

REFERENCE SECTION

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Turtles and Other Non-Target Species on Hook Gear

REFERENCE #: A001

Rollefsen, G. 1953. The selectivity of different fishing gear used in Lofoten. J. Cons. Cons. Int. Explor. Mer. 19:191-194.

B. History and statistics

"The oldest of the fishing gears still in use in Lofoten is that employing a single hook - a handline furnished with a heavy stone or iron sinker and a special device to keep the hook free of the line. The hook is fairly large and has a bright coating of cast lead or pewter in the form of a small fish, and, as a rule, a piece of white fish-skin is fastened to the hook." p. 191

"The longline, which was introduced to Lofoten in 1580, carries a large number of hooks baited with herring or mussels. The line may rest on the bottom or be kept at a certain depth by means of floats. The success of this gear also depends on the activity of the fish." p. 191

"The use of nets in Lofoten dates from about 1650. A varying number of nets are joined to form a fleet. The nets may be used as bottom nets or float nets anchored to remain a certain distance above the bottom. The meshes of the nets are of a size corresponding to the average size of the fish. However, as the average size of the fish may change from year to year the fishermen...try to choose a mesh width in accordance with their experience of the preceding year." p. 191

C. Selectivity

"The sex ratio for hooks is 40% males to 60% females; for nets it is 60% males to 40% females. It is obvious that the male cod is much more active than the female during the spawning time. From observations in aquaria we learn that it is the male cod which is the more aggressive. Accordingly the activity of the male sex may be the reason for the high percentage of males caught by net. On the other hand, a female fish just hovering about, with no fixed aim, no pronounced urge, may very well not only avoid the risk of running into a net, but also have time to investigate objects which might be edible. This may be the reason why the females are more frequently found on lines." p. 192

"The purse seines used in Lofoten work in the usual way, except that they are lowered to a depth of 20-30 fathoms below the surface ... The gear takes no account of whether the fish is hungry or dejected, male or female, or whether it is large or small. The circular curtain of the purse seine sinks down and cuts out a portion of the shoal of fish and brings it up without any prejudice as to sex or size. But we have to bear in mind that the fish may have a tendency to stratify or segregate themselves with respect to size, sex, or stage of maturity. Our confidence in the purse seine catches is... strengthened by the fact that the sex ratio in them seems to be 50-50." p. 192

"If we compare the relative number in each length-group of fish caught by line and purse seine, we find that the lines catch 5 times as many cod belonging to the 70 cm group as the purse seine, and twice as many fish of 80 cm length. The smaller size-groups have a very pronounced tendency to be caught on longlines, while on the other hand the larger size-groups are under-represented in line catches compared with those from the purse seine." p. 193

"The tendency of the cod to be caught by line decreases with increasing number of spawnings and the fish seem to be able to keep clear of the nets more and more effectively." p. 194.

F. Management issues

"The purse seine has demonstrated the existence of a group of fish which has been naturally protected against longlines and nets by their large size and by their behaviour. It will be very interesting to follow the fate of this reserve of old fish in the years to come, now that we have introduced gear which apparently takes a heavy toll of these as of younger fish."

REFERENCE #: A002

Rhule, P. 1969. Longlining for swordfish. New England Marine Resources Information Program, Publ. No. 4. 8p.

A. Gear Construction and Operation

"The lines are suspended from buoys, each buoy line being about 5 fathoms long. In the summer when fish are swimming high in the water, the buoy lines can be shortened to 2.5 fathoms but this is dangerous for passing steamers which can cut the lines. The hooks are attached to gangings or snoods about 3 fathoms long. Usually 5 snoods are attached, 10 fathoms apart, between the buoy lines. The maximum number of hooks between buoys is 10."

"Marker dhans or poles fitted with radar reflectors should be attached to the line, at least one every 1/2 mile or 3/4 mile. The higher the radar reflector, the further it will be seen, and the closer the dhans are to each other, the less line will be lost."

"One of the best kinds of bait is Boston mackerel of about 1 lb. in weight. It is possible to fish with mackerel of less than one pound but those under 3/4 pound are of no use. They will not take swordfish."

D. Incidental Fishing Mortality

"Blue sharks are fairly small (under 200 lbs) and tend to prefer the colder water (48-60 deg F). In the spring they are moving inshore and one should try to set the lines behind them i. e. to seaward. By mid-June most of the blue sharks will have moved inshore and the problem thereafter is to stay ahead of the brown sharks which prefer the warmer water. The brown sharks are very large and can cause considerable damage to the hooked swordfish. Mako sharks also attack hooked fish. If a shark is caught on a hook, the best procedure is to cut the snood and let both hook and shark away. This enables you to haul faster when sharks are biting."

"Setting usually commences just as the sun hits the water. One should avoid setting earlier as the sharks bite well in the late afternoon. Also if the sharks hit the line soon after setting, they may sever it and the broken portion can drift a long way before morning."

REFERENCE #: A003

Forster, G.R. 1973. Line fishing on the continental slope- The selective effect of different hook patterns. J. Mar. Biol. Ass. U.K. 53: 749-751.

C. Selectivity

This is a brief report covering the results of several sets made with a 100 hook longline in 800-3600 m in the South Biscay area continental slope. An incurving hook design was compared to a normal hook design. Of 14 species caught, seven were in sufficient numbers to make a comparison.

Equal catches were made, between the two hook designs, of large elasmobranches (*Centrophorus* sp.). However, the incurving hooks caught more of the smaller species of elasmobranches, and more of two gadoid species, *Mora moro* and *Antimora rostrata*.

"For the incurving hook to function there must be some slack in the line or snood, allowing the fish to move away with snood trailing. At the end of the slack the fishes head is pulled around and the hook (providing the point has engaged) makes a half turn usually in the corner of the mouth. Once one of these hooks is engaged it is very difficult for it to be shaken out."

D. Incidental Fishing Mortality

"The skin covering of the lower jaw of some deep-sea fish is rather delicate. After several hauls a number of *Mora* and *Antimora* were picked up floating at the surface having become detached from the line shortly before the end of hauling. These fish all had a slit of 2-3 cm length in the skin of the lower jaw; they had presumably become freed from the hook by the irregularity of the hauling rate caused by the role of the ship; also near the surface rapid expansion of the gas from the swim bladder makes the fish positively buoyant."

REFERENCE #: A004

Ferno, A., S. Tilseth, and P. Solemdal. 1977. The behavior of whiting (*Gadus merlangus*) in relation to longlines. ICES C. M. 1977/B:44. 11p.

A. Gear Construction and Operation

Eighty-nine percent of the fish that were attracted to the baited hooks swam against the current.

C. Selectivity

The reaction of fish to longline hooks was observed using underwater TV. This series of experiments observed two Mustad No. 8 and two No. 10 hooks on 40 cm long snoods spaced 40 cm apart. One hook of each type was blunted and the other sharp; they were baited with mackerel.

In this study two periods of high activity were observed; 6 to 10 am and 7 to 10 pm. When several fish were hooked there was more activity than if no fish were hooked. "The sharpness of the hook did not significantly influence the hooking probability, but a small hook (#10) was about twice as effective as a bigger hook (#8)." Whiting seemed to increase each other's activity through competition. Cod were seen chasing away whiting, thus the authors speculate that the presence of one species may influence the catch of another.

D. Incidental Fishing Mortality

Out of 53 whiting that were hooked in the experiment, six broke loose and two were lost during hauling. "Thirty-eight fish were hooked in the mouth and seven fish had swallowed the hooks."

Cod were observed biting at hooked whiting.

REFERENCE #: A005

Ralston, S. 1982. Influence of hook size in the Hawaiian deep-sea handline fishery. *Can. J. Fish. Aquat. Sci.* 39: 1297-1302.

C. Selectivity

"Experimental bottom fishing trials were conducted in the Northwestern Hawaiian Islands where four different hook sizes (Nos. 28, 30, 34, and 38) were fished simultaneously. Within this series the biggest hook is about 71% larger than the smallest hook. Alterations in gear within this range have no substantive effect on the catch of bottom fish. In all cases examined, variation in catch statistics associated with differing replications (days and sites) greatly exceeded any effect attributable to different hook sizes. It is concluded that for medium- and large-sized fish, the catch is reasonably representative of those fish which strike the hooks and that a sigmoid selection curve most accurately describes the selective properties of the gear in this fishery." Abstract.

The author reviews hook selectivity literature that supports two possible representations of hook selectivity; dome-shaped selectivity curves similar to that for gill nets and sigmoid-shaped selection curves similar to that for trawls.

This experiment caught 1110 fish, mostly opakapaka and snappers. The mean size of opakapaka caught ranged from 37-61 cm. The variation in hook size had no impact on bait retention.

The sigmoidal-shaped curve best represents the selection process in this experiment since there was little differential sampling of the larger fish while the small hooks seem to be more effective at retaining smaller fish.

The author uses an index which measures the size range of hooks by forming a ratio of the largest hook/smallest hook; hook size being the product of hook length and width. If hook sizes are significantly different, the size composition of the catch must ultimately vary. This explains why in some cases researchers reported seemingly different selection results.

REFERENCE #: A006

Ferno, A. and I. Huse. 1983. The effect of experience on the behaviour of cod (*Gadus morhua* L.) towards a baited hook. Fisheries Research 2: 19-28.

C. Selectivity

The authors present some evidence that fish can learn hook avoidance. The results include a number of identified behavioural patterns. Cod that have been held in tanks are tested individually in an experimental tank with a single baited hook. Their behavioural patterns were recorded in 134 trials.

"The experimental cod showed a decrease in the intensity of the response after experience with a baited hook whether or not the fish was hooked. The decreased intensity could be caused by conditioning- biting the hook could act as a negative reinforcement to the cod in the same way as a stickleback's spines induce cessation of feeding response in pike or perch." "...in experiments with baits attached with a string instead of a hook where the fish movement was similarly restrained, no decrease of response intensity was found."

Different degrees of response were noted over the time of the experiment which was related to the seasonal change in cod feeding response.

The authors conclude that cod do learn and this probably affects an individual's vulnerability to hooks for at least a period of time. Referencing a study where cod catches on monofilament longline were 40-300% higher than on multi-twine line the authors postulate that "It is possible to explain this difference with a learning process in the fish. If both types of lines are attacked equally often initially, the more visible multi-twine line could be more easily recognized by a conditioned fish and therefore more effectively avoided."

Regarding hooks that curve inward..."This hook shape may decrease the probability that a fish comes into contact with the point of the hook and thus experiences aversive stimulation when biting which in turn could lead to a greater number of strong responses and higher percentage of hooked fish. Such an effect could combine with a higher hooking probability when fish rush on a bent hook as opposed to a straight hook."

REFERENCE #: A007

McEachron, L.W., J.F. Doerzbacher, G.C. Matlock, A.W. Green, and G.E. Saul. 1988. Reducing the bycatch in a commercial trotline fishery. Fish. Bull. U.S. 86: 109-117.

D. Incidental Fishing Mortality

"Trotlines are a specialized longline used in shallow (<4 m) Texas estuaries to catch fish...Red drum, *Sciaenops ocellatus*, and spotted seatrout, *Cynoscion nebulosus*, were the primary targets until 1981 when their sale was prohibited because of overfishing...The effort has since been redirected toward black drum, *Pogonias cromis*." Regulations requiring the use of circle hooks were placed into effect but a bycatch still occurred.

The year-long experiment took place in two locations, used three different baits, and had the hooks either on the bottom or suspended in the water column. Details of the gear and illustrations of the setting are provided. Twenty species were caught, totalling 4324 fish.

The results show that bottom set hooks reduce the bycatch without affecting the catch of the target species, black drum. "Catch rates for hardhead catfish, red drum, spotted seatrout and total fishes were significantly lower on bottom trotlines." Sight feeders, such as spotted seatrout, probably do not take baits laying on the bottom as readily as baits suspended in the water column.

F. Management Issues

"Management objectives could better be met by requiring placement of trotline hooks on bottom than by allowing hooks to be fished from the surface...Operational efficiency of commercial fishermen should improve with less handling of non-target species. Mortality of non-target fishes would decrease because they would not be caught and subsequently handled."

REFERENCE #: A008

Way, E. 1988. Comparative fishing trials of moored monofilament longlines-feather hooks vs baited hooks- conducted in Newfoundland-1988. DFO Fish. Devl. Div., St. John's, Newfoundland. 11p.

A. Gear Construction and Operation

The gear consisted of 400 lb test monofilament groundlines, with snood lengths of 20 inches, to which 80 hooks (#15) were attached with a spacing of 42 inches. Five to six lines were attached for total longline lengths of 250-300 fathoms. Greater hook spacing (78 inches) was used during part of the experiment.

The feathered hooks were made by affixing red polyethylene strands, from rope, to the hook by wrapping one strand around the others and melting the strand to weld the unit together.

C. Selectivity

A total of 46,100 hooks (half baited, half feathered) were fished over a period of 42 days. The total catch of cod was 17,293 kg; 57% caught on the feathered hooks.

Feathered hooks have several advantages over baited hooks. Since bait is not required, all costs (including environmental) associated with bait are eliminated. The feathered hooks are easier to set and haul since no time is involved in baiting and the fish come off easy. More feathered hooks can be hauled per day.

"The feather hooks continue to fish as long as they are in the water. The baited hook fishes only as long as the bait stays on the hook or until the bait spoils. This is an important factor when poor weather prevents daily hauling of the gear. Higher catches are experienced on the feather hooks after several nights fishing. There is no difference in the average size of fish caught on either the feather or baited hook."

REFERENCE #: A009

Lokkeborg, S., A. Bjordal, and A. Ferno. 1989. Responses of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) to baited hooks in the natural environment. Can. J. Fish. Aquat. Sci. 46: 1478-1483.

C. Selectivity

The authors used underwater television, suspended from an oil platform in the North Sea, to observe the behaviour of cod and haddock towards baited hooks. The paper's observations are based on 2956 cod and 860 haddock. Behaviour is only reported for hooks baited with mackerel. Many observations are presented, some of which follow:

"Both species exhibit a diel rhythm of feeding activity, most pronounced in cod, with an increase at dawn and a decrease at dusk. The activity rhythm of cod changed from bimodal with peaks in the morning and afternoon in September, to unimodal in December."

"Activity in fish decreased at high current velocities. Both cod and haddock swam upstream towards baited hooks. More haddock responded to the bait than cod, but haddock showed a less intense response characterized by biting repeatedly at parts of the bait, whereas cod completely ingested the bait and thereby increased the probability of getting hooked." "...the hooking probability for haddock was 0.11 (calculated as the ratio between number of hooked fish and number of bites, 52/456). The probability of being hooked was twice as high in September ($42/284=0.15$) as in December ($10/172=0.06$)."

Cod responded to struggling hooked haddock. "Of the total number of cod hooked on mackerel bait, 50% were hooked while another fish was making an intense response as jerk or rush. Attacks by cod towards hooked haddock were also observed." "The hooking probability for cod was 0.37 (16/43), significantly higher than for haddock...The probability of being hooked was 52% higher in September than in December..." Cod and haddock vertically migrate off the bottom at night possibly accounting for the low activity observed during that period. The differences between September and December observations may be related to spawning.

"A small bait increases the probability of fish biting the hook. Smaller bait size could, on the one hand, increase the hooking probability for haddock. Cod can, on the other hand, take larger baits into the mouth, and the bait size will not influence the hooking probability to the same degree...For such species, like cod, a bait that effectively triggers biting and swallowing is perhaps more crucial than gear design in the overall efficiency of the longline."

REFERENCE #: A010

Huse, I. and A. Ferno. 1990. Fish behavior studies as an aid to improved longline hook design. Fisheries Research 9: 287-297.

A. Gear Construction and Operation

The paper briefly describes the two basic hook designs referred to as the Atlantic-type and the Pacific-type (Ruvetus hook). The Atlantic-type was originally made of bone with some hooks dating from 7000 BC. Bronze versions of this hook were used in 200 BC and are very similar to the present form. "The hook has a barb; the point is close to parallel with the shank, pointing in the same direction as the eye end of the hook, forming a semicircular hook head."

The Pacific-type hook were made of wood and bone. This design originally did not have a barb; the point itself served the barb function of keeping the hook in place in the fish mouth. The point curved around pointing to the shaft rather than the eye end. New versions of this hook have barbs, but the hooking principal is the same.

Recent hook design efforts have focused on facilitating baiting and gear handling.

C. Selectivity

Observations were made of the behaviour of cod and haddock towards baited hooks. The behaviour patterns were standardized and recorded for both species. The paper presents the results as a matrix of transitions from one behaviour to another. There was some evidence of hook-avoidance learning in the experiments. There were some marked differences between cod and haddock in their behaviour towards the hooks.

Several experimental hook designs were constructed and tested. The design was based on an hypothesis formulated from the behaviour work; hooks with points toward the line of pull will catch more fish than those with points parallel to the line of pull.

The experimental hooks caught more fish than the standard hooks in all experiments. In one experiment, the increase in catch was 34%. In another experiment, where there was a high proportion of swallowed hooks, the results were not as clear.

REFERENCE #: A011

Matthews, P. 1990. A blueprint for the year 2000. Longlining Symposium, Halifax, Nova Scotia. 17 p.

F. Management Issues

This presentation compared operating and fixed costs for three different types of trawlers and longliners. Assumptions included that the vessels operated out of Nova Scotian ports in a manner appropriate for their size, stocks were at reasonable levels, there were no catch limits, and the vessels were new. Crew costs were excluded.

The results, based on straight operating costs and fixed expenses, find that a 65-foot and 90-foot trawler have the lowest cost per pound of fish landed (\$0.21 and \$0.27) and a 150-foot trawler the highest (\$0.31). The longliners fell in between at \$0.24, \$0.25, and \$0.27. One comparison, between a 99-foot longliner and a 90-foot trawler, found the longliner fishing 10 more days per year but catching a half million pounds (25%) less fish than the trawler.

The author then goes on to discuss the environmental costs of fishing by asking whether trawler fishing has turned the fishery into a non-renewable resource (resource extraction exceeding regenerative capacity). He believes that the true cost of catching fish must include the environmental costs. As an example, he cites that longliners catch fish in the 20-30 pound range versus 3-7 pound fish caught by trawlers. Trawlers thus catch three to seven times more fish than trawlers for the same landed weight. Longliner discard rate is only 0.002 percent.

Costs that need to be quantified include immature fish tonnage, lost spawning potential, community costs (plant shut downs due to over-harvest), enforcement and management. If the true costs were calculated, the author believes trawling costs would be significantly higher than longlining. He believes that Canadian managers have neglected the impact of fishing technology, and that the root cause of the fishery problems is the trawler. "...getting the resource to long term sustainability is the only basis for a successful commercial fishery.."
Destructive fishing methods must be phased out by phasing in more appropriate harvesting technology using catch based incentives (more quota).

Hooks are easier to manage because hook size can not be tampered with as mesh can. There are limits to the number of hooks that can be fished per day. The author ends his remarks with management measures that can be used on trawlers, longliners, and gill netters.

REFERENCE #: A012

Ralston, S. 1990. Size selection of snappers (*Lutjanidae*) by hook and line gear. Can. J. Fish. Aquat. Sci. 47: 696-700.

