for attending captured turtles, and instructions on how to rig drags with turtle chains (Figure 2).

In designing turtle chains we adhered with the following key criteria: the materials used were common in the fishery and readily available, maintenance would not be a significant issue, the modifications were easily enforced, and that costs were acceptable to the industry. Fishermen were already experienced with the rigging and use of rock chains. Operationally, the turtle chains are similar with the differences being the chain material and details of hanging. We overcame the latter problem by working with industry to produce a laminated vessel card detailing the rigging. We overcame problems associated with using a lighter chain by specifying a much stronger, albeit more expensive, hardened grade 70 chain. This chain does not stretch or wear to the extent found with the traditional grade 30 chain. Many vessels are already using the turtle chains on a voluntary basis when the industry called for its mandated use in 2004. Finally, in September 2006, the use of turtle chains became mandatory.

The key remaining question with turtle chains is whether or not turtles are encountering the drag rigged with turtle chains and have injuries resulting from encounters. During the turtle chain tests no turtles were found on top of the drags, a common mode of capture, indicating that possibly the noise generated by the chains may decrease encounters. There is no evidence that the rate of injury due to encounters would be different between drags rigged with or without chains. Related to the rate of encounters and injury question is the issue of where in the water column the encounters are taking place and what factors may be causing the encounters.

FIGURE 2

Turtle chain mats are rigged over the opening that exists between the sweep chain and the drag frame, effectively preventing turtles from entering the gear.



Ongoing Research-Excluder Frames

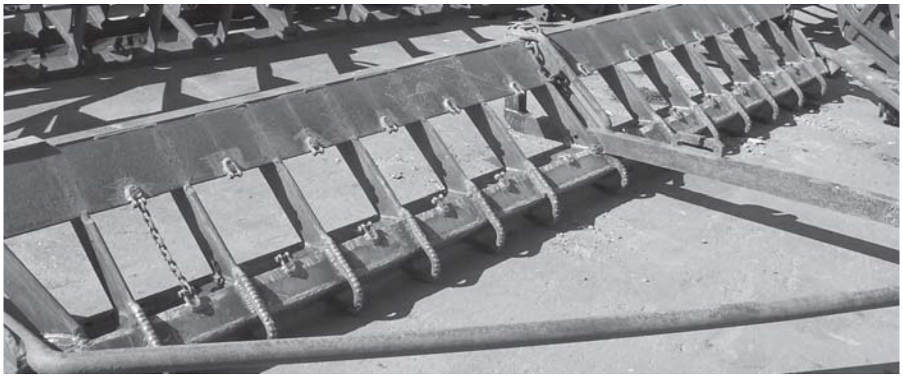
While turtle chains prevent sea turtles from getting trapped inside the drag there needs to be a frame modification to prevent entrapment on top of the drag. When a sea turtle encounters the drag it either passes underneath the drag or over the top of the drag. We still do not know if these encounters take place while the drag is on the sea floor or up in the water column (during setting and haul back). If the sea turtle passes under the drag frame on a drag that is not equipped with turtle chains it stands a good chance of being caught in the drag bag.

If the turtle passes over the top of the front part of the drag frame, known as the bale, it can get caught in the space between the depressor plate and the cutting bar. Fishermen, and NMFS observers, have witnessed this form of entrapment on numerous occasions. Usually, when the drag is stopped during haul back alongside the vessel the turtle can be seen to swim away unharmed. However, many times the turtle is lifted up aboard the vessel and falls on the deck and becomes injured.

Recently, Coonamessett Farm designed a new drag frame modification that comes out of years of experience working with scallop drags. Frame alterations can have significant effects on catch and bycatch rates. In previous work, to reduce fish bycatch, we have altered the design of the bale so that it extends forward of the main frame eighteen inches before tapering toward the hauling point (bullring). This allowed us to test sweeps and blocking over the entire drag width. Blocking is an approach used to prevent fish from entering the drag from above the cutting bar and below the depressor plate. We have investigated blocking this space with rope, mesh, steel scallop rings, and 1-inch bar stock but have found these materials do not hold up to the rigors of scallop fishing.

FIGURE 3

The new excluder frame design eliminates potential turtle entanglement by providing a clear pathway over the gear while minimizing the possibility of a turtle going under the gear. This drag design has also shown promise in reducing finfish and skate bycatch.



The new frame design is a significant departure from existing designs in that the cutting bar is moved forward of the depressor plate so that instead of confronting a vertical structure, a sea turtle or large barndoor skate, encounters a sloping structure (Figure 3). The design then increases the width of the depressor plate and extends the struts, at twelve inch spacing, between the depressor plate and the forward positioned cutting bar. Thus a sea turtle can not get trapped in this space and is gently guided over the drag.

The new modifications to the drag frame will not require any changes to the handling and operation of the drag as there will be no alteration to the frame length or width. However, the hydrodynamics of the drag will probably change and only field testing will determine the impact on catch of these changes. Preliminary trials indicate the changes to the bale design discussed above have increased the drag efficiency on scallops by 10-20%.

A gear solution to the problem of sea turtle interactions with scallop drags has significant beneficial economic consequences to the individuals that make up the scallop industry. The only regulatory alternative to gear modifications is seasonal area closures. Since the sea turtle scallop fishery interaction takes place over a long season (June through October) and over a vast area (Cape Hatteras to Southern New England) the closure approach would have devastating economic consequences. Many vessels that fish in this area are too small to travel to the scallop areas on Georges Bank. The closure would force the vessels capable of fishing Georges to all focus their fishing effort on Georges Bank and thus create significant problems related to scallop management and groundfish bycatch issues. A gear solution would allow optimum utilization of the scallop resource and the associated profitability.

Conclusion

Worldwide environmental interests are focusing on marine fisheries. In response, the United Nations FAO has issued a Code of Conduct for Responsible Fishing. Member nations are required to examine the environmental aspects of their fisheries including impacts on the sea bed, ecology, and bycatches.

Fishing gear specialists from around the world meeting as an FAO Ad Hoc Working Group defined selective fishing as "The ability to target and capture fish by size and species during harvesting operations, allowing by-catch, i.e. small (or juvenile) fish and non-target species to escape unharmed. Furthermore, selectivity means abandoning the traditional emphasis on quantity and making a definite shift to sustainable harvesting practices. It means catching targeted fish, allowing the escape of those fish that are not wanted, as well as turtles and marine mammals, in a condition that they can survive, thus reducing overall pressure on the marine resource."

In the U.S. scallop fishery, rotational area management was a prerequisite for achieving success with gear modifications. There has been more conservation oriented gear changes in the last few years than during the entire previous history of the fleet and the research continues.

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