C. Selectivity

"There has been no coherent development of theory concerning the manner in which fish hooks sample a population...To determine which type of curve (logistic or normal) best describes the selective sampling characteristics of fish hooks, an experiment was conducted in the Marianas Islands during 1982-84. During all fishing operations two different hook sizes (#20 and #28) of circle fish hooks were fished simultaneously and in equal number." The length-frequency ratios of snapper were used to then determine the best curve fit.

Over 7000 thousand fish, consisting of more than 30 species, were caught. Analysis looked at 86% of the catch which consisted of four snapper species.

"While small hooks caught substantially more small fish, large hooks were somewhat more effective in capturing the larger size classes." The results do not clearly support the gill net or trawl type models of selection. Increasing hook size shifts the selection curve to the right, but also shows increasing catchability. "Thus, the assumption that catchability in the fully vulnerable size range is independent of gear size is too simplistic."

REFERENCE #: A013

Aguilar, R., J. Mas, and X. Pastor. 1992. Impact of Spanish swordfish longline fisheries on the loggerhead sea turtle, *Caretta caretta*, population in the Western Mediterranean. Greenpeace Mediterranean Sea Project, presented at 12th Ann. Wkshp. on Sea Turtle Biol. and Conserv., Feb. 25-29, Jekyll Island, GA, USA. 9p.

A. Gear Construction and Operation

A fleet of 60-80 Spanish vessels, typically 15 m wood boats of 40 gross tons and 300 HP, longline for swordfish with eight man crews. Their gear consists of a 300 m surface main line with 12 hooks (90 mm per 35 mm), 20 m apart, attached using 25 m snoods. As many as 200 of these main lines are attached together, reaching lengths of 60 km with 2400 hooks. Hooks are baited with flying squid, mackerel, and gilt sardine. Sets are made at sunset and hauled at sunrise. Bycatch consists of turtles, stingrays, sharks, and tuna.

D. Incidental Fishing Mortality

"More than 20,000 subadult loggerhead turtles are incidentally captured every year as a result of the Spanish longlining fishery activities. Turtles are usually released alive with the longline hook still lodged internally. However, at least 20% of the sea turtles captured by this fishing gear could eventually die, due to the injuries caused by the hooks."

"Observers onboard 26 fishing boats during a period of 143 days, between the summer months of 1990 and 1991, recorded the captures of 1,098 loggerhead (*Caretta caretta*) and two leatherback (*Dermochelys coriacea*) sea turtles. 94% of the turtles captured while observers were onboard were tagged and released..."

REFERENCE #: A014

Lokkeborg, S. and A. Bjordal. 1992. Species and size selectivity in longline fishing: a review. Fisheries Research 13: 311-322.

C. Selectivity

This paper is a general review of longlining examining the impact on selectivity of various factors including fish distribution, fishing strategy, feeding range, fish competition, type and size of bait, and hook design.

The literature reviewed indicates that fishing location plays a key role in species composition of the catch. The location of the hook in the water column as well as the hook position relative to the bottom are important factors. Species composition can change seasonally in a particular location.

Bait is the most important factor affecting species selectivity of hooks. Different species have different preferences for bait type and this preference can vary seasonally. Bait size may also have a species selective effect.

Hook size and shape plays a role in species selectivity. Larger and stronger fish species have a different probability of being hooked than smaller and weaker species. Even similar sized species, such as cod and haddock, have shown differences in catch rates between hook designs.

Bait is probably an important factor affecting the size selectivity of hooks based on studies that have found a linear relation between predator size and optimal prey size. Field work has found that larger baits caught larger cod independent of hook size.

There is contradictory information about hook size and size selectivity within the range of commercial hook sizes that would be used for a particular fishery. Moderate changes in hook size may not affect size selectivity. Hook spacing may also have an effect on size selectivity.

REFERENCE #: A015

Skillman, Robert A., 1992. Leatherback turtle captured by ingestion of squid bait on swordfish longline. *Fishery Bulletin*, U.S. 90:807-808.

This paper reports capture of a leatherback turtle, *Dermochelys coriacea*, by longline gear while fishing for swordfish in the eastern Pacific. The leatherback is listed as endangered under the U.S. Endangered Species Act, the International Union for Conservation of Nature, and the Convention on International Trade in Endangered Species. While ingestion of baited hooks has not been reported in the literature, entanglement has been reported with lobster pot lines, drift nets, pelagic longline, gillnets, and swordfish tangle nets.

In January 1991, a leatherback turtle was hooked and released alive at 26°58.3' N, long. 168°53.5'W, while experimental longline fishing operations were being conducted. The hook line could be seen coming from the turtle's mouth. (The turtle's long flippers have been hooked in other tuna and swordfish longline interactions.) The turtle was caught in 2400 metres of water at 21.4°. The longline gear consisted of 16 km of 4.0 or 3.2 mm monofilament main line suspended with floats every 3 hook lines. The turtle was taken on the first hook of a 3-hook basket located about mid-set. Each hook was baited with a whole, Argentinean squid. An estimate of time of hooking is not available, though gear was set between 1818h and 0907h the next day.

Other researchers have suggested the potential importance of bioluminescence to turtles during the night or on deep dives when preying upon free-swimming tunicates. The chemical light sticks used to attract swordfish may have attracted the leatherback to the gear.

REFERENCE #: A016

Lokkeborg, Svein, 1990. Reduced catch of under-sized cod (*Gadus morhua*) in longlining by using artificial bait. *Can J. Fish. Aquat. Sci.*, Vol. 47, 1990.

This study describes how the shape and size of artificial bait affects the size of cod caught compared to natural shrimp bait. Manipulating the size of fish harvested has mostly been approached with different gear configurations, as opposed to selection by line fishing. Other studies have shown that both hook and bait size may influence the size of fish caught.

Fishing trials were conducted during the spring fishery for Atlantic cod on a commercial longliner operating off the coast of Northern Norway. Experimental longlines were baited with two baits - one artificial and the other, natural - in clusters of 48 similarly baited hooks. The artificial baits were composed of reinforced polyurethane foam injected with feeding attractants similar to those found in natural shrimp bait. The natural bait (*Pandalus borealis*) was of generally one size (mean 79x33x14 mm), which was larger than the small, medium, and large sizes of the artificial bait (large size being 50x20x8 mm).

The length distribution of the catch was influenced by both bait type and bait size. In all comparisons artificial baits caught a lower number of small cod, whereas there was no difference in the number of large cod. Mean cod length was therefore higher on the artificial baits. The proportion of under-sized cod (<42 cm) caught on artificial baits was significantly lower than for natural shrimp bait.

Preference by small cod for natural shrimp bait may be based on discrimination between the different shapes of natural and artificial baits. Since larger cod have a greater diet breadth, this preference by small cod may also reflect a restrained response towards attacking novel prey, or differences in texture and taste. The present results indicate that the size selectivity of this gear could be further improved by using baits of certain shapes and sizes.

REFERENCE #: A017

Yetman, L., L. Hogan and M. Lacey. 1991. Longline hook selectivity study - south coast of Newfoundland. Atlantic Fisheries Adjustment Programme Project Report 1991-181.

A. Gear construction and operation

This study compared the sizes of cod caught using four different hook sizes: #16, #15, #14 and #6/0. All were J-hooks produced by O. Mustad and Son. The #16 hook was generally preferred by fishermen, and the object was to compare the catch of those hooks with the larger #15 and #14 and the differently-shaped #6/0. Work was conducted on the south coast of Newfoundland in January to March 1991.

The #16 and #6/0 hooks were the most effective at catching fish. However, the larger #14 hook caught the same number of large fish but fewer smaller fish

“There was a relationship between the size of hook used and the size of fish that the fish catches. That is, larger hooks are more selective, catching fewer small fish.” p. 17

F. Management issues

“Changing to larger hooks could result in a reduction of profit for fishermen. With this, two scenarios are possible. One involves the fishermen changing to larger hooks without increasing the number of hooks fished above normal, resulting in a drop in catch. The second involves the fishermen changing to larger hooks and increasing the number of hooks fished to compensate for lost catch, leading to increased operating costs.” p. 17

**Seabirds on Hook Gear
and in Gill Nets**

REFERENCE #: B001

Cornelisse, K.J., and K.D. Christensen, 1993. Investigation of a cover net designed to reduce southern cormorant (*Phalacrocorax carbo sinensis*) fisheries depredation in a pound net. ICES J. mar. Sci., 50: 279-284.

A cover net was placed over the pot of a pound net to determine if cormorant predation on Atlantic herring, cod, and flounder would decrease, and thereby increase the total catch. The protected southern cormorant population in Denmark has grown to 33,000 breeding pairs from a few hundred pairs in the 1960s. Cormorants commonly feed at pound nets, and conflict between fishermen and cormorants has intensified. Over the years methods of deterrence have been investigated, though cover nets have not been used to date.

A 17 mm mesh bar net was stretched over and tied to the upper edge of a pound net pot, and hung down just below the surface of the water. Cormorant activity was monitored inside and out of the net, with and without a cover net in place during periods in the morning and afternoon. Total catch was compared with and without the cover net in place.

The total number of cormorants observed did not differ with and without the cover net in place. The total daily number of fish caught with and without the cover net was not significant, and individual species (herring, cod, and flounder) were not significantly affected by the presence or absence of the net.

Cormorants quickly adjusted to the cover net. A narrow strip around the inside edge of the pot where the cover net did not touch the surface of the water allowed cormorants to dive into the pot. This may be prevented by a floating net; studies using a floating 100 mm mesh cover net are recommended.

REFERENCE #: B002

Brothers, N., A. Foster and G. Robertson. 1995. The influence of bait quality on the sink rate of bait used in the Japanese longline fishing industry: an experimental approach. CCAMLR Science 2:123-129

A. Gear Construction and Operation:

In the Japanese tuna longline fishery the rate at which baited hooks sink once deployed is an important factor contributing to seabird mortality and the associated economic cost to fishermen of bait loss incurred by birds.... The likelihood of successful bait strikes and subsequent hooking of seabirds should decrease with increased bait sink rates, particularly if the baits can be made to sink to a depth greater than that achievable by diving birds within the area astern of a ship that is protected by a bird scaring streamer line.

The purpose of this study was to determine the sink rates of bait of different species, size and condition (thawed or frozen), and to examine the contribution to sink rates of adding weight to baited hooks.

The most powerful effect was due to the condition of the samples when deployed: all thawed baits sank and all frozen baits floated.

For the bait species tested the results indicate:

(a) thawed bait with deflated swim bladders sank while most frozen baits floated. Baits that are totally thawed when deployed by Japanese vessels longlining for tuna are therefore less likely to be eaten by seabirds.

(b) inflated swim bladders caused some specimens to float when thawed. Fish belonging to species suspected of maintaining air in their swim bladders when caught should be spiked to expel air before they are to be used as bait.

(c) the sink rate of baited hooks was greatly improved by adding lead sinkers to hooks (e.g. a 20 gram sinker to a conventional 20 gram tuna hook).

Assuming the sink characteristics of these baits resemble those of bait deployed from a longliner, it is possible to speculate on the protection afforded by the bird scaring streamer line during line setting. At a line setting speed of 10.5 knots, baits will be left astern at a rate of 5.4 m/sec. This means that the fastest sinking baits would still only be at a depth of 1 m when 31 m astern, 2 m at 62 m and 3 m at 93 m. At the latter distance from the ship the bait can be protected by a properly constructed and deployed streamer line, and should be too deep to allow direct attack by albatrosses. In contrast, the slowest sinking baits would not reach a depth of 3 m until over 400 m astern, which is about 300 m or 1 min beyond the protection zone of the streamer line.

REFERENCE #: B003

Klaer, N. And T. Polachek. 1995. Japanese longline seabird bycatch in the Australian Fishing Zone April 1991 - March 1994. CSIRO Division of Fisheries Report, Australia

B. History and Statistics

The Japanese longline fishery for southern bluefin (SBT) tuna is the largest fishery which is likely to have significant takes of albatross. While global Japanese effort targeting SBT has decreased recently, about 1/3 of the effort occurs in Australian waters. This report uses observer and logbook data from vessels fishing within the Australian EEZ to examine the effect of variations in fishing practices on seabird bycatch rates.

C. Selectivity

Almost all of the birds which were retrieved dead during hauling were hooked during line setting. The authors found that catch rates varied with season and area, as well as interannually. A number of mitigation measures were shown to be effective in reducing seabird bycatch rates including: setting the longline in the dark rather than in daylight, the use of tori poles and lines which frighten birds away from baits floating near the water surface, use of bait throwing machines which reduce the time that baits float near the water surface, and the use of thawed baits which sink more quickly than those which are frozen. However, there was insufficient information available in most cases (except for night setting) to accurately estimate the degree of effectiveness of each mitigation measure.

D. Incidental Fishing Mortality:

The overall seabird catch rates during both 1992 and 1993 were 0.16 birds per 1,000 hooks. The figure for 1991 was lower at 0.08 per 1,000 hooks, but the authors cite several factors which suggest the 1991 data were not representative.

For the three years examined, black browed and shy albatross appeared to be caught in the greatest numbers, while catches of yellow nosed, wandering and grey headed albatross were also significant. Individual species catch proportions varied considerably from year to year.

REFERENCE #: B004

Anon. 1996. Report of the CCAMLR Working Group on Fish Stock Assessment, Hobart, Australia, 10-18 October 1995.

B. History and Statistics

Catches of this Patagonian toothfish in the waters of the southwest Atlantic (South Georgia and adjacent high seas) have ranged between 4,200 tonnes and 8,500 tonnes over the past five years, including increasing amounts of so-called illegal fishing (i.e. out of season, no licence).

C. Selectivity

One working paper reviewed by the Working Group documented seabird bycatch by Chilean and Argentinian vessels. An overall lower catch rate compared to earlier years was attributed to a combination of night-time setting, fishing later in the breeding season of the most vulnerable seabird species and the use of streamer lines. Seabird catch composition had also changed, with a far lower percentage of the catch being albatross and corresponding increase in petrels. The Group noted that this change was probably due to the setting of the lines at night, and emphasized the need to use streamer lines at all times.

F. Management Issues

CCAMLR has adopted Conservation Measure 29/XIV concerning the reduction of seabird bycatch. Among its provisions:

- fishing must be done in such a way that the hooks sink as rapidly as possible: only thawed bait can be used
- lines must be set at night, and deck lighting must be kept to a minimum
- the dumping of offal (which attracts birds) should be avoided as much as possible during line setting or discharged on the opposite side of the vessel
- a streamer line must be used during line setting (detailed specifications are included) .

REFERENCE #: B005

Brothers, N. 1995. An investigation into the causes of seabird mortality and solutions to this in the Spanish system of demersal longline fishing for Patagonian toothfish *Dissostichus eleginoides* in the South Atlantic Ocean. Report prepared for Consolidated Fisheries Limited, Falkland Islands.

A. Gear Construction and Operation

This report examined the Spanish System of longlining, in which one heavy 20 mm line is connected by 30 m long joining lines to a 4 mm diameter hook line. The hook line is weighted at 35 m intervals with stones, and the hooks are placed on 1 m nylon snoods at 1.2 m intervals between the stones. Generally 2 of these lines were set, each about 10 km long with 10,000 hooks.

B. History and Statistics

The fishing grounds were in the Falklands Outer Fishing Zone

C. Selectivity

The study made a number of recommendations for reducing the incidental mortality of seabirds, and noted the advantages and disadvantages for each recommendation:

- adopt a fishing strategy using only one, longer fishing line
- confine line setting to night-time
- avoid use of line tension to pull stones off the ship, either by having crew push them or by some mechanical process
- discharge offal from opposite side of the ship to that from which the line is set
- discharge homogenized offal, not large solid pieces of offal
- detailed recommendations on stone weight and spacing
- use bird scaring line or lines

The author also urged that fishing vessels which have a history of high bird bycatch NOT be left out of the fishery, as that would mean that these vessels will simply move elsewhere to fish with the same problem. Rather, these vessels should be targeted for observers in order to determine, and then rectify, the reason for their high bycatch rate. He also noted that fishing technology will evolve, with consequences for bird bycatch. New technologies should be assessed before they are adopted in order to avoid or adapt those with negative results for bycatch

D. Incidental Fishing Mortality

A total of 42 seabirds were caught on 38 lines: 37 albatrosses, 3 Cape petrels and 2 southern giant petrels. All were caught on lines set at night.

Marine Mammals in Gill Nets

REFERENCE #: C001

Goujon, M., L. Antoine, and A. Collet, 1993. Incidental catches of cetaceans by the French albacore tuna driftnet fishery - preliminary results. ICES Statutory Meeting, N:13 Ref. H.

Not to be cited without prior reference to the author

This study is part of a two-year research program to assess the ecological risk of the Northeast Atlantic French driftnet fishery, which uses 5 km long nets to catch albacore tuna during the summer. In 1992, the European Council banned the use of driftnets longer than 2.5 km in the French community tuna fleet, following a recommendation by the United Nations. Vessels fishing for albacore tuna with driftnets in the Northeast Atlantic were exempt. Subsequently, the French Ministry of the Sea solicited data to assess the ecological impacts of the fishery.

In 1992, observers monitored forty percent of the exempted fleet for bycatch and incidental catch. Eighty-five percent of the catch in the driftnets was albacore tuna. Four hundred seventy-five cetaceans were caught, representing 0.17% of the overall catch. The total number of cetaceans incidentally caught by the exempted and non-exempted fleet is estimated to be 1700 individuals. Principal cetaceans involved are the striped dolphin (69%) and the common dolphin (24%). Incidental catches occur during the whole season from May-September, with the greatest number per fishing operation occurring in August and September. Calves of the year represent almost half of the incidental catches.

These results are preliminary. Further discussion will follow after receiving a progress report from studies done on the biological samples from the cetacean mortalities.

REFERENCE #: C002

Jefferson, Thomas A. and Barbara E. Curry, (1994). A global review of porpoise (*Cetacea: Phocoenidae*) mortality in gillnets. *Biological Conservation* 67, 167-183.

This paper reviews known incidental takes of six species of porpoises throughout the world, including information on species distribution and abundance, and the status of affected populations. Gillnet fisheries present a major problem for all six species of porpoises (the term gillnet in this paper is used to describe passive nets and includes setnets, driftnets, and trammel nets). The most threatened species is the vaquita, in danger of extinction due to catches in gillnets.

Gillnets represent the single most important threat to porpoises as a group. Following is a list of the porpoises, and the areas in which they are affected:

<u>Species</u>	<u>Geographic region of impact</u>
Harbor porpoise, <i>Phocoena phocoena</i>	North Pacific western and eastern North Atlantic
Vaquita, <i>P. sinus</i>	Gulf of California, Mexico
Burmeister's porpoises, <i>P. spinipinnis</i>	South America (mainly Peru)
Spectacled porpoises, <i>Australophocaena dioptrica</i>	southern South America
Dall's porpoises, <i>Phocoenoides dalli</i>	western North Pacific
Finless porpoise, <i>Neophocaena phocaenoides</i>	China

Precise areas, fishery type, and known and estimated takes are tabled for each species.

Recommendations:

According to the authors, "there is a lack of understanding of the reasons why porpoises become entangled in gillnets. Studies of gillnet detection are needed, though technological solutions may not be the only answer to reducing incidental takes of porpoises. Other solutions may be to 1) ban the use of gillnets, 2) require fishermen to switch to more selective gear, or 3) enforce time and area restrictions on gillnet use. Fisheries where incidental takes are not fully known should be monitored with 100% observer coverage. In addition, fishermen must be included to a greater degree in documenting, studying, and solving the problem of porpoise entanglement. Where closures or gear bans are in effect, government and private organizations should be willing to provide economic incentives to fishermen for their cooperation. Solutions to the porpoise bycatch problem will entail combinations of technological developments, scientific discoveries, management enforcement actions, educational programs, cooperative studies, and economic and social reforms."

REFERENCE #: C003

Klinowka, M., D. Goodson, and P. Bloom, 1992. Progress in the development of efficient warning devices to prevent the entrapment of cetaceans (dolphins, porpoises, and whales) in fishing nets. ICES C.M./N:17-Ref. B.

* Consulting authors before citation recommended

Two field experiments are described to test whether dolphins are able to detect with their sonar emissions nets equipped with passive acoustic reflectors. This approach to reducing incidental mortality of cetaceans in fishing nets considers the animals' behaviour and sensory abilities. If proved successful, reflectors on nets would also assist in the retrieval of lost nets using ship sonar. This would help prevent another danger to marine life, and reduce financial loss to the fishing industry.

Non-acoustic approaches to avoiding cetacean by-catch entails either modifying fishing gear, or modifying how the gear is deployed. The latter involves orienting the gear in such a way as to not interfere with the environmental cues the cetacean is using to navigate. Work has been done in modifying gear which indicates that lowering the head rope of the net below the surface greatly reduces the by-catch of sea birds, and may mitigate cetacean entanglements. In addition, certain chemicals treated to nets could serve as a warning signal to animals.

Acoustic approaches may be active (such as pingers which emit a pulse frequency sound) or passive, described here. The idea behind the passive reflector is that it will make the net more detectable to the dolphin by altering the interface between the net and water. The "acoustic transparency of the net is probably a major cause of the dolphin's perception problem."

Field tests took place in the Moray Firth, northeast Scotland. In the first test, researchers deployed a 200 m headrope with rope tails attached, on which the reflectors were placed at 2 m intervals. No net webbing was present. Over a period of several days, no dolphins attempted to penetrate the barrier of prototype acoustic reflectors. Data obtained were limited, and the reflectors need refinement, though the initial results were promising. In the second test researchers deployed a net with unmodified net panels and panels with reflectors. This was performed to test gear deployment, and how the gear would be perceived 'acoustically' by the dolphin. While successful in providing sidescan sonar images of normal and modified net panels, the experimental method for attaching the reflectors proved unsatisfactory in several respects in a working environment.

The potential for an acoustic engineering approach to mitigate cetacean by-catch should be assessed further. "While it is clear that no single modification of gear or deployment is likely to provide complete protection, a combination of techniques, possibly specific to the fishery and area in question, could be effective."

REFERENCE #: C004

Kraus S., A. Read, E. Anderson, K. Baldwin, A. Solow, T. Spradlin, and J. Williamson, April 1995. A field test of the use of acoustic alarms to reduce incidental mortality of harbor porpoises in gill nets. IWC report SC/47/SM17, 28 pp.

This study tests whether acoustic alarms set in gill nets are an effective means of reducing the incidental catch of harbor porpoises in the Gulf of Maine. Harbor porpoises have been subject to a significant level of incidental mortality in gill nets targeting demersal fish species. The effect of these mortalities on the porpoise population has provoked efforts to list the species as 'Threatened' under the U.S. Endangered Species Act. The New England Fishery Management Council has regulated specific areas closed to fishing where harbor porpoises are subject to by-catch. Some view closures and further sanctions under the ESA, however, as threats to the future of the sink gill net fishery in New England.

In autumn of 1994 a field test of acoustic alarms was conducted off the coast of New Hampshire where large numbers of porpoises are known to be taken (primarily Jeffrey's Ledge). Fifteen fishermen set strings of nets and observers were placed on vessels to record data. Each string was comprised of 12 nets equipped with either 13 active or 13 control alarms placed 300 feet apart. Active alarms produced a signal centred at 10 kHz with a source level of 132 dB, emitting only when submerged in water, and control alarms were silent. Neither fishermen nor observers were aware of which alarms were active or control.

Active and control strings were set in similar water depths and locations, and soak times were similar. Control and active strings captured similar quantities of cod and pollock, and herring was caught less frequently in active strings. Two harbor porpoises were captured in 423 active strings and 25 were taken in 421 control strings. The use of alarms caused no adverse effects on targeted commercial fish, nor on the frequency of damage to the catch caused by seal predation.

According to the authors, "the use of acoustic alarms appears to hold considerable promise as a mitigation measure to reduce the number of harbor porpoises killed in sink gill nets in the Gulf of Maine." The porpoises may be responding directly to the sound produced by the alarms, or they may be affected indirectly by the behaviour of herring, a primary source of prey in the Gulf of Maine. Unlike other fishes, herring have an unusual capacity for high-frequency hearing, sensitive to up to 10 kHz.

"To ensure that the incidental catch of harbor porpoises in the sink gill net fishery of the Gulf of Maine is as effective as possible, we recommend that alarms be used in conjunction with existing area closures. We provisionally recommend that alarms be built to standard specifications (described), with a minimum standard of 3 months of underwater life required for commercial alarms (low maintenance)."

REFERENCE#: C005

Perrin, W.F., G.P. Donovan and J. Barlow [ed]. 1994. Gillnets and cetaceans. Report of the International Whaling Commission. Special Issue 15. vi+629 pp.

This volume contains the report of a symposium and workshop which was held in October 1990 to (i) identify and describe net and trap fisheries which entangle cetaceans, (ii) investigate why and how entanglement occurs, (iii) estimate mortality and its impact on the populations and (iv) to consider possible ways to reduce net-caused mortality. Note that only passive gear was considered, and the impact of active gear such as seines and trawls was ignored. The report provides a comprehensive survey of fisheries throughout the world which were known to catch cetaceans as well as a review of those aspects of cetacean physiology, behaviour and morphology which could affect entanglement. The final section of the report considers approaches to mitigating the mortality including modifications to nets, time and/or area closures, outright bans of certain gears or practices and others.

Among the many conclusions of the report were:

- cetacean populations in general seem unable to sustain kill rates of more than a small percentage of the population per year, such that even rates as low as 2% per year may not be sustainable;
- the impacts of coastal gillnets and traps were especially important;
- the data then available indicated that several populations were unable to sustain current levels of entanglement mortality (vaquita in the Gulf of California, baiji in the Yangtze River, Indo-Pacific hump-backed dolphins on the Natal coast, striped dolphins in the Mediterranean, harbour porpoises in the western North Atlantic, bottlenose dolphins on the Natal coast); other populations could also be affected but insufficient data were available;
- wherever cetaceans and gillnets are found in the same area, at least some cetaceans are caught;
- there is no universal cause or solution to cetacean entanglement;
- small cetaceans have sensory abilities which can detect the rigging and webbing of gillnets and other passive gear, though less is known of the sensory abilities of large cetaceans.

The report's recommendations included:

- the collection of better data on fisheries and their cetacean bycatch;
- that new fisheries should only be opened after a rigorous assessment of its impact on target and non-target species, including cetaceans;
- further research is needed on the causes and solutions of cetacean entanglement;
- studies on solutions to cetacean bycatch should consider the impact on the bycatch of other species;
- significant technological changes in fisheries should be preceded by an assessment of their likely impacts.

The volume also contains 43 papers which review the entanglement of cetaceans in specific fisheries. Eight others examine possible causes and solutions in some detail, including a theoretical discussion of sonar detection of gillnets by dolphin (W.W.L. Au), two reviews of the potential for reduction of entanglement by acoustic modifications to gillnets (A.D. Goodson et al. and S.M. Dawson - see Annotated Reference XXX) and a description of the response of harbour porpoise to gillnet modifications (Silber et al.).

REFERENCE #: C006

Dawson, S.M. 1994. The potential for reducing entanglement of dolphins and porpoises with acoustic modifications to gillnets. pp 573-578 *in* Perrin, W.F., G.P. Donovan and J. Barlow [ed]. Gillnets and cetaceans. Report of the International Whaling Commission. Special Issue 15. vi+629 pp.

Frequent proposals have been made to render gillnets more acoustically visible to small cetaceans and thus reduce incidental mortality. This paper reviews the results of several such experiments, the difficulties inherent in this approach and makes specific recommendations for managing the bycatch problem.

In order to be accepted and effective, net modifications must meet several conditions: they must have reasonable longevity under actual commercial fishing conditions; the modifications must be safe to handle, reasonably lightweight and inexpensive; they must not decrease the catch rates of the target species.

A number of experiments have been conducted to increase acoustic visibility, but with limited success. Japanese workers intertwined three air-tube threads into the central band of a standard gillnet, which reduced entanglement by about 20% in four of the six seasons it was tested. In other nets, three multifilament threads were interwoven into the central band. Results were variable, with significantly lower entanglement in some seasons and insignificant differences in other tests. In one test the multifilament net caught more porpoises than the air-filled net. The insertion of metal bead chains into nets did not significantly reduce dolphin entanglement; indeed, in one season, it even increased the catch rate, though insignificantly.

The author discusses possible reasons for these sometimes conflicting results. Few of the experiments were conducted following a balanced design, with equal numbers of modified and unmodified nets. Further, the strategy of increasing target strength relies on the assumption that the sonar of cetaceans is unable to detect nets, which the author doubts. For instance, harbour porpoise can detect nylon filaments of 0.1 mm diameter, yet are routinely entangled in gillnets made of much thicker fibres (0.8 mm). Increasing acoustic visibility is useless if the cetaceans are not using their sonar when they encounter the nets, and it is noted that no study has quantified the amount of time which free-ranging dolphins and porpoises spend echo-locating, which would be a very difficult task. Finally, it is possible that cetaceans lack a 'search image' which interprets echoes from gillnets as an impassable barrier.

The effective use of active sound emitters to reduce entanglement of cetaceans require that the sound frightens the cetaceans from the nets but has no such effect on the target fish. Habituation could also be a problem.

The author urges two possible courses of action:

- (i) abandon work on acoustic gillnet modifications and concentrate on time/area closures and/or gear restrictions to achieve the necessary reductions in incidental catch, or
- (ii) if acoustic approaches are to be pursued, use experiments of balanced design, using power analysis to determine the appropriate scale for the work.

REFERENCE#: C007

D. Potter, T. Smith, D. Palka and F. Serchuk. 1996. Further results from experimental fisheries using acoustic devices to reduce harbor porpoise bycatch. Paper SMWP 19 submitted to 1996 meeting of the International Whaling Commission. (mimeo)

A. Gear construction and operation

To test the efficacy of acoustic deterrents (“pingers”) in reducing the entanglement of harbour porpoise in the Gulf of Maine sink gillnet fishery, short-term experimental fisheries have been conducted during 1995 and 1996 in areas and seasons where bycatch rates have been historically high and which were closed to normal fishing operations as part of a management programme to reduce bycatch. . Two were conducted on Jefferys Ledge (autumn 1995, spring 1996), the same area as an earlier 1994 experiment (Annotated Reference C004) and two in more southerly areas of the Gulf of Maine (Massachusetts Bay, south of Cape Cod, both in spring 1996). Fishermen were required to use pingers meeting the acoustic standards of the earlier experiment (i.e. signal centred at 10 kHz with a source level of 132 dB). Data collected by observers were used to compare catch rates in each fishery to those rates observed in previous years in the same area and time during operations without pingers.

D. Incidental fishing mortality

Harbour porpoise bycatch rates (number of dead porpoise per observed haul) varied from 0 to 0.10. In the autumn 1995 experiment, no porpoise were observed in 225 hauls, while data show that in the five previous years, fishing without pingers during the same season yielded catch rates of 0.02 to 0.03 porpoise per haul. In the spring 1996 fishery south of Cape Cod, no porpoise were observed in 53 hauls. In the other two fisheries, on Jefferys Ledge (spring 1996) and Massachusetts Bay, 2 and 9 porpoise were caught in 171 and 88 hauls respectively. These result in catch rates of 0.01 and 0.10, the same as has been observed historically.

“Although the results of the autumn 1994 experimental fishery were consistent with the results of the 1994 Kraus et al. scientific experiments, the experimental fisheries conducted in spring 1996 suggest that pingers may not be effective in reducing by-catch during that season. Further analyses are required to determine the probability of the spring experimental fishery by-catch rates being observed by chance. Pending these analyses, we tentatively conclude that there is no evidence that pingers were effective in mitigating harbor porpoise by-catch in the spring in either Massachusetts Bay or in the Mid-Coast region of the Gulf of Maine.”

The failure rate of pingers was no different from the 1994 experiment and could not account for the lack of efficacy.

During the 1994 experiment, it was noted that nets with pingers caught fewer herring, a principle prey of harbour porpoise. Similarly, anecdotal evidence suggests that shad catches have been reduced when pingers are used. The authors suggest two hypotheses: “First, if porpoise are actively pursuing prey such as herring, and if these prey species are being deterred from the nets by the pingers (rather than the porpoise themselves), then the by-catch of harbour porpoise might be expected to be substantially reduced when pinger-equipped nets are used. On the other hand, if porpoise are feeding on other species of fish that do not respond to the acoustic signals of the pingers, then by-catch rates in pinger-equipped gear would not be expected to be any different than in non-pingered gear.”

Non-Target Commercial Species in Gill Nets

REFERENCE #: D001

Kennedy, W.A. 1951. The relationship of fishing effort by gill nets to the interval between lifts. J. Res. Bd. Can., 8(4): 264-274.

C. Selectivity

"The trend of the values...suggests that the greater the catch that can be made in nets that are lifted daily, the more the catch in nets that are lifted on alternate days departs from the expected value of twice the catch made in a daily lift. This is what is to be expected if it is the presence of previously caught fish which decreases the efficiency of a net. Some obvious ways in which efficiency could be decreased are: a fish already captured occupies a certain space in the net, which may be considerable because of the way that fish tangle the net around themselves; the presence of captured fish, especially when struggling... probably makes the net more obvious; the violent movements of captured fish may frighten others away; if, as fishermen say, fish avoid areas where there are dead fish, this would be a factor since some fish die immediately after capture." p. 267

D. Fishing mortality

"Probably nets become supersaturated when a large quantity of fish is caught within a short time, say an hour, so that before the net can become tangled from their struggle to escape it contains more fish than would normally saturate it." p. 269

"...it was observed that specific fish which were seen one day in gill nets that were left undisturbed had escaped by the following day, leaving the nets slightly tangled, that is, less efficient than before. When a net becomes supersaturated it probably begins to lose more fish than it gains because those that escape are not replaced by further fish because they leave the net in a partly tangled condition." p. 269 "...dead fish in nets probably decrease the rate at which further fish are caught to a greater extent than do the same quantity of live fish." p. 270

"...at very low levels of availability, doubling the interval between lifts will probably double the average catch, at moderate levels of availability a given number of nets will probably yield more if cleared daily than if cleared at longer intervals, and at high levels of availability nets can become saturated during the first day so that they will catch no more fish if they are left in the water for a longer time." p. 273. Using data from Great Slave Lake the author presents an example demonstrating that "...the fisherman who lifts daily will catch on average 1.54 times as many fish from the same number of nets as the fisherman who lifts every other day." " These advantages of lifting daily are in addition to any advantages that result from not having to discard any fish because they are rotten." p. 274

REFERENCE #: D002

McCombie, A. M. and F.E. Fry. 1960. Selectivity of gill nets for lake whitefish, *Coregonus clupeaformis*. Trans. Am. Fish. Soc. 89: 176-184.

C. Selectivity

"These experiments indicate that the nylon nets take about three times as many whitefish as the cotton, but take fish of essentially the same size composition." abstract

"There is also some evidence that nylon nets are more effective in clear waters, where the lesser visibility of thread would be an advantage (Brandt and Liepolt, 1955). On the other hand, cotton nets sometimes captured more fish than nylon during dark phases of the moon, when the lesser visibility of the latter material would be of no special advantage." p. 182

"As the girth: perimeter ratio exceeds unity, the efficiency of the net increases rapidly until it reaches a maximum value at a ratio of 1.26 (log value 0.10). The girth: perimeter ratio for maximal efficiency agrees well with values found by Baranov, Koltanovsky, and Leksutkin for the roach, barbel, and other species (Andreev, 1955)." p. 183

"...all size classes which are taken with an efficiency of 50 percent of the peak efficiency or greater lie within a range which is of the order of +/- 15 percent of the modal length." p. 183

F. Fisheries management

"When nylon gill nets were introduced, it was expected that their capacity to catch fish might differ from that of cotton, linen, or hemp nets because there were differences in the thickness, elasticity, and visibility of the threads. Reports soon came in that the catches from the nylon nets were much greater than those from nets of other materials, and in some cases appeared to be of different size composition. Consequently, a controversy arose concerning the possible effects of nylon gill nets on fish stocks and the need for special regulations on such gear." From Van Oosten, J. 1949. Condensed transcript of proceedings of the conference on nylon fish netting held at Erie, Pennsylvania. 30pp. (mimeo). p. 182

REFERENCE #: D003

Larkins, H.A. 1963. Comparison of salmon catches in monofilament and multifilament gill nets. *Commerc. Fish. Rev.* 25(5): 1-11.

A. Gear construction and operation

"Because of the length of the present net string (two nautical miles), the cost of providing nets and spares for a single string, plus the expense of handling and maintenance, has become great. Loss of gear due to bad weather, whales, shipping, etc., has also increased with the longer string." p. 2

B. History and statistics

"Since the beginning of the commercial use of monofilament nets in the North Pacific Ocean during the late 1950's, the popular fisheries news media have reported the apparent superiority of the clear, almost transparent filament over the conventional multifilament nylon twine (Pacific Fisherman, Sept. 1961, p. 29). The efficiency of the monofilament gill nets appeared so great that the states of Oregon, Washington, Alaska, and the Province of British Columbia have prohibited their use in the coastal salmon fisheries." p. 1

C. Selectivity

"An experiment designed to compare the salmon catches of monofilament and multifilament gill nets was conducted in 1962... Monofilament gill nets of 3 1/4-inch and 4 1/2-inch mesh were inserted in the normal multifilament net string and the catches of the two types were analysed in terms of number of fish, length, age, and species composition. In general, the monofilament greatly outfished the multifilament and took the same lengths and ages of salmon as the multifilament although the species composition differed. The presence of monofilament apparently reduced the salmon catch of adjacent 3 1/4-inch multifilament nets." abstract

"The data...indicate that the monofilament nets were more efficient than the multifilament for all three species but the increased efficiency appears to be of a different magnitude for each species. Within both mesh sizes the relative efficiency of the monofilament is highest for chum salmon, intermediate for red salmon, and lowest for pink salmon." p.3

REFERENCE #: D004

Hansen, R.G. 1974. Effect of different filament diameters on the selective action of monofilament gill nets. Trans. Am. Fish. Soc. 103(2): 386-387.

C. Selectivity

"As part of a selectivity study...monofilament gill nets with filament diameters of 0.133 mm and 0.267 mm were used in 38.1 mm (1.5 in) stretch mesh horizontal gill nets that were hung 2:1 horizontally and 1.5:1 vertically."
"...the smaller filament diameter captured larger fish. The difference was probably due to the elasticity of the monofilament nylon. The smaller diameter could be stretched more and caught larger fish, while the larger diameter did not stretch as easily and hence on the average caught smaller fish. Also, the smaller diameter was more flexible, and cut into the body of the fish more than the larger filament did."

REFERENCE #: D005

Lear, W. H. and O. Christensen. 1974. Selectivity and relative efficiency of salmon drift nets. ICNAF Res. Doc. 74/41. 9p.

C. Selectivity

"The 140 mm and 150 mm monofilament caught larger fish than the corresponding multifilament nets." p. 3 "In terms of relative efficiency of nets of various mesh sizes and fibre types it would appear that monofilament nets were superior to multifilament nets of the same size for catching Atlantic salmon." p. 3 "Results of commercial vessel data however indicates in general 160 mm multifilament nets outfish monofilament nets of approximately the same mesh size by a factor of approximately 2, the reverse of that found by research vessel data."

"The apparent inconsistency between the relative efficiency of multifilament versus monofilament nets by the A.T. Cameron and commercial vessels can possibly be explained by the different methods of fishing...by research and commercial vessels. The A.T. Cameron set her nets at dawn and hauled them back at noon or early afternoon while the commercial vessels generally set their nets before sunset and begin hauling at or before dawn the next day. In the case of the research vessels fishing the multifilament nets would possibly be more visible during daylight hours than the monofilament nets. The salmon would follow along the multifilament nets until they came to a "window" formed by the monofilament nets through which they would possibly attempt to pass and be caught. In experiments in the Pacific using combinations of multifilament and monofilament nets it was found (Larkins, 1964) that the relative efficiency was highest for alternate monofilament-multifilament, moderate for all-monofilament and lowest for all-multifilament. Thus it would appear that the efficiency of the monofilament nets is increased by alternating them in the fleet with multifilament nets which possibly serve as leaders to guide fish into the monofilament nets."

"In the case of the commercial gear the multifilament nets would not be so visible during the night and hence would be equally effective in catching salmon. Since the multifilament nets are weighted less heavily and the fibres are less rigid, hence they would possibly be more effective for entangling salmon than monofilament which are strictly speaking gill nets rather than entangling nets."

"That salmon sometimes "run" along a fleet of nets in an attempt to avoid the barrier presented can be supported by three observations (May, MS, 1970).(1) Less salmon are usually caught when nets were tightly stretched in a straight line than when wind and current conditions caused them to assume a meandering configuration. (2) When wind and sea conditions caused one end of the fleet to drift back toward the centre of the gear, larger numbers of salmon were caught in the loop or trap so formed than along the straight part of the fleet. (3) Salmon lying on the nets were occasionally driven in by the small boat used for tagging.

REFERENCE #: D006

Hamley, John M. 1975. Review of gillnet selectivity. J. Fish. Res. Bd. Canada. Vol. 32(11). p.1943-1969.

C. Selectivity

"This paper reviews studies on gillnet selectivity: the relevant characteristics of fish and nets, graphical and mathematical representation of selectivity curves, and methods of estimation."

"Selectivity depends mainly on fish size and shape and mesh size, but is also affected by the thickness, material, and colour of net twine, hanging of net, and method of fishing. The left slopes of selectivity curves represent smaller fish wedged in the meshes; the right slopes, larger fish mainly tangled by head parts. The curves may be skewed or multimodal for fish that are easily tangled."

"The most reliable, though expensive, estimate of gillnet selectivity are by 'direct' methods of fishing a population of known size-frequency distribution. The more popular but biased 'indirect' estimates compare catches by two or more mesh sizes. Other methods used are prediction from girth measurements and the Delury method." abstract

"Fish may be very adept at avoiding nets (Leggett and Jones 1971). The reaction of fish to nets may be complex: Ochiai and Asano (1955) found that schooling minnows (*Orizias latipes*) approached nets more freely than lone fish did. Learning may also be a factor: Hunter and Wisby (1964) demonstrated learning in the reactions of several species of fish to moving barrier nets." p.1948

"Lagler (1968) suggested that the reason for the greater efficiency of larger-meshed nets is that larger fish move about more and therefore are more likely to encounter nets." p.1948

"Because the reaction to net color varies with species of fish, choosing the proper color can reduce catches of unwanted species, without affecting catches of the target species (Steinberg 1962; Jester 1973)." p.1949

"Visual sensitivity and acuity may improve as a fish grows, because the density of cones in its eye declines less rapidly than the image area increases (Hester 1968)." p.1949

"Gillnet selectivity should be defined as the probability of capture, given the fishing effort- not as the probability of capture after a fish encountered the net- because part of the observed selectivity may be due to different probabilities of large and small fish encountering the nets." p.1964

REFERENCE #: D007

Hylen, A. and T. Jakobsen. 1979. A fishing experiment with multifilament, monofilament and monotwine gill nets in Lofoten during the spawning season of Arcto-Norwegian cod in 1974. FiskDir. Skr. Ser. AvUnders., 16: 531-550.

A. Gear construction and operation

"Monofilament is made of single thin and nearly transparent thread which presumably has low visibility in water. Continuous multifilament is made by a number of fibers spun into a yarn. The visibility in water is obviously higher than for the monofilament. Monofilament is stiffer and more elastic than multifilament yarn. In case of strong water movement, the stiffness may help to prevent the meshes from closing. The monotwine consists of a number of monofilament wires, in this case three, which are twisted into a twine. It is thicker than the corresponding monofilament, and the visibility in water is accordingly higher, but probably less than for multifilament. The twisting reduces the elasticity." p. 532

B. History and statistics

"For nearly twenty years continuous multifilament nylon has been the common material in gill nets used in the Norwegian cod and saithe fisheries. During the last few years some fishermen have changed over to monofilament gill nets... In Europe, monofilament gill nets have up to now been used mainly in freshwater fisheries and in saltwater fisheries for salmon. In some areas, however, particularly in the Far East, they are widely used in marine fisheries." p. 532

C. Selectivity

"The different types of nets were combined to make up one gill net setting consisting of 40 to 92 single nets, half of which were multifilament nylon nets and one quarter each monofilament and monotwine nets. The result for the total experiment was that the monofilament nets caught 26% (in numbers) more cod than multifilament nylon nets and 38% more than the monotwine nets. For saithe the monotwine nets were apparently the most and the multifilament nylon nets the least efficient. The average length of the captured fish was slightly higher for the multifilament nylon than for the monofilament nets whereas the fish caught by the monotwine nets were somewhat smaller."

REFERENCE #: D008

Watson, A., R. Millner, and B. Mumford. 1979. Selection of sole (*Solea solea*) by trammel nets and the effect of mesh size on catches. ICES C.M. 1979/B:12. 6p

A. Gear construction and operation

"A trammel net consists of an inner panel of small mesh nylon or terylene netting which is sandwiched between two outer walls of wide meshed net. The inner net is usually at least twice as high and twice as long as the outer walls so that when held between them there is plenty of slack net." "...at Hastings...standard gear consists of an inner net with a stretched mesh size of approximately 114 mm and two outer walls of approximately 610 mm mesh..." p. 1

C. Selectivity

"Trammel nets with 60, 88, 119, and 144 mm stretched mesh inner nets were fished off Hastings on the south coast of England to assess their effectiveness at catching soles. Although the 88 mm net consistently outfished the other nets in terms of both numbers and weight of soles caught, 48% of the soles were below a marketable size. In contrast, less than 4% of the soles caught in the larger nets were unsuitable for the market. The additional time taken to clear the fish from the 60 and 88 mm nets together with the large number of undersized and unmarketable fish which were caught makes these nets commercially uneconomic to fish." p. 1

REFERENCE #: D009

Doubleday, W.G. and D.G. Reddin. 1980. Gear selectivity and escapement mortality of Atlantic salmon in drift nets at West Greenland. CAFSAC Research Doc. 80/11. 10 pp.

C. Selectivity

"Fish with a maximum girth larger than the net lumen and an operculum smaller than the net lumen are likely to be retained by the net for some period of time depending on their velocity and angle of approach to the net (Konda 1966)." p. 1

"Since the West Greenland fishery utilizes mainly 127 mm and 140 mm nets, an estimate of 28% for the number of fish encountering the gear and escaping is appropriate for the commercial fishery." p.5

D. Fishing mortality

"There is a portion of the population that dies as a direct or indirect result of fishing activities but is not recorded as catch; termed non-catch fishing mortality. The non-catch mortality due directly to injuries sustained during encounters with nets, or due directly to greater susceptibility to predation or disease from those injuries, is termed escapement mortality (Ritter et al. 1979). It has been suggested that some of the survivors of encounters with gill nets may have impaired spawning potential (Petrova 1964)." p. 1

"Hunter et al. (1972) presented evidence that an average 73% of sockeye salmon escaping gill nets in Puget Sound on the Pacific Coast died in six days compared with 10% for a control group. Thus, the mortality rate on the escapees could be as high as 60%. For further calculations, it is assumed that 50% of the escapees from encounter with the net die as a result of the encounter. If this were the case in the Greenland fishery, and Ritter et al. (1979) present evidence suggesting that this is most likely; then, for a catch of 1,200 tonnes at Greenland, 28% or 336 tonnes would escape the gill nets and about 50% of these, or 168 tonnes, would subsequently die." p.6

The author concludes that escape mortality in this fishery equals 10% of the catch.

REFERENCE #: D010

Angelsen, K. K. 1981. Engineering and fish reaction aspects of gillnetting - a review. ICES C.M. 1981, B:34. 10pp

A. Gear construction and operation

"Comparative fishing experiments have shown that multifilament gill nets are less efficient than nets made of monofilament materials. In the dark period of autumn and winter in Northern Norway this difference is not so pronounced and gill nets made of multifilament polyamide are still much used, because they are cheaper." p. 3.
"In general lightly floated nets fish best, but they are also more easily flattened by currents. The amount of buoyancy also affects the catching efficiency of the net." p. 5

"Data on fuel consumption in different types of fishing has been reported by Endal (1980) who found that the fuel ratio (kg fuel/kg fish) for coastal fishing was 1/10 of that for middle water bottom trawling and 1/2 of the figure for near water longlining. In coastal fishing, gill netting is the most important gear and the fuel ratio, 0.1 kg fuel per kg fish caught demonstrates that gill netting is low in fuel consumption compared with other types of fishing." p. 6

C. Selectivity

"Experiments in Norway on spawning cod also demonstrate that the catch per net is changing with the hanging ratio." p. 4. "In shallow waters gill nets seem to fish better in the night than during day (Pristas and Trent 1977)." p. 5

Tank experiments with salmon indicated the following: "Fish that hit the net without being gilled wrench strongly with head or tail at the same time as they move backwards or alongside the net. Therefore, if the net hangs loosely, there is a great chance of the fish getting entangled. Fish that are gilled on a mesh swim strongly forwards and try to pull the net with them. If they do not slide through, they soon turn and swim in the opposite direction getting still more entangled (Angelsen and Holm, 1978)." p. 7

"In the cases of cod and halibut, when fished on the spawning grounds, it is the more active males that easiest get caught." p. 7. "Fish may be chased into the net either by predators or human action, or conversely they may encounter the net when chasing their prey." p. 7

"A recent experiment in the North Sea to compare the effectiveness of gill nets and longlines, gave no cod caught on longlines which gill nets gave an average of 3-4 cod per net." p. 8. Regarding Rollesen (1953)(Ann. Ref. A001) on cod: "The conclusion was that the smaller size groups have a very pronounced tendency to be caught on longlines, while on the other hand the larger size groups are under represented in line catches compared to those of the purse seine. The purse seine demonstrated also the existence of a group of fish that had previously been naturally protected against longlines and nets by their larger size and by their behaviour." p. 9

D. Fishing mortality

"Observations made by UTV (Olsen, K. 1981) showed a number of dead herring laying on the sea bottom in the vicinity of cod gill nets. An estimated additional 40-50% of the catch landed appeared to be killed and lost. Probably other forms of net damage such as loss of scales might lead to further deaths at a later time." p. 8

"In some of the Norwegian rivers up to 90% of the salmon caught had gill net marks on their body, and there is a serious fear about their ability to survive." p. 8

E. Habitat impact

"In the demersal gill net fishery in the North Sea the fish are found and caught mostly on hard stony- or coral bottom. This has also a negative effect on the catch, in some areas up to 40% of the gill net catches were destroyed (eaten up) by amphipods and similar bottom animals." p. 5

REFERENCE #: D011

Stewart, P.A.M. 1984. Gill net selectivity in the North-East Scottish inshore cod fishery. ICES C.M. 1984/B:29. 7p

A. Gear construction and operation

"Four nets were constructed from each type of twine, ie monofilament (MO), multi-monofilament (MM), and twisted multi-filament (TM). The mesh size was nominally 152 mm and the netting was 22.5 meshes deep." p. 2

C. Selectivity

"The outcome of a selectivity experiment for a particular species in a given area is likely to be influenced by local biological and environmental factors such as schooling and migratory behavior, light level, water turbidity, tidal flow rate, etc, which will affect the availability of fish." p. 2 "...a composite net constructed from equal length panels of multi-monofilament and monofilament netting was tested. Observations in the aquarium on cod showed that when confronted by such a net, the fish swam parallel to the netting then turned into the less visible material close to the panel joints." p. 2

"The fish caught in MO nets were mainly gilled, those in the TM were mainly tangled and the catch in the MM nets showed both characteristics. The size range of the catch in the MO nets peaked at 60-65 cm, whilst that in the TM nets peaked at 40-45 cm. In the MM nets the size range of the catch had two peaks. In the MO nets the snagged fish had a similar size distribution to the gilled fish, suggesting that they had perhaps entered a mesh and then tried to withdraw." p. 3 "The majority were taken in the bottom eight meshes but some fish were taken higher up the net." p. 3

"The differences between the size distributions of the catches taken by the nets of different materials is the most striking result of this study. The textures of the materials is very different. Twisted multifilament is very soft and snags easily, monofilament is hard and springy and multi-monofilament has intermediate properties. Although the MM nets did not catch as many large fish as the MO nets during this experiment, their performance was adequate. As multi-monofilament is easier to handle on deck, the preference of fishermen for this material can be understood." "...most of the gilled cod were caught in the bottom of the nets. Together with the information on net height, this suggests that the fish were moving mostly at slack water when the nets would be upright. This evidence confirms the views of fishermen that cod tend to be mobile only at slack water. P. 4

F. Management issues

"If conservation of the stocks is considered, then monofilament seems to be the best material for gill nets and twisted multi-filament the worst. The TM nets as hung were unselective and caught a wide size range of fish and crustacea. Nevertheless, all the fish caught were larger than the legal minimum size and the method is far less destructive of juvenile fish than trawling or seining." p. 4

REFERENCE #: D012

Carr, H.A. and R.A. Cooper. 1987. Manned submersible and ROV assessment of ghost gillnets in the Gulf of Maine. In Proceedings of the Oceans 87 Conference, Halifax, Nova Scotia. Marine Technology Society: 622-624.

D. Incidental Fishing Mortality

This is a report on a three year study to determine the impact of lost demersal gillnets on two fishing grounds; Jeffreys Ledge and Stellwagen Bank. Lost nets were observed for vertical profile, net integrity, fouling, catch, and fate of the catch. Nets found in the first year were revisited in years two and three.

On Jeffreys Ledge about 0.1 square nautical miles were visually examined. "During these transects...we found two 20 mm trawl wires, one 5-8 metre piece of braided nylon netting, two derelict longlines, a series of overturned boulders and rocks, and one 10 m piece of gillnet." No catch or evidence of catch was observed in or around the net. On Stellwagen Bank a similar amount of ground was covered and sightings included "...one trawl wire, three pieces of large diameter hawsers, one longline, two active gillnets, one small gillnet fragment and one derelict net that was 700 m long." The derelict net had a maximum vertical profile of 1 m and was mostly covered with filamentous growth. There was a catch of 37 dogfish in various life stages from alive to only the notochord remaining. Other species in the net included bluefish, lobster, and Cancer crabs. Hagfish were observed preying on the caught fish. The net was observed one month later and no live or recently deceased catch was found; only some dogfish notochords.

A number of other derelict nets were found and repeatedly observed. "...we calculate that approximately 2240 ghost nets lay in the 64 square nautical miles of traditional gillnet grounds. We define a net as a standard 300 (91 m) foot long gillnet. These nets were fishing at a rate that was about 15% of what commercial groundfish gillnets would normally fish. This estimate is based on our data on reduced vertical profile, fouling, and integrity of the nets."

"All of the ghost nets found were nets that appear to be at least four years old; most are probably seven years or older. We believe these nets were lost about 1980 when the commercial gillnet fishery was most active and was comprised of fishermen with little experience. Gillnet losses today are much less and not due to inexperience as much as conflict with mobile gear."

REFERENCE #: D013

Carr, H. A. and A. Blott. 1991. A study of ghost gill nets in the inshore waters of southern New England. Proc. Fish. Conservation Workshop, Rhode Island Sea Grant. p.2-5.

D. Fishing mortality

"The specific objective of this study was to determine if degradable float systems reduce the active fishing life of a bottom tending derelict gill net."

"Three different types of degradable plastics were used. Two types had different shapes but were both composites of polyethylene and 15 percent starch with aluminum stearate and a copper acetylacetonate catalyst. The other was a blend of a low density polyethylene (80 percent) and polycaprolactone (20 percent), (Gonsalves et al 1989). Twenty floats were attached over a 48 m section of netting with these plastic panels.." p.3.

"On the second and third days after the initial setting of the nets, the vertical profile of the buoyant sections diminished as fish became gilled or entangled and twisted in the webbing, which reduced the height in specific locations."

"The experimental floatation arrangements were intact...73 days after the gear was set. By this time the monofilament webbing was becoming fouled with bryozoans. The fouling increased the visibility of the webbing. Along certain locations of the net, the webbing was clean with no bryozoans. This was usually the result of entangled fish cleaning the immediate webbing while struggling to escape."

"The bluefish catch was initially high, 22 fish, but quickly decreased as the net became fouled with bryozoans."

"We did observe...finfish escaping from the net. One of the most notable incidents was a bluefish which was entangled about the jaw. When divers approached the site where the bluefish was entangled, the fish twisted and managed to free itself.

"Finfish were also observed feeding on entangled fish and invertebrates. The cunner (*Tautogalabrus adspersus*) was most numerous near the nets and was the most aggressive feeder. One event...was a school of cunner feeding on a dogfish carcass."

"The predominant invertebrate caught in the nets was the American Lobster. On July 6 the total catch was 18 lobsters; on July 19 the total catch was 37 lobsters; and on August 28 the catch was 36 lobsters. On January 25 the lobster catch was five, four alive and one dead. We presume that most, if not all, of the lobsters caught in the gill net die. Dead lobsters were seen in the net with there exoskeletons intact."

REFERENCE #: D014

Breen, P.A. 1990. A review of ghost fishing by traps and gillnets. In R.S. Shomura and M.L. Godfrey (eds.) Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dept. Comm., NOAA Tech. Memo. NMFS. NOAA-TM-NMFS-SWFSC-154: 571-599.

D. Incidental Fishing Mortality

This is a review paper on what is known about ghost fishing in trap and gillnet fisheries. There is a limited amount of information available on ghost fishing in trap fisheries, except for a few fisheries in North America. Ghost fishing has been documented in gillnets, but to what extent it is a problem is not known.

The paper clarifies terminology and reviews the documented mechanisms of capture and retention in traps. "...ghost fishing can occur through a variety of mechanisms: auto-rebaiting, rebaiting by other species, attraction by living conspecifics, or attraction by the trap alone. The trap may kill through starvation or by facilitating cannibalism and predation. For some species, conspecific repellency may prevent or reduce ghost fishing. Ghost fishing may be significant on species other than the target species." p. 574.

Ghost fishing has been documented by the recovery of lost gear, trap loading experiments, laboratory and field observations. Trap loss rates are given for several fisheries and the fate of lost traps discussed. There is a detailed discussion of measures to prevent and reduce ghost fishing in trap fisheries.

The paper also contains a review of the mechanisms associated with ghost fishing in gillnets which seems to be overshadowed by the incidental taking of marine mammals. Underwater observations of lost nets and field experiments simulating ghost fishing are presented. Rates of gillnet loss and the fate of lost nets has been documented to a limited extent but there is limited information on potential solutions.

The author concludes that ghost fishing has not been well studied and that the potential problem may be significant due to the large amount of trap and gillnet gear in use worldwide. The paper has almost 100 references listed.

REFERENCE #: D015

Gagnon, M. and M. Boudreau. 1991. Sea trials of a galvanic corrosion delayed release mechanism for snow crab traps. Canadian Technical Report of Fisheries and Aquatic Sciences. No, 1803

A. Gear construction and operation

Every year, several thousand snow crab traps are lost in the Gulf of St. Lawrence. Crabs entering these traps are unable to leave, and research has shown that the polypropylene mesh covering the traps can last for 5 years before decomposing. Lost traps can thus fish for years, causing significant mortality.

Three types of delayed release mechanism have been tried to allow the catch to escape:

- part of the trap is made of a biodegradable or corrosive material (wood, cotton, untreated metal);
- the door is held shut by a biodegradable or corrosive attachment
- some meshes are replaced by a biodegradable or corrosive thread

The timing of the release of the biodegradable or corrosive sections depends upon many factors and is thus unpredictable, and so fishermen hesitate to use these devices as they worry about premature release.

A galvanic time release mechanism consists of an active metal cylinder (anode) joining together two stable metal eyelets (the cathodes). Immersion in a conducting electrolyte (sea water) produces accelerated corrosion of the anode while the cathodic corrosion is slowed.

Trials showed that good predictability of release date was possible. For instance, one device AG75, released after an average of 75 days, with 95% releasing between 71 and 78 days, and AG100 released after 115 days (95% from 109-121 days). As the speed of corrosion of these galvanic devices is less dependent upon local conditions (temperature, salinity, etc.) the predictability of the timing of release is greater, a significant advantage over other devices.

The Impact of Towed Gear on the Benthos

REFERENCE #: E001

Gibbs, P.J., A.J. Collins, and L.C. Collett. 1980. Effect of otter prawn trawling on the macrobenthos of a sandy substratum in a New South Wales estuary. *Aust. J. Mar. Freshwater. Res.* 31: 509-516.

D. Incidental Fishing Mortality

This study was initiated because recreational fishermen were claiming that otter prawn trawling was killing benthic organisms thus reducing their angling success. The trawls used were 11 m in length, 38 mm mesh, and had no tickler chains. The gear was designed to skim lightly over the bottom.

The experiment was conducted in Botany and Jervis Bays. In Botany Bay, a trawl was repeatedly towed over known sites for one week. Benthic samples were collected before and after the towing period using a grab sampler. A total of 3546 individuals were collected representing 103 taxa.

Underwater observations were made in Jervis Bay. The footrope was observed to skim lightly over the bottom, disturbing very little sand, and the doors made a more noticeable disturbance, ie, generated a sand cloud. The sea bottom was only lightly marked after repeated tows.

"The classificatory analysis of the dominant species and the analysis of the community statistics of the different faunal groups indicate that otter prawn trawling, as carried out in most New South Wales estuaries, causes no detectable alterations in the macrobenthic fauna. This conclusion is further confirmed by our underwater observations."

REFERENCE #: E002

Main, J. and G.I. Sangster. 1981. A study of the sand clouds produced by trawl boards and their possible effect on fish capture. Scottish Fisheries Research Report 20: 20 p.

A. Gear Construction and Operation

Underwater observations were made on four types of trawl doors; wooden rectangular flat, steel rectangular cambered, steel polyvalent, and steel rectangular vee. Angle of attack and spread were measured as well as sand cloud parameters. The report contains photographs and plots depicting the sand clouds.

Polyvalent and cambered doors produced a narrower sand cloud than the flat and vee doors. The authors believe that it may be advantageous to place small pony doors between the main doors and bridles to fill in any gaps in the sand cloud.

C. Selectivity

Trawl performance can vary significantly based on how the doors are rigged. "Correct bridle angle in relation to towing speed is essential for effective herding of larger fish into the mouth of the net leaving the smaller sizes behind. Too small a bridle angle could lead to the effective herding of the small fish and the loss of the important larger fish.

E. Habitat Impact

Tidal flow during the experiment was low. Sediment type in the tow area was fine sand (median diam: 169-185 μm) with small amounts of organic matter and very little clay (0.3%).

"The appearance of the sand cloud, but not its size, is governed by the type of seabed. Brief observations on different seabed types show that soft, light-coloured mud produces the most opaque and reflective type of cloud and the fine mud remains in suspension much longer than coarse sand. When the board passes over small patches of hard ground no cloud is generated but larger particles are seen sucked up which immediately settle (Main and Sangster, 1979) (Plate VII)."

REFERENCE #: E003

Dolah, R.F. Van, P.H. Wendt, and N. Nicholson. 1987. Effects of a research trawl on a hard-bottom assemblage of sponges and corals. Fisheries Research 5: 39-54.

D. Incidental Fishing Mortality

"The effects of a research trawl on several sponges and coral species was assessed in a shallow-water, hard-bottom area located southeast of Savannah, Georgia. The study entailed a census of the numerically dominant species...located along five transects established across a trawling alley. The density of undamaged sponges and corals was assessed in trawled and non-trawled (control) portions of each transect immediately before, immediately after, and 12 months after a 40/54 roller-rigged trawl was dragged through the alley once."
Abstract.

Limited damage was observed after the tow; one species of barrel sponge was significantly reduced in number. After the 12 month period, species density was back up to, and even higher than, the original census. Damaged specimens could no longer be detected.

The gear used in this experiment had a 12,2 m headrope and a 16.5 m footrope. The sweep consisted of six 30-cm rubber rollers separated by 15-cm disk spacers. The doors were 1.8 x 1.2 m China-V type attached to the net with 30.5 m legs. The resulting impact of this gear was substantially less than a previous study (Tilmant, 1979). Tilmant's study used a roller frame trawl that had non-flexible roller assemblies, 13 cm in diameter, which the authors speculated would have caused more damage. Tilmant's study area was also subject to additional fishing by commercial vessels.

Corals and sponges of many species may be very slow growing, some taking 40 years to reach heights of 50 cm. The height of these organisms, especially on flat bottom, is an important feature in attracting fish to these areas.

The authors conclude that much of the damage was caused by the lower legs connecting the door to the trawl. "Trawls with doors attached directly to the nets would greatly reduce the bottom area damaged by trawling activities, as would any modifications to the net roller rig that would raise the lower leg lines further off the bottom." p.52.

REFERENCE #: E004

Fahraeus-Van Ree, G.E. 1990. Reproductive success in Atlantic cod (*Gadus morhua* L.): the potential impact of trawling. A report prepared by Oceans Ltd. for Newfoundland Inshore Fisheries Association, St. John's, Newfoundland: 112p.

D. Incidental Fishing Mortality

This report is primarily a summary of what is known about the reproductive processes in cod and factors that may impact on these processes. The report's focus is on the northern cod stock found off Labrador and Newfoundland. Characteristics of this stock and its ecosystem are presented. Sections of the report cover reproductive processes, reproductive behaviour, fecundity, spawning grounds, growth, recruitment, and the impacts of trawling.

"Canada's Atlantic offshore fishing companies are using trawlers which can catch up to 100 tonnes of fish per day. One tow can cover 6-12 miles in 1.5-3 hours; with an average of 8 tows per day. This means that the otter trawl can cover 100 miles of seabed in one day." With the aid of hydroacoustic fish finding systems, these trawlers can concentrate their effort on prespawning, spawning and post spawning aggregations. "...the pattern of spawning behaviour in cod is a delicate process and can be easily disturbed by internal and external factors. It is likely that spawning fish that have not been caught will be influenced by the trawling activity." Trawling can physically disperse fish leading to suppression of courtship behaviour.

Trawling activity can disperse eggs and milt leading to high rates of fertilization failure. Sediment stirred up by trawling clouds the water column. "This cloudy water may negatively influence the physical (visual, auditory, hydrodynamic, tactile and bioelectric) and chemical (pheromones) interactions between cod males and females as well as the interactions between eggs and milt." Eggs are adhesive thus mud stirred up by trawling can coat the eggs preventing fertilization and even proper metabolic functioning. Mechanical damage and bacterial infection, resulting from stirred up sediment, may increase egg mortality. "At the end of the yolk-sac stage, the larvae are able to feed and will move downward in the water column. At that stage the physical and chemical damage caused by trawlers may be enormous. As cod larvae have proven to be visual feeders at the onset of exogenous feeding, the ability to capture prey organisms may be locally reduced by the mud stirred by the trawlers. In addition, mud may cover the respiratory epithelia preventing the necessary gas exchange." p.86.

Noise due to trawling activities has been shown to influence cod behaviour and may interrupt courtship.

Trawling increases the stress on the spawning fish affecting hormonal balance. This can lead to poor quality gametes and high fertilization failure.

The selective harvest of large cod from an area can lead to an increase in predators that prey on cod eggs, larvae and young fish.

REFERENCE #: E005

Hutchings, Pat. 1990. Review of the effects of trawling on macrobenthic epifaunal communities. Aust. J. Mar. Freshwater Res. 41: 111-120.

D. Incidental Fishing Mortality

This review examines macrobenthic species composition and seasonal changes in tropical areas of Australia, though many references to information outside of this geographic area are included. The specific area of concern is the inter-reef communities subject to trawling. At the time of the review, 1100 trawlers were licensed to fish in the area of concern. The trawls utilize tickler chains, but the net itself is designed to stay slightly off the bottom to minimize the catch of epibenthos.

The primary sedentary macro-benthic organisms of inter-reef tropical areas include sponges, ascidians, alcyonarians, gorgonians, echinoderms, molluscs, and encrusting organisms. These organisms often occur together in small patch reefs on the sand and mud substrates. Much of what is known about the species composition comes from research trawls. Many of the organisms that occur in the inter-reef areas do not occur on the coral reefs and thus are distinct from the reef communities.

The inter-reef areas can be further classified as inshore and offshore. Different communities exist in these environments for reasons sometimes correlated with substrate type, depth, distance from shore, and physical disturbance. Diversity generally increases from shallow to deep sites.

There is a discussion of reproduction, recruitment and growth rates which points out the lack of information. Many corals reproduce by dispersal and survival of fragments, in nature due to storms.

Sedentary fauna are important for providing shelter for juvenile fish. Epifauna are important for reworking sediment and scavenging. The degree of importance is unknown, however as a related example, where seagrass beds have been lost, all infauna has been lost.

Regarding trawling, the author states that repeated trawling physically removes or damages much of the macrobenthos. A number of papers are referenced that demonstrate a loss of species diversity, biomass and individual specimen size in areas that have trawl fisheries. Recovery of these areas is affected by "...size of the trawling ground, the distance from nearby untrawled areas from where larval recruitment may occur, the type and frequency of trawling undertaken, and the time of year when fishing occurs..."

REFERENCE #: E006

Groot, S.J. de and J. Apeldoorn. 1971. Some experiments on the influence of the beam trawl on the bottom fauna. ICES C.M. 1971/B:2. 5 pp.

C. Selectivity

"Cod...there is only a slight increase in catch when the number of tickler chains is increased to four...Whiting...there is hardly any increase in catch when the number of tickler chains is increased to four...Sole... there is an increase in catch when the number of tickler chains is increased to two of about 2.3 ... when using 5 ticklers we know that there is an increase of 4 times compared with no ticklers...when using a sole beam trawl with 5 ticklers this may be about 10 times."

D. Incidental fishing mortality

"Hydrozoa (sea-firs): The damage to the Tubularia species (mainly T. indivisa) is great, however, this effect is mainly caused by the drag of the belly of the net along the bottom...We must assume that nearly all Tubularia in the trawl path will be destroyed by any tow net used...Ctenophora (comb-jellies): Nearly all individuals will be destroyed due to the pressure in the net...Scyphozoa (jelly fish): All individuals are completely destroyed due to the pressure in the net...Bryozoa (sea-mats): ...considerable quantities are caught in the trawl, the damage to the individuals is insignificant...Crustacea-Decapoda:...nearly all hermit crabs survive their stay in the net and on deck."

"...the marketable quality of plaice...is reduced owing to ticklers...we caught frequently clusters of squid eggs, which were affected by the pressure and the mass of items caught in the net."

REFERENCE #: E007

Groot, S.J. de. 1984. The impact of bottom trawling on benthic fauna of the North Sea. *Ocean Management* 9: 177-190.

D. Incidental Fishing Mortality

This frequently-cited paper starts off with a review of historical complaints against trawling. The complaints focused on the fact that trawls catch small fish and destroy bottom organisms that provide feed. Historically, complaints came from the fishermen that did not use trawls but more recently environmentalists have joined in with their concerns.

The review covers some of the early work of Graham (1955) and Arntz and Weber (1970). ICES began to look at the problem in the early 1970's when the French expressed concerns that bottom topography was being altered by trawling around Corsica. Though the Mediterranean is quite different than the North Sea, a series of investigations were launched.

The report examines trawl-related damage by species covering coelenterates, bryozoans, nemertea, annelids, crustaceans, molluscs and echinoderms. Most of the results are discussed in terms of the number of tickler chains used.

There is some discussion of long-term impacts, referencing the work of Reise and others. There were documented changes in faunal composition due to fishing, most notably the Sabellaria-reefs in the German Wadden Sea.

The author felt that the impact of trawl chains and dredges should not be considered separately. "...it is a proven fact that bottom trawls influence benthic life in a negative way. However, as we accept fisheries as a method to support our food supply and as the damage is relatively small, these negative effects may be considered to be acceptable. There is enough food available to sustain the fish stocks, so no negative effects on fish stocks are to be expected."

The author considered benthic organisms as very adaptable to harsh conditions, such as being covered and uncovered by sand. "Still a shift in species distribution and numbers from one group or groups of animals to some others cannot be ruled out in the long-term. As this shift is in principle reversible it constitutes no major threat to benthic life."

REFERENCE #: E008

Rijnsdorp. A.D., P. Groot, and F.A. van Beek. 1991. The micro distribution of beam trawl effort in the southern North Sea. ICES C.M. 1991/G:49: 1-20.

E. Habitat Impact

The studies on beam trawls in the early 1970's concluded that the impacts of beam trawls on the sea bed were not any more significant than other gear types, however no assessment was made on potential effects on benthic organisms. In 1988 an ICES group concluded that it could not be ruled out that " a change in the benthic community from low productive slowly reproducing organisms to quickly reproducing opportunistic species could partly be related to the effect of fishing."

Assessing the impact of fishing gear on the bottom fauna is difficult because the resolution of the spatial distribution of fishing effort is 30 x 30 miles. This data would give the impression that every square meter of bottom was trawled many times per year on average. However, this conclusion would be based on assuming that fishing effort was uniformly distributed when in fact it is not. This study analyzed the actual distribution of fishing effort on 18 Dutch beam trawl fishing trips using 1 x 1 mile resolution.

The data showed that in three out of five ICES rectangles (30 x 30 miles) less than 60% of the available area was trawled. The authors conclude "...the species of the benthic community most vulnerable for trawling can still survive in the untrawled areas and perhaps in those parts that are trawled only lightly, and thus throws doubts on the conclusion that fishing is the main factor involved in the observed benthic changes (Bergman et al, 1991)".

REFERENCE #: E009

Peterson, C. H., H. C. Summerson, and S. R. Fegley. 1987. Ecological consequences of mechanical harvesting of clams. Fish. Bull. Vol. 85, No. 2: 281-298

D. Habitat impact

"Clam harvest did not affect either the density or species composition of small benthic macroinvertebrates from sediment cores, probably because of their rapid capacity for recolonization and generally short life spans." p. 281

"The failure of the benthic macroinvertebrate density to respond to clam harvest treatments in both sand flats and seagrass beds implies that the polychaetes which dominate recover rapidly from disturbance and are probably not adversely affected by clam harvest." p. 281

REFERENCE #: E010

Murawski, S.A. and F.M. Serchuk. 1989. Environmental effects of offshore dredge fisheries for bivalves. ICES C.M. 1989/K:27: 22p.

D. Incidental Fishing Mortality

This is a report on the results of submersible operations, conducted in 1986-7, to evaluate the incidental mortality to sea scallops and clams by the respective commercial dredges. Clams are harvested by hydraulic dredges that utilize water pumped from the surface to dig into the bottom. Scallops are harvested by dredges that tend to skip over the bottom. Since scallops swim, scallop dredges need to be towed faster (4 knots) than clam dredges (1 knot). The submersible dives found a "...dearth of broken or mutilated scallops...in the vicinity of the path after the dredge had passed. Our observations suggest the dredge-induced damage and mortality of uncaught scallops is low (< 5%)." This is a lower mortality rate than previously observed on hard bottom. These tows were conducted on smooth bottom devoid of rocks; rocks possibly playing a significant roll in dredge-induced mortality. In addition, dredges used on hard (rocky) bottom are heavier than on sand bottom thus possibly accounting for differences in mortality.

"We did note, however, invertebrate predators (i.e., starfish) consuming scallop viscera cast from the fishing vessels after shucking. Finfish surveys have previously revealed significant quantities of scallop viscera in fish stomachs...when fish sampling was conducted on scallop fishing grounds. Under normal conditions, scallops would not normally be eaten by these species. Thus, predation on scallop viscera seems to be an important path for energy transfer between trophic levels as a direct result of at-sea shucking of scallops." "...the 1988 USA scallop catch of 13 thousand metric tons of meats...represents 26 thousand tons of biomass recycled as potential fish and invertebrate food." Scallops, ranging in size from 33 to 122 mm, were also tagged during this project and returned to the sea for short-term survival (1-3 days) studies. Survival rates were over 90% suggesting a culling mortality no higher than 10% for the Mid-Atlantic region in summer. The data also indicated high dredge efficiency (> 90%) for commercial gear in the study area.

Regarding clams "Submersible observations indicated that non-harvest mortality of ocean quahaugs was significant and far greater, on a percentage basis, than for sea scallops. Heavily damaged quahaugs were observed lying in dredge tracks, and up to five meters outside the tracks." "Unlike the sea scallop observations, numerous fish and invertebrate predators were seen in and near the hydraulic dredge tracks consuming broken quahaugs." Predators included rock crabs, starfish, red hake, spotted hake, and skate. Dives one hour after a tow found "...dredge track densities of crabs and starfish were clearly much higher than those in surrounding environs (2-5 times more dense). Eight hours after dredging, predator density was more than 10 times that of the nearby vicinity indicating that predators are attracted to the tracks from an extensive area."

Clams were marked and returned to the sea to study culling mortality. Over 90% of the quahaugs survived while over 50% of the surf clams died. This is probably due to the fact that quahaug shells close tightly, surf clam shell remain slightly ajar. "The considerable numbers of minute starfish and benthic feeding fishes seen in the dredge tracks suggest that benthic microfauna 'tilled up' by the action of the dredge were a major prey source."

F. Management Issues

"The fate of small animals (sub-legals) culled from the catch at sea to comply with minimum size requirements is critical to determining the conservation and economic value of fisheries regulations based on minimum or average landing sizes."

"If, in fact, dredge-induced, non-catch mortality is high, significant changes in harvesting technology and gear design may be required to attain maximum resource utilization." "If the harvesting process is inefficient (either in terms of capture/retention performance or species/size selectivity), then shellfish beds may be subjected to both dredge-induced and culling mortalities many times over. Thus, even if the efficiency of a single dredge tow is low, the cumulative effects of multiple dredge passes may be substantial and induce a significant loss in potential yield."

REFERENCE #: E011

McLoughlin, R.J., P.C. Young, R.B. Martin, and J. Parslow. 1991. The Australian scallop dredge: estimates of catching efficiency and associated indirect fishing mortality. *Fisheries Research* 11: 1-24.

A. Gear Construction and Operation

The self-tipping "mud" dredge was developed for the scallop fishery in Australia in the early 1960's. It is designed for easy handling on deck. A typical dredge, such as the one used in this experiment, is 4.2 m wide and weighs about 500 kg. The dredge has teeth and a fixed cage on runners. The authors indicate that the dredges are often towed longer than needed to fill the dredge in dense scallop beds.

C. Selectivity

The catching efficiency and selectivity of the Australian scallop "mud" dredge was examined by an experiment using plots seeded with scallops, *Pecten fumatus*, in the Bass Straits. Catching efficiency was found to be 11.6% overall and 1%-28% increasing with size from 57 mm to 86 mm in shell height. No difference in selectivity was found between two different mesh sizes tested. The authors reference previous work indicating that efficiency varies in three stages; high efficiency at the beginning of a tow, declining efficiency as the dredge fills, and zero efficiency when the dredge is full. The length of the various stages depends on catch and bycatch.

D. Incidental Fishing Mortality

Incidental scallop mortality was determined by carefully monitoring specific areas in Bass Straits before and during the scallop season. Subsamples of commercial scallop catches were examined for dead and injured scallops. A high density bed was identified that was fished by a fleet of 60-80 vessels the first two weeks of the scallop season. "After the first week, as catches declined and large numbers of decomposing scallops on the sea bed began to taint the catches, vessels started to move to other regions...10000 dredge hauls were made in the 2200 boat hours fished during these two weeks..." The authors estimate, using DeLury methods, that the stock was reduced in the two week period by 950 tons, of which only 204 tons were landed. Post-fishing mortality in the study area was 9-15 times higher than on an unfished bed. Four to five times as many scallops were crushed and damaged by the gear as were landed.

"It is worth noting that despite the high indirect fishing mortality over the first 14 days, the CPUE data suggests that >30% of the population was still alive on Day 14. However, post-fishing mortality reduced the proportion surviving to 0.7% after 300 days and 0.1% after 400 days. Thus, while only 12-22% of the initial stock went to the commercial catch, virtually the entire stock was lost within 9 months from the start of fishing."

"A limited amount of micro-biological evidence suggests that *Vibrio* spp. are the predominant natural bacterial types occurring in *Pecten fumatus* and...are responsible for post-catch spoilage. Several catches of freshly landed scallops from Banks Strait were condemned...because of bacterial contamination...Mass mortality caused by *Vibrio* infection has been observed in environmentally stressed pearl shell..."

The authors conclude that scallop fisheries that use heavy dredge gear should examine alternate harvesting strategies.

REFERENCE #: E012

ICES. 1988. Report of the study group on the effects of bottom trawling. ICES C.M. 1988/B:56: 30 p.

A. Gear Construction and Operation

This report presents details on the vessels and gears being fished by the ICES member countries fishing in the North Sea. Plots include the relationship between gear weights and beam lengths for the Dutch flatfish fishery, gear resistance and fishing speed, and components of the resistance of a beam trawl.

B. History and Statistics

Tables and text are provided listing the number of vessels, by horsepower, fishing various gear types in the North Sea.

D. Incidental Fishing Mortality

The document contains a number of reports by individuals summarizing various studies. Excerpts follow:

"Besides the fact that the experiments of the seventies carried out with light gears towed by low powered vessels at low speed (2-4 knots) are not comparable with the ship size, gear size, and towing speed in use today, they describe the effect of a trawl towed only once over a particular type of sea bed." "Based on the number of beam trawl hours per statistical rectangle for the Dutch beam trawl fleet in 1975...Rauck (1985) calculated that in certain squares with high trawl hours, each square metre on average had been fished 3 to 5 times a year. This implies that certain areas within a square might have been trawled 10 times, others not at all during a particular year." "...in coastal waters of the German Bight, benthos is being dug out of the ground by chain mats and tickler chains, damaged or killed and eaten by fish. Those benthic organisms able to survive the first net will be killed or eaten after several further trawl nets have passed."

A study in Kieler Bucht, Western Baltic, gave the following preliminary results: "Trawl tracks can be found in the whole study area below 20 m water depth, sometimes in a density leading to an almost complete coverage of the sea floor." "Immediately after the passage of an otter board, the abundance and biomass of benthic organisms is decreased by 50% and more in the tracks. Release of nutrients from the sediment is qualitatively documented by in situ experiments."

E. Habitat Impact

"On a commercial beam trawl, the tickler chains from the groundrope may need to be changed about every 6 weeks and the tickler chains from the shoes every 12 weeks, indicating the extent of abrasion by the chains on the sea bed." "The depth to which the shoes of a beam or chains of a beam or otter trawl penetrate into the sediment will depend on the consistency of the sediment and also critically on the relationship between the speed of the tow and weight of the gear. The faster the tow, the greater is the lift generated and the more likely the gear to lift off the bottom." "Under normal conditions, the beam trawl is towed at the maximum speed possible just to prevent the gear from coming off the sea bed. In this situation the downward force is greatly reduced, which implies that the weight of the gear is not relevant to the disturbance to the ground."

Regarding sediment suspension, the report concludes that where the natural sediment movement is high the benthic organisms are probably well adapted. In deeper areas, with lower current speeds, the benthic organisms may not survive as well. "An increase in growth rate of flatfish species, especially those feeding on polychaetes (soles) has been observed in areas regularly disturbed by bottom trawls.. ICES young fish surveys do not indicate a reduction in recruitment of flatfish populations and thus do not indicate a major deterioration of the environment in the nursery areas."

The Study Group concluded "...that areas with a soft bottom or with low tidal flows are more likely to be affected by bottom trawling than areas with hard bottoms and strong tidal currents or turbulence e.g. caused by gales in shallow water." Further "...that bottom trawling had both long term and short term effects on benthic communities and that these changes may even be beneficial for the productivity of food organisms for

commercially important species."

REFERENCE #: E013

ICES. 1991. Report of the study group on ecosystem effects of fishing activities. ICES C.M. 1991/G:7: Session Y, 66 p.

E. Habitat Impact

The study group that put together this document focused on the North Sea. The report classifies the effects of fishery activities into short term direct impacts and indirect/longer term effects. Direct impacts include reworking and resuspension of the sediment, catch and bycatch, non-catch mortality and injury, dumping of discards and offal, and litter generated by fishing vessels. Indirect and long term effects are trophic changes in species interactions, habitat alteration, and changes in genetic complement of populations. The document is heavily referenced. The following are selected extracts from the report:

"Compared to a host of other anthropogenic activities, fishing seems to be the most important activity causing physical disturbance of the seabed. However, many benthic communities are likely to experience disturbing events due to storms and currents which may be at least equivalent to those caused by fishing. The present knowledge is, however, insufficient to quantify the relative importance of these two sources of disturbance."

"Discarded fish provide a source of food to seabirds feeding at or near the surface. Estimates of the amount of discarded fish and offal suggest that substantial numbers of certain birds, e.g., fulmars, may be sustained by this source of food. Little is known about the fate of items which sink beyond the reach of birds, but these constitute a potential source of food for pelagic and demersal fish as well as for benthic scavengers."

"It is difficult to ensure that the direct impacts of fishing are in fact comparable to the direct impacts of other processes." "At present, science is not able to provide defensible advice on trophic consequences of fisheries impacts, except for a relatively few commercially important species." "We also know little of the population genetics of marine species whose populations are harvested. The long-term implications of fishery-induced selection may be important, particularly the possibility that populations and assemblages would not return to pre-fishery conditions, were fishing pressure removed."

"...spatial distribution of fishing disturbance is likely to be patchy, both within and between habitats. This patchiness will have profound effects when assessing the importance of fishing disturbance." "Fixed gill and tangle nets have minimal effect on benthos except to increase mortality on crabs which become entangled in the nets. In shrimp trawls, pair trawls, Danish and anchor seines there is little penetration of the gear into the sediment and the main effect is the removal of epibenthos in the path of the net and their damage in the cod-end or during treatment on board."

"Scallop dredges are designed to dig into the surface of the sediment and can cause extensive mortality to the benthic organisms particularly in areas with established sessile epifauna. A high percentage of the catch can consist of larger epibenthos which are discarded and are likely to die as a result of the damage suffered in the dredge." p. 6.

"In future, if net-mesh sizes used in the northern North sea are increased, fewer fish may be expected to be discarded, and those that are will be of a larger size. Due to the selectivity of seabirds, and the dominance of the larger species around fishing vessels, it has been predicted that herring gulls and great skuas will suffer in competition with great black-backed gulls and gannets (Hudson and Furness 1988). More extreme proposals, such as the cessation of discarding, will surely have a major impact on the scavenging seabird populations." p. 41.

REFERENCE #: E014

Mayer, L.M., D.F. Schick, R.H. Findlay, and D.L. Rice. 1991. Effects of commercial dragging on sedimentary organic matter. *Marine Environmental Research* 31: 249-261.

E. Habitat Impact

"A heavy scallop dredge caused two types of organic matter translocation- some of the surficial organic matter was exported from the drag site and the remaining material was mixed into subsurface sediments." "Sediment mixing by some types of gear will likely result in burial of labile organic matter and hence may shift sediment metabolism toward microbial and anaerobic food chains." Abstract.

"The use of bottom-dragging gear by the commercial fishing industry can have a variety of impacts on the benthic ecosystem. These impacts will depend on many factors, such as the type of bottom being dragged, the type of gear and its manner of deployment, and the time of the year. Impacts may be expressed by changes in the biology, sedimentology, and biogeochemistry of the benthic environment."

This research project took place along the coast of Maine at two sites; an 8 m deep mud-bottom tidal area and a 20 m deep protected basin. Bottom cores were taken before and after towing. The gear towed on the first site was a New Bedford style scallop drag; the second site was towed by a small otter trawl. Extensive chemical analysis was undertaken on the core samples.

Divers observed that the scallop drag reduced the sediment height in its path by about 2 cm and that the drag tilled to a depth of 9 cm below the original sediment-water interface. Organic matter vertical profiles were strongly affected by the drag. At the second site, the otter trawl had little impact in this regard, but there was some lateral transport of surficial material.

Vertical mixing may impact decomposition kinetics. "The importance of estuarine and shelf sediments in the global carbon cycle, coupled to the ubiquity of dragging these areas, makes such studies important ones relative to human perturbations of the carbon cycle." p. 260.

REFERENCE #: E015

Messieh, S.N., T.W. Rowell, D.L. Peer, and P.J. Cranford. 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. *Continental Shelf Research* 11(8-10): 1237-1263.

E. Habitat Impact

This is a review paper that starts out with a description of the eastern Canadian shelf surficial sediments and benthos. Details are provided on the fishing industry in these waters which consists of 4000 mobile gear vessels. The fleet harvests groundfish, scallops, clams, and marine plants. Attention is also given to non-fishing activities involving dredge spoils and drilling waste.

Gear impacts on habitat are listed and include incidental mortality or damage to species, increased predation of exposed infaunal species, alteration of sediment chemistry and sediment resuspension. Sediment resuspension can reduce the food available to filter feeders, affect metabolic rates, smother spawning areas, damage gills, introduce toxic contaminants and increase rates of benthic/pelagic nutrient flux. The latter condition might stimulate plankton blooms. Impacts may have net positive or negative results.

Physical impacts are easy to observe and consist of tracks and marks left by the gear on the bottom. The authors estimate that in 1985, mobile gear covered 4.3 million miles of track in 785,510 hours of fishing time.

Biological impact studies are reviewed, including studies from other areas. The report concludes..."The available information on the effects of trawling and dredging for fish and shellfish on the eastern Canadian continental shelf clearly demonstrates numerous short-term effects on both seabed and benthic organisms. Evidence for either positive or negative long-term impacts is more limited and hampered by the lack of historical data on benthic communities and the effects of natural perturbations."

Regarding sediment resuspension..."Chronic sub-lethal effects on essential biological processes (e.g. feeding, respiration, etc.) may however result in lower population production and/or have damaging implications for the reproductive success of adults and the survival of egg and larval stages of some species. This could lead to long term changes in community structure."

REFERENCE #: E016

Jones, J.B. 1992. Environmental impact of trawling on the seabed: a review. *New Zealand Journal of Marine and Freshwater Research* 26: 59-67.

E. Habitat Impact

This paper contains an extensive review of the literature available on the impact of otter trawls, beam trawls, dredges, and Danish seines. The author categorizes the observed effects as scraping and ploughing, sediment resuspension, destruction of non-target benthos, and dumping of processing wastes. Several examples of indirect effects are presented.

"There are few conclusive studies linking trawling to observed environmental changes since it is difficult to isolate the cause. However, permanent faunal changes brought about by trawling have been recorded. Research has established that the degree of environmental perturbation from bottom trawling activities is related to the weight of the gear on the seabed, the towing speed, the nature of the bottom sediments, and the strength of the tides and currents. The greater the frequency of gear impact on an area, the greater the likelihood of permanent change. In deeper water where the fauna is less adapted to changes in sediment regimes and disturbance from storm events, the effects of gear take longer to disappear. Studies indicate that in deeper water (>1000 m), the recovery time is probably measured in decades." Abstract.

The author concludes that changes in the seabed can affect the fisheries above, but to what extent this is a factor in fishery declines has seldom been considered in the literature.

REFERENCE #: E017

Bergman, M.J.N., and M. Hup, 1992. Direct effects of beamtrawling on macrofauna in a sandy sediment in the southern North Sea. ICES J. mar. Sci, 49: 5-11.

In order to gain more information on the depth of penetration of heavy, high-speed beam trawls, sampling of benthic fauna was carried out before and after fishing with a commercial beamtrawler in the North Sea. Beamtrawlers in the North Sea have become more popular over the last 20 years. Modern gear is heavier than in the past, and towing speeds have increased. Past studies have shown that light beamtrawl towing at a speed of 4-7 km h⁻¹ may cause damage to organisms on and below the bottom layer, and beamtrawls rigged out with heavier tickler chains will catch more organisms below the bottom layer. In this study researchers gauge the effects of modern beamtrawling on benthic fauna by measuring differences in densities of benthic animals before and after trawling.

Fauna was sampled four times in a specified area: 1) before trawling started, 2) 8 hours after the area was fished once, 3) 16 hours after the area was fished for the second and third times, and 4) two weeks after the second sampling. Three-fold trawling lowered the densities of the echinoderms, *Asterias rubens* and small *Echinocardium cordatum*, as well as the tube-dwelling polychaete worms, *Lanice conchilega* and *Spiophanes bombyx*, by 40-60 percent. There was a significant increase in density of one species of worm. The density of the fauna caught two weeks after the second sampling was significantly lower than the density before trawling started.

Based on the presence in the hauls of the heart urchin, *E. cordatum*, and the bivalve, *Arctica islandica*, the tickler chains must have penetrated at least 6 cm into the sediment. Species such as these may help indicate the thickness of the sediment layer scraped off by the trawl tickler chains since they inhabit certain regions within the sediment. Only a minor part of the population of *E. cordatum* is reached by the net, mainly the smaller individuals living in the first 10 cm below the surface. The vertical distribution of the different species in the sediments seems to be an important factor determining the catchability of the fauna.

Beamtrawling may contribute to changes in the benthic system in terms of species composition and possibly production rate. Long-term effects of beamtrawling on the North Sea ecosystem can be carried out only if trawling is banned in a representative fishing area for an extent of time.

REFERENCE #: E018

Kaiser, M.J., and B.E. Spencer, 1993. Opportunistic feeding on benthos by fishes after the passage of a 4-m beam trawl. ICES Demersal Fish Committee, CM/G:27.

Not to be cited without prior reference to the authors

Two species of gurnard, *Eutrigla gurnardus* (L.) and *Aspartrigula cuculus* (L.), and lesser-spotted dogfish, *Scyliorhinus canicula* (L.), were collected in the Irish Sea before and after passage of a 4-m beam trawl to test whether benthic animals in trawl tracks become more susceptible to predation. Other studies have indicated that beam and otter trawls damage fragile benthic species and then become a potential food source for epibenthic predators. As yet, there are no quantitative studies to support the opportunistic use of this temporal food source.

Fish were collected before and 3 hours after fishing the same track three times with a 4-m beam trawl. A comparison of the species found in the stomach contents of fish indicated that fish were feeding selectively. Gurnards increased their intake of *Ampelisca brevicornis* (amphipod) and *Crangon crangon* (crustacean sp.) significantly after the passage of the beam trawl, whereas dogfish only increased their intake of *A. brevicornis*. Some species of crustaceans were only found in gurnard and dogfish stomachs after trawling.

The chain mat of the trawl passing through the upper layers of the substratum may have disturbed amphipods so that they were more easily preyed upon. Crustacean species which increased in the stomach of gurnard after trawling (*L. holsatus* and *C. crangon*) are mobile epibenthic scavengers and may congregate around tracks by responding to the scent of the animals damaged by trawling. They may also have been killed directly, becoming available to predators.

The authors conclude that predatory fish benefit from animals killed or disturbed from their burrows, or other smaller predators that move into a recently trawled area. They also showed that 3 hours after fishing there were almost 4 times as many shoals of fish over the trawl tracks compared with the adjacent unfished area. "Food generated by beam trawling could provide a significant component of the diets of certain opportunistic fish species in some areas subject to intensive beam trawl activity."

REFERENCE #: E019

Sainsbury, K.J., R.A. Campbell, R. Lindholm, A.W. Whitelaw. Experimental management of an Australian multispecies fishery: examining the possibility of trawl induced habitat modification. Unpublished MS.

B. History and Statistics

The Northwest Shelf in Australia supports a diverse Indo-West Pacific fish fauna of several hundred species. There was a brief period of trawling in 1959-63 and then intensive pair trawling began in 1971. A small domestic trap fishery began in 1984. To test the effect of trawling on the fish communities, one portion of the Shelf area was closed to foreign trawling in 1985 and another in 1987, while one area remained open. Trap fishing was allowed throughout the area. A domestic trawl fishery began in 1989 in the region closed to foreign trawling, which complicated the experimental design.

C. Selectivity

Video cameras mounted on the trawl showed the interaction between the trawl footrope and the epibenthic organisms. Possibilities were (a) no effect, (b) removal with the organism rolling under the net, (c) removal with the organism moving into the net and (d) unknown. Of those encounters when the result was observable (i.e. a, b or c) 89% showed removal of the organism from the substrate (b or c). The vast majority were dislodged and rolled under the net (b) with only about 8% being retained by the net (c). Most removals of benthic organisms by trawling will not be detected, and their fate is unknown.

E. Habitat Impact

Research surveys conducted between 1962 and 1983 showed that the abundance of high valued fish (from the genera *Lethrinus* and *Lutjanus* in particular) declined with the development of trawl fishing, and that the abundance of some lower valued fish (*Nemipterus* and *Saurida* in particular). The catch rate of epibenthic organisms such as sponges also decreased. Photographic surveys of the seabed in the early 1980s showed that *Lethrinus* and *Lutjanus* were more often found in areas with large (>25 cm) benthic organisms than in areas without them. *Nemipterus* and *Saurida* were more often found in areas without large epibenthos.

This paper reports observations during the first 5 years of the experiment (1985-1990). In areas which were closed to trawling, the density of fish increased, the abundance of small benthos increased and the abundance of large benthos was constant or increased slightly. In the area open to trawling, the abundance of fish, large benthos and small benthos all decreased.

F. Management Issues

The results of the management experiment strongly indicate that habitat recovery dynamics are slower than was previously thought to be the case, so that resource recovery will be slow. Furthermore, direct observations of trawl-habitat interactions have shown a high rate of damage to the habitat on encounter with trawl gear. Consequently a high-yield fishery is expected to be slow to attain, and difficult to maintain if existing trawl fishing methods are used.

REFERENCE #: E020

Rutherford, J.C. 1987. A preliminary study of the dispersion of hoki wastes and potential oxygen depletion off the west coast of South Island. Fisheries Research Centre Internal Report No. 79. New Zealand Ministry of Agriculture and Fisheries.

E. Habitat impact

“The objectives of this study were to:

- (i) make a preliminary assessment of the comparative impacts of the present methods for disposal of hoki wastes over the fishing grounds versus proposed methods (minced);
- (ii) conduct experiments to measure the total amount and rate at which oxygen is consumed by hoki wastes and the sinking rate of wastes; and
- (iii) develop a simple mathematical model which incorporates sinking, dispersion, decay and oxygen depletion, and also allows for consumption by sea birds and bluefin tuna; use literature values or best guesses for model parameters that have not been measured; Quantify the uncertainty in predicted impacts to facilitate decision-making.” pg 2

Some important conclusions of the paper:

- the sinking rate at 19° were 10-15 cm/sec for unminced wastes, 10 cm/sec for the large fraction of minced wastes, 5 cm/sec for the small size fraction of minced wastes and about 3 cm/sec for very fine material.
- currents along the west coast of South Island would be expected to advect the wastes from 0.7-2.8 km while they sink, so the wastes dumped over the fishing grounds are likely still on the grounds by the time they reach bottom.
- for the Hokitika Canyon grounds (off South Island), scavenging would account for less than 1% of the 47,800 tonnes of wastes which are estimated to be dumped each year.
- based on data collected on northern hemisphere fish related to hoki, it is suggested that hoki have a lower oxygen tolerance of 6 g m^{-3}
- if 140,000 tonnes of hoki are caught in the 200 km^2 fishing grounds of the Hokitika Canyon and wastes are dumped during a 60 day period, then oxygen depletion near the seabed of at least 2 g m^{-3} would be expected, which would reduce oxygen concentrations to $4-5 \text{ g m}^{-3}$. It is possible that adult hoki would find these oxygen levels stressful. The oxygen depletion would be confined to water within 30-50 m of the seabed and would persist for 10-30 days after fishing terminated. If fishing is concentrated over a smaller area, say 40 km^2 then anoxic bottom waters can be expected with the production of lethal levels of hydrogen sulphide in a zone of 50 m or more above the seabed.
- waste disposal undoubtedly has a greater effect on benthic communities than on hoki but the author made no attempt to quantify such effects

REFERENCE #: E021

Chopin, F.S. and T. Arimoto. 1995. The condition of fish escaping from fishing gears - a review. Fisheries Research 21:315-327

D. Incidental fishing mortality

“The capture of immature fish in many fishing gears is controlled by restricting the use of fishing gears or elements of fishing gears that prevent the escape of immature fish. Improving the selective characteristics of fishing gear is based on the assumption that fish escaping are not seriously damaged and able to make a complete recovery. If fish escape and die as a direct result of stress and injuries or indirectly due to disease and predation associated with gear damage, then increasing the opportunity for escape by improving selectivity may result in an increased level of unaccounted fishing mortality.” abstract

The paper reviews the mortality rates of fish and other species escaping from various gear types and found them to be highly variable, both within and between studies: seine nets, 0-85%; trawls, 0-100%; dredges, 10-88%; gillnets, 2-100%; hooks and lines, 0-86%. Differences in methodology, duration of the observations, definition of injury could account for some of the variability.

The authors note that most attempts to reduce mortality of juvenile fish concentrate on allowing the fish to escape, rather than developing alternatives which allow the fish to avoid contact with the gear. Fish are thus subjected to all the capture stressors and physical injuries due to contact with other fish, debris and the fishing gear. The limited research which has been done suggests that the effects of these stresses can be quite severe.

F. Management issues

“In conclusion, the main requirement for determining the fate of fish after escape should be in the commercial fishing sector where the problems of excess fishing pressure on both domestic and high seas fish resources and the decline in fish stocks continues to be a global problem. The use of gear selectivity as a fishery management tool without adequate research into the fate of fish encountering the fishing gear but not caught should be a cause for concern in any fishery but especially those that either fully or over exploited..... It is therefore likely that any attempts to increase the number of fish escaping from fishing gears will result in an increase in the levels of mortality and injury to escapees. In this respect, regulatory measures to increase the escape of immature fish by increasing codend mesh size, using square mesh, etc. might also result in increased levels of mortality. Thus, using fishing gear selectivity as a fisheries management tool without adequate research into the condition of fish escaping from fishing gear may not be the most effective way to protect immature fish.” pg 324

Non-Target Catch in Groundfish Trawls

REFERENCE #: F001

Robertson, J. H. B. 1985. The selection of trawl codends with long and short extensions. Working Paper No 9/85, DAFS, Aberdeen. 10pp.

C. Selectivity

Underwater observations found that codend mesh openings were affected by the length of the extension (the portion of the net just in front of the codend). The test trawl used in this experiment had a section in front of the codend that was 12.2 m long. "This can be thought of as the first section of the extension. In the short extension case the codend was attached directly to this tapered section. In the long extension case, a 12.2 m long untapered section of netting (nominally 80 mm mesh size) was inserted between the codend and tapered section." The codend was 120 meshes around and 65 meshes long with a mesh size of 83.4 mm.

It was found that the short extension gave a greater 50% retention length due to the fact that there were more open meshes in the codend. "The selection is sharper in the short extension and this is typified by the smaller selection range which is a little over half that of the long extension for haddock and exactly half for whiting. The results support the basic idea. They demonstrate that by shortening the typically long extensions used in trawl nets a measurable improvement in the selection properties of the codend can be achieved."

F. Management Issues

High discard levels may be reduced if short extensions were used. "...present fisheries regulations only specify the minimum mesh size allowable. No other trawl dimensions are legally accountable."

"Robertson and Emslie (1985) have demonstrated that alteration of the width of the codend can also reduce discards. If a short extension were combined with a narrow codend an even greater reduction in discard levels may be achieved. These results suggest that there could be benefits to the fishery, by minimizing discards of undersized haddock and whiting, by means other than mesh size increases."

REFERENCE #: F002

Robertson, J. H. B. and D. C. Emslie. 1985. Selection differences in narrow and wide trawl codends with the same mesh size. Working Paper No 7/85, DAFS Marine Laboratory, Aberdeen. 8 pp.

C. Selectivity

High discard rates of immature haddock and whiting in the Scottish North Sea fishery prompted the Aberdeen marine laboratory to investigate codend design as a means to reduce discard. This paper covers the results of an experiment comparing a narrow codend (60 meshes around) to a wide codend (120 meshes around). The codends were constructed of double braided polyethylene twine having mesh sizes of 78.7 mm (narrow codend) and 81.4 mm (wide codend). A covered codend experiment was conducted using a 26.3 mm cover.

It was found that for haddock the wide codend 50% retention length was 3 cm lower than that for the narrow codend. This is probably due to the fact that the meshes are more open in the narrow codend. The result is a higher selection factor for narrow codends.

F. Management Issues

"Present fisheries regulations specify minimum codend mesh sizes but no other dimensions. This work has demonstrated that reducing the number of meshes on the codend circumference has the same effect on the 50% length as increasing mesh size. To achieve the same 3 cm increase in 50% length in a conventional codend, an increase to about 90 mm mesh size would be required. It might be suggested from these results that the regulations should specify more of the codend dimensions than simply the mesh size."

REFERENCE #: F003

Burd, A.C. 1986. Why increase mesh sizes. Lab. Leaflet, MAFF Direct. Fish. Res., Lowestoft (58). 20 pp.

B. History and statistics

"[In 1376 King Edward III's parliament complained about the use of "the wondychoun (a beam trawl) with meshes the length and breadth of two thumbs" with which "...the fishermen take such quantity of small fish that they do not know what to do with them; and that they feed and fat their pigs with them, to the great damage of the Commons of the realm and the destruction of the fisheries, and they pray for a remedy.]"

"[It was in the reign of Elizabeth I, nearly 200 years later, that the first Act of Parliament was passed which introduced a mesh size limit of "two inches and a half broad" and minimum landing sizes for pike, salmon and barbel]"

"[...another Act was passed in 1714. This "enacted that, as the breed and fry of sea fish has been of late years greatly prejudiced and destroyed by the using of too small size of mesh, and by other illegal and unwarrantable practices, no one shall use at sea, upon the coast of England, any trawl-net, drag-net, or set-net for catching any kind of fish except herrings, pilchards, sprats, or lavidnian (sandeels), which has any mesh less size than three and a half inches (i.e. 90 mm) from knot to knot, or which has any false or double bottom, cod, or pouch."]"

REFERENCE #: F004

Goudey, C.A. and G. Loverage. 1987. Reducing the bottom impact of Alaskan groundfish trawls. In Proceedings of the Oceans 87 Conference, Halifax, Nova Scotia. Marine Technology Society: 632-637.

A. Gear Construction and Operation

This paper describes scale model experiments used to study the effects of trawl design and rigging on bottom-tending performance. High aspect ratio trawl doors spread nets with out dependence on ground sharing forces, and thus have become the fleet standard in the yellowfin sole fishery of the Bering Sea.

Theoretically, these doors can decrease crab bycatch and mortality through a combination of three mechanisms. "First, their narrow width and low angle of attack directly reduce their 'footprint' and therefore the number of crabs exposed to direct impact. Second, their cambered airfoil shape results in a hydrodynamic force which is affected by its proximity to the bottom...This causes a marked inward tilt, and directs the spreading force upward, reducing the on-bottom force of the door. A third effect may be the result of the extreme height of the door. Due to the tension in the ground wire and the bridles, this door height reduces the portion of the cable in contact with the seabed. Importantly, this reduction in crab exposure has not been accompanied by a drop in yellowfin sole harvest...we also observed that when the trawl was underspread (less than 10 degrees) the netting behind the centre of the footrope became loose and sagged toward the seabed. We also noted that, at the highest speeds and widest spreads, the portions of the net just behind the end of the footrope extensions increased their degree of contact with the bottom. Both of these above conditions would seem to increase the likelihood of crab impact, demonstrating the importance of proper trawl operation as well as design."

Two crab sorting devices were also tested for mechanical performance. "One was a forward-facing fabric cone placed in the lower portion of the intermediate section of the net, just ahead of the codend. It is assumed that crabs travelling or tumbling back along the lower panels of the trawl would enter this cone and drop out its narrow end which penetrates the lower netting. Further, it was postulated that targeted fish would avoid the disturbance created by this cone, passing over it into the codend. The second device was a crab escape panel made of evenly spaced longitudinal ropes replacing the lower section of netting behind the footrope. This panel would allow easy escape of crab. It is suspected that finfish would avoid this region due to the mud cloud generated by the ground gear, which direct observations have shown propagate upwards, obscuring the netting in this part of the trawl."

REFERENCE #: F005

West, B. 1987. 1986 Bering Sea trawling impact project. In Proceedings of the Oceans 87 Conference, Halifax, Nova Scotia. Marine Technology Society: 626-631.

A. Gear Construction and Operation

A research project was carried out in the eastern Bering Sea to determine the impact of otter trawls on demersal fauna and habitat. Observations of the gear towed at 3.0 and 3.5 knots were made using a towed underwater camera system.

Two types of trawls were used from a 40 m, 1125 HP vessel; typical of the gear and vessels used in the yellowfin sole JV fleet. The first trawl was a NETS Bering Sea combination trawl using high aspect ratio V-form "Fishbuster" doors. This gear was the most modern of the two tested. The older type gear was an Aberdeen-style 700 mesh Bering Sea western trawl using conventional rectangular V-doors. The footrope of the NETS trawl consisted of chain covered with 6-inch diameter cookies and 14-inch diameter rubber bobbins spaced every 2-3 feet. The western trawl had a chain footrope covered with 8-inch rubber discs throughout.

The project was hampered by weather and poor underwater visibility in areas of crab abundance however, many observations were made on how the gear actually fished relative to bottom contact. Regarding the NETS gear "...it is reasonable to assume that a substantial portion of the sweeps and lower bridles will be held completely off bottom by the tensions resulting from the characteristically high vertical openings of these trawls, the doors' spreading force, large drag forces from the trawl, and from the load in the codend, and the ship's thrust. Only those parts of the lower bridles closest to the trawl, and the region of the sweeps near the midpoint between the trawl and the doors, were seen to make more than occasional contact with the bottom. If the sweeps and lower bridles are fitted with large diameter discs widely separated along the span of the wires, as was the project's gear, then the area of the bottom actually contacted by the rigging will be even less since the large discs tend to hold the rest of the gear off bottom." "...the NETS trawl's footrope, where the large diameter discs and bobbins held the actual footrope some distance above the bottom, provided numerous avenues between them where no ground contact occurred...On the other hand, starfish were observed piling up on and spilling over the Bering Sea Western trawl's heavy, continuous footrope. Confirming these visual observations, when catches from the crab-producing area were compared the Bering Sea Western caught more crabs and starfish than the more modern trawl."

Catch results also indicated that there was not a substantial loss of finfish catch with the modern footrope. From visual observations..."It appeared that the fish reacted as strongly to the sand cloud produced by the NETS ground gear as they did to the physical barrier of the Bering Sea Western's continuous footrope. This suggests that it may be possible to design footropes for even lighter ground contact (and thus less potential for injuring crabs) while preserving fish-catching efficiency so long as the footropes can be made to generate a dense, continuous sand cloud." "...it has generally been accepted that for maximum herding efficiency, bridle angles should not exceed 12-15 degrees...it was believed that at angles greater than this the sand clouds from the doors would pass outside the rigging and wingends of the trawl and thus would not herd fish into the mouth area." However, with the introduction of high performance door designs, such as the 'Fishbusters' "...boats using them consistently reported increases of 50% or more in their catch per unit effort." Bridle angles with these doors can easily exceed 20-30 degrees and the sand clouds are very small. This would indicate "...that stimuli associated with the sweeps and bridles may be at least as important to herding as the door clouds."

D. Incidental Fishing Mortality

"Red king crabs caught by the trawl and held in the codend for short periods (about an hour or less) together with small fish catches (5000 lbs or less) suffered relatively low rates of injury or mortality." Better than 84% of the crabs survived after 48 hours of being held in tanks on deck.

E. Habitat Impact

ROV surveys of the track, one day after towing the trawls, found that it was possible to detect door scrape marks (shallow gouges about 5 cm wide and up to 5 cm deep) but other traces of the gear's passage were not discernible.

REFERENCE #: F006

Cooper, C. and W. Hickey. 1988. Selectivity experiments with square mesh cod-ends of 130, 140, and 155 mm. In Proc. of the Square Mesh Workshop, St. John's, Newfoundland, 25 Nov. 1988. Mass. Div. Mar. Fish. Vol II: 37-46.

C. Selectivity

This paper summarizes a series of selectivity experiments using three techniques; alternate tows, cod-end covers, and trouser trawls. The trouser trawl was found to be the best method.

"Preliminary results show "...that square mesh compared to the equivalent size diamond mesh has higher 50% retention lengths and selection factors. Square mesh cod-ends appear to perform as effectively as a 10 mm larger diamond mesh on the cod, haddock and pollock stock. For flounder, such as American plaice and yellowtail the diamond mesh is more effective in releasing juveniles." Abstract.

"...differences in mean length were often small being in the order of 2 to 5 cm..."

The selection range was always lower (steeper selection curve) for square mesh for cod, haddock and pollock.

REFERENCE #: F007

DeAlteris, J.T. and D.M. Reifsteck. 1988. Selectivity of cod-ends on scup, *Stenotomus chrysops*, and the survivability of cod-end escapees: a preliminary report. In Proc. of the Square Mesh Workshop, St. John's, Newfoundland, 25 Nov. 1988. Mass. Div. Mar. Fish. Vol I: 38-53.

C. Selectivity

Covered codend tows were used to determine the selectivity of square and diamond mesh on scup in Narragansett Bay, RI, USA. Within the limits of the experiment, no significant differences were found between the codend types.

D. Incidental Fishing Mortality

"In the survivability experiments fish were initially captured using handlines and barbless hooks...Treated fish were released into a towed cylindrical small mesh netting section that was coupled to a square or diamond mesh cod-end with a small cover. Fish behavior was observed by a diver who signalled the escape of the fish from the cod-end...The fish were...later transferred to a cage on the bottom where the fish were monitored for mortality. Control fish were handled similarly, but not treated..."

Fish used in the study were below the 30% retention point of the mesh size used. "Survivability of control fish was approximately 95%. The mean survivability of square and diamond mesh escapees was 94 and 50% respectively..."

It took significantly longer for fish to escape from the diamond mesh codend when compared to the square mesh codend. The longer swimming times increased stress on the fish resulting in higher mortality. This mortality decreased with decreasing water temperature.

REFERENCE #: F008

Engas, A., B. Isaksen, and J.W. Valdemarsen. 1988. Escape behaviour of fish in cod-ends of trawls. In Proc. of the Square Mesh Workshop, St. John's, Newfoundland, 25 Nov. 1988. Mass. Div. Mar. Fish. Vol II: 60-64.

C. Selectivity

Direct observations of cod and haddock escape behaviour in square and diamond mesh cod-ends were made, using underwater video cameras, off the coast of Finnmark, Norway. Catches were mainly haddock (35-50 cm) and some cod (40-65 cm).

The report presents the observations on escapement in the front and rear part of the cod-end for empty and full conditions. Escape in the front part seems to be more random than from the rear section just in front of the collected catch.

In a square mesh cod-end, with light catches, the fish seem to expend more effort to maintain position than in the equivalent diamond mesh situation. This seemed to affect successful escapement.

"Direct observation of square mesh cod-ends has shown that this design has open meshes along the whole cod-end, and gives the fish a much larger escape area than in a conventional cod-end. Although escape is observed along the whole length, the main selection and escapement occur in the rear part of the cod-end, and in front of the accumulated catch, just as in conventional cod-ends. Square mesh codends are relatively wide compared to conventional ones, and this may be a disadvantage in stimulating fish to use the escapement possibilities in the frontal and central part of this cod-end."

REFERENCE #: F009

Fonteyne, R. and R. M'Rabet. 1988. Selectivity experiments with square mesh codends in the sole beam trawl fishery. In Proc. of the Square Mesh Workshop, St. John's, Newfoundland, 25 Nov. 1988. Mass. Div. Mar. Fish. Vol I: 27-36.

C. Selectivity

This is a report on comparative experiments with diamond and square mesh codends. The vessel was a Belgium beam trawler (20.6 m) using two 7 m beams (2 tickler chains) and 75 mm mesh. A total of 14 covered codend tows were made with each codend type.

The results found no significant differences between the square and diamond codends. The 50% lengths were 20.6 and 20.3 cm for diamond and square respectively. The selection factor for sole was 2.7 for both codend types.

The authors conclude that due to body shape and suppleness, soles can easily can escape through either mesh type.

REFERENCE #: F010

Hearn, D. 1988. Square mesh codend experiment aboard the F.V. Zandvoort: March-April, 1984. In Proc. of the Square Mesh Workshop, St. John's, Newfoundland, 25 Nov. 1988. Mass. Div. Mar. Fish. Vol I: 99-110.

C. Selectivity

This report is on the results of a square mesh codend test conducted aboard a Newfoundland trawler in the northern cod fishery in 1984. High catch rates, 20-50 tons per hour, caused excessive bruising of the catch as well as retention of small fish. Cutting holes in the extension of the trawl limited the size of the catch but did not improve selectivity. Increasing diamond mesh size was ineffective due to the catch volumes.

The trawler fished its regular 135 mm diamond codend for the first part of the trip catching 68,000 kg of cod. A square mesh codend (135 mm) was then used catching an additional 180,000 kg. The diamond mesh codend retained a significantly greater amount of cod less than 50 cm consistently. "The predominate length of cod moved from the 51-53 cm range for the diamond codend to the 57-59 cm range for the square mesh codend."

F. Management Issues

"...the number of fish per 100 lbs for the square codend was 26 as compared to 34 for the diamond mesh gear. This change represented a decrease of 4 cents per lb on production costs."

REFERENCE #: F011

Hillis, J.P. and J. Carroll. 1988. Further experiments with separator trawls in the Irish Sea. ICES C.M. 1988/B:51: 9 p.

C. Selectivity

Earlier studies (Hillis, 1983, 1984, 1985) "...showed good vertical separation of Nephrops (downwards) and whiting (upwards) in a two cod-end separator trawl." A commercial captain suggested extending the separator panel into the cod-end to avoid the handling problems associated with dual cod-ends. This study compared two trawl types possessing and lacking respectively a short separator panel in the rear of the trawl. Two commercial boats were given the gear to test.

The report discusses several problems associated with the rigging of the gear that affected the selection. Low percentages of whiting in the upper section of the net indicated the separator panel was too high. Attempts to remedy the problem with floats and strops were not very successful. Moving the leading edge of the panel further back into the net, where the net height to width ratio was greater, gave better results.

"Most mean percentages of landed catch of Nephrops in the lower compartment were in the range 79-87% whilst percentages of whiting in the upper one ranged from 74-94%. The panel in the rear part of the trawl body appears to have little advantage over that confined to the cod-end." Abstract.

"Plaice were predictably found to be 100% in the lower compartment in ten out of fourteen hauls where they occurred but with low percentages therein of 73.6 and 62.6 in two large hauls..." "Cod...displayed a consistently high percentage in the upper compartment in 19 out of 23 hauls, reaching 100 in several early hauls. This was rather neatly reversed for a period of three consecutive days..." p. 4.

A single separator cod-end seems to give less separation than dual cod-ends, possibly due to the movement of catch through the separator panel during hauling. Work by Main and Sangster (1985) found better separation with a 50 mm panel versus 85 mm, thus supporting this hypothesis.

The high percentage of cod taken in the upper net contrasts with Main and Sangster (1985), possibly because the latter gear separated species at the trawl mouth while the former gear performed the separation near the cod-end where the narrowness may have elicited an upward escape response.

The leading edge of the separator panel must be taut for the gear to function properly.

REFERENCE #: F012

Innes, L. 1988. Square meshes in cod ends; Their effect and reception by Scottish inshoremen. In Proc. of the Square Mesh Workshop, St. John's, Newfoundland, 25 Nov. 1988. Mass. Div. Mar. Fish. Vol I: 54-59.

F. Management Issues

This brief paper was prepared by a Scottish fisherman that was involved with the testing of square mesh cod ends. The experiments took place when the conventional mesh (diamond) requirement was 75-80 mm.

A 70 mm square mesh cod end resulted in "...a good haul...though less than that of the conventional net, almost every fish was of marketable size. Indeed, quality both in size and firmness (due to less crushing) were markedly improved. When the 80 mm square codend was used, average catches were taken with no discards what-so-ever and all fish in prime condition. On the market it was noticeable that a vessel landing less fish caught with the square-codends, had a much better gross, money-wise than, one with the conventional netting."

The author points out that "...the Scot loves to see bulk of fish irrespective of what is marketable out of them and many and varied excuses are given to their disfavour of square meshes or even an increase in the conventional netting."

There is mention of the problems associated with undersize and lined codends.

REFERENCE #: F013

Isaksen, B. and J.W. Valdemarsen. 1988. Selectivity experiments with square mesh codends in bottom trawl, 1985-1987. In Proc. of the Square Mesh Workshop, St. John's, Newfoundland, 25 Nov. 1988. Mass. Div. Mar. Fish. Vol II: 4-12.

C. Selectivity

Four trawl trips were made to compare diamond versus square meshes using a trouser trawl technique in the Barents Sea. Several different codend constructions were tested.

"Square mesh codends have given higher 50% retention lengths than diamond mesh codends, and when fished commercially, these codends have caught less undersized and small fish than the diamond mesh codends. Bycatch of redfish has given more meshing in a square mesh codend than in a normal codend, due to open meshes in the whole length of the codend. When emptying big hauls aboard stern trawlers, some problems arose due to the fixed circumference of the square mesh codend, a problem that was solved by introducing diamond mesh netting in the bottom panel." Abstract.

"The difference in selectivity properties has, however, been most obvious when the catches have been fairly small, and when they have consisted of mainly cod and haddock."

"The fact that redfish are taken as bycatch in many areas in the Barents Sea, together with the high degree of meshing of this species in square mesh codends, might reduce the selectivity properties of these codends when fished commercially without being cleaned between every haul. It is well known that meshed redfish sometimes are used to reduce the actual selectivity when fishing haddock and saithe." p.4.

REFERENCE #: F014

Larsson, P., B. Claesson, and L. Nyberg. 1988. Catches of undersized cod in codends with square and diamond meshes. ICES C.M. 1988/B:57: 8 p.

C. Selectivity

"A comparison regarding proportion of undersized cod caught by codends with diamond and square meshes was performed in the Baltic in 1988. Eleven parallel hauls were made by two commercial vessels with almost identical trawls (95 mm meshes in the codend) except for one of them having square meshes in part of the codend". The number of cod retained greater than 35 cm was almost identical between gear types. "The proportion of cod below 35 cm was 48% higher (below 30 cm 83% higher) for the codend with diamond meshes... On average, 10.4% of the diamond mesh catch was undersized cod that would of not been retained by the square mesh. "Applied to the present total catch of cod in the Baltic, that would mean more than 20 million undersized fishes escaping annually with a potential later to contribute to the fishery with up to 20000 tonnes." Abstract.

Bycatches of herring, flounder and plaice were significantly lower in the square mesh net.

REFERENCE #: F015

Main, J. and G.I. Sangster. 1988. Scale damage and survival of young gadoid fish escaping from the cod-end of a demersal trawl. In *Trawl-net Selectivity and the Survival of Fish Escaping from Cod-ends*. Proc. of Rhode Island Sea Grant: 17-34.

D. Incidental Fishing Mortality

Not as many small fish escape cod-ends as would be expected based on mesh size alone. Some small fish do not escape because of fatigue, blocked meshes, and limited area of open meshes.

Underwater video observations have shown fish struggling to escape through meshes resulting in scale removal. "Fish scales are often seen billowing around the cod-end. Furthermore, after escaping, some roundfish swam away while others did not swim normally but were tossed around bodily in the wake of the cod-end."

This report presents the results of a series of experiments to assess the impact of scale loss on survival of cod-end escapees. Fish were collected underwater as they escaped through the cod-end meshes as well as from inside of the cod-end. Other fish were collected by hook and line. The fish were held in underwater cages for mortality assessment.

In 1986, after 108 days of holding in cages, the survival of diamond mesh haddock escapees was only 18% compared to 100% survival for uninjured hand line caught controls. In 1987, after 52 days of holding, there was 0% survival of diamond mesh escapees versus 75% survival of square mesh escapees; control survival was 100%. In both years, the survival of haddock retained in the cod-end was about 70%.

The study showed '...that the control fish and the 'square-mesh escapes' survived well in confinement. The 'diamond-mesh escapes' did not endure as well in captivity, but it is difficult to draw a concrete conclusion from these experiments." p.27.

REFERENCE #: F016

Thorsteinsson, G. 1988. Icelandic investigations on the selectivity of square mesh codend in bottom trawl. In Proc. of the Square Mesh Workshop, St. John's, Newfoundland, 25 Nov. 1988. Mass. Div. Mar. Fish. Vol I: 5-21.

C. Selectivity

This paper reports on research conducted in Iceland during 1987-8 on the impact of square mesh codends in their cod fishery. A series of experiments were conducted on commercial and research vessels using trouser trawl and covered trawl techniques. The mesh size tested was the Icelandic regulated 155 mm mesh. Underwater camera observations were also made which indicated some potential problems with the trouser trawl method; fish behaviour that tended towards one side or the other.

The report presents detailed results of the selectivity trials and concludes "...use of square mesh netting in bottom trawl codends would reduce the catch of small cod considerably when the catch rates are not higher than approximately 2 tonnes in the trawling hour. High bycatch rates of especially flatfish reduce the selectivity of both types of codend netting. High catch rates of rather passive cod can reduce the selectivity of the square mesh considerably in some cases down to the same level as for the diamond mesh netting." The selectivity was lower when cod were feeding on Euphausiids.

The report indicates some shrinkage problems with the square mesh used during the experiment.

F. Management Issues

Icelandic regulations close fishing grounds when 25% of the catch of cod are under 55 cm in length as reported by observers. While square mesh netting would seem to mean a reduction in short-term catches, in fact, fishing grounds may remain open longer negating the short-term loss.

REFERENCE #: F017

Godo, O. R., A. Engas, and E. Ona. 1990. Trawl bottom contact and its influence on species and size composition of the catch. Inst. Marine Research, Bergen, Norway. 8p. (mimeo).

C. Selectivity

This paper discusses changes in size composition, of cod and haddock catches, in several types of bottom and pelagic trawls. The results show that ground gear contact is an important factor in trawl efficiency and selectivity for these two species.

A pelagic trawl (high opening with poor bottom contact) was compared to a low opening shrimp trawl (with good bottom contact). The latter was found to be more efficient in catching both cod and haddock of all sizes. The shrimp trawl also caught more small fish.

"The bobbins gear allows for a length-dependent escape under the trawl." "Rockhopper ground gear increases the efficiency of the trawl for all sizes of fish, but more for small than for large fish."

The authors reference research that found that small cod enter the trawl and escape close to the bottom, while haddock enter the trawl at the top and can escape over the headline. This experiment confirms these observations.

F. Management Issues

The authors believe that these selectivity observations can help in balancing cod and haddock catches in a quota based management system. Heavy rockhopper gear considerably increases catches and can be used where small fish are not a problem. If managers want to decrease the proportion of haddock in the catch, they can require lower headlines.

REFERENCE #: F018

Stevens, B. G. 1990. Survival of king and Tanner crabs captured by commercial sole trawls. Fishery Bulletin (US) 88: 731-744.

D. Incidental Fishing Mortality

"King crabs *Paralithodes camtschaticus* and Tanner crabs *Chionoecetes bairdi* captured incidentally by Bering Sea trawlers were examined for immediate mortality, vitality, and injuries resulting from trawl capture. A number were held aboard ship for 2 days in seawater to determine delayed mortality. Overall survival, including immediate and delayed effects, was 21% for king crabs and 22% for Tanner crabs." Abstract.

"In 1988, 88,000 red king crabs, 751,000 *C. bairdi*, and 2.4 million *C. opilio* were captured in 1.30 million metric tons of groundfish by JV fishing vessels, representing catch rates of 0.07, 0.58, and 1.84 crabs/t, respectively..." These crabs are considered prohibited species, in the JV trawl fishery which targets sole and cod, by the local management authority and thus must be returned to the sea.

The author used a system of vitality coding with three levels: alive and active, moribund, and dead. Physical injuries were also observed and recorded. The catch during the study consisted of 6200 tons of fish and 50,000 crabs. Vitality was coded for 10,750 crabs, injuries recorded for 3353 crabs, and 691 were held in tanks for delayed mortality observation.

No relationship was found between catch size and mortality. There was low survival for uninjured king crabs suggesting suffocation in the net or on deck as a contributing factor.

High vitality was a better indicator of survival than observed lack of injuries.

The paper has a lengthy discussion of the results. The author concludes that the already low bycatch mortality can be further reduced by decreasing handling time on deck and by not conducting trawl operations during molting periods.

Regarding mortality to crabs remaining on the bottom the author states "The possibility of additional, unseen mortality of crabs due to trawling has largely been discounted by submersible studies (West 1987, Highliners Association 1988) in which the observed trawls made little or no contact with the sea bottom, caused no observable injuries to crabs contacted, and no injured or dead animals were observed in the wake of the net." p.743.

REFERENCE #: F019

DeAlteris, J. T., K. Castro, and S. A. Testaverde. 1991. Effect of mesh size in the body of a bottom trawl on the catch retained in the cod end. Proc. Fish. Conservation Engr. Workshop. Rhode Island Sea Grant. P. 12-18.

C. Selectivity

"Two experiments were conducted to investigate the effect of mesh size in the body of a bottom trawl on the catch retained in the cod end. The purpose of the experiment was to evaluate the potential impact on the catches of the trawl fishing industry of minimum mesh size regulations throughout the entire trawl rather than only in the cod end. Catches of small mesh trawls with large-mesh regulated cod ends (standard trawls) were compared to catches of trawls with mesh sizes equal to or larger than the regulation cod end mesh size (experimental trawls). The target species were Atlantic cod, haddock, and yellowtail flounder."

"The results of the experiments indicated no significant differences in the catches of the standard trawls compared to the experimental trawls with respect to both the numbers of fish captured and length-frequency distribution of the catch."

F. Management issues

"...regulations affecting mesh size in the body of the trawl will have no effect on catches of the trawl fishing industry, and may improve compliance with minimum mesh size regulations because of the absence of webbing with a mesh size smaller than the regulation mesh size onboard the fishing vessel."

"...some vessels were circumventing the minimum mesh size regulations via a technique called "tying off." Since the minimum mesh size regulations only pertained to the cod end, the body and extension piece of trawl net were permitted to have mesh sizes smaller than 140 mm. Hence, "tying off" refers to the choking of the net at the junction of a smaller mesh size extension piece and the beginning of the regulated 140 mm mesh size cod end. The tie off rope used to constrict the junction point consists of a material that breaks during the haul back." p. 12

REFERENCE #: F020

Walsh, S.J., R.B. Millar, C.G. Cooper, and W.M. Hickey. 1992. Codend selection in American plaice: diamond versus square mesh. *Fisheries Research* 13: 235-254.

C. Selectivity

The Canadian groundfishery on the Grand Banks had a large discard problem consisting of catches of undersized American plaice. In 1979 the Canadian fleet discarded 29 million undersized American plaice. The problem was compounded by the fact that large and small plaice occur in the same areas.

This study examined mesh sizes of 130 mm, 140 mm, and 155 mm in diamond and square mesh codends utilizing a trouser trawl. Knotless netting was used in the codend construction. Towing speeds were 3.5-4 knots and towing times were mostly between 30-60 minutes.

"In the 155 mm mesh selection experiment, the weighted mean lengths of plaice were higher in the diamond mesh codend than in the square mesh codend, while there was no apparent difference in weighted mean length in the 130 mm or 140 mm mesh selection experiments."

In the 130 mm mesh experiment it was found that the selection range in the diamond mesh was considerably larger than in the square mesh (7 cm versus 4 cm). In the 140 mm mesh experiment the 50% retention length for diamond mesh was 7 cm higher than for the square mesh; in the 155 mm mesh it was 6 cm higher. The results gave higher selection factors and greater selection ranges for diamond mesh for all three mesh sizes.

"...mesh selection parameters for the square mesh codends tend to be less variable." The authors speculate that this may be attributable to the change in shape of diamond mesh as the codend fills.

The report contains a discussion of some problems that occurred with the use of the trouser trawl method. The authors conclude that managers must be aware that in a mixed fishery of gadoids and flatfish, discarding of flat fish may increase with square mesh.

REFERENCE #: F021

Houghton, R.G., T. Williams and R. W. Blacker. 1971. Some effects of double beam trawling. ICES C. M. 1971/B:5. 9pp.

A. Gear construction and operation

Two vessels were primarily used in this experiment: (1) MV ENNIE EN APPIE, a 700 HP Dutch beam vessel fishing two 9.5 m beam trawls equipped with ten tickler chains from the trawl head and seven from the groundrope and (2) MV SILVER STAR, a 175 HP vessel equipped with an otter trawl using a 20 m headrope and 26 m rubber disc covered footrope.

C. Selectivity

"...the selective action of the cod-end mesh in use on the beam trawl was apparently the same as that of the cod-end on the otter trawl."

"The beam trawler's catch contained a relatively higher proportion of buried species than those of the otter trawlers, whose catches consisted almost entirely of non-burrowing species.."

"The similarity of the length composition of soles and plaice caught by ENNIE EN APPIE and SILVER STAR indicates that the selective action of the 75 mm cod-end on the beam trawler was not appreciably restricted by the larger quantities of debris and invertebrates in the catch."

D. Incidental fishing mortality

"The biggest difference between the two vessels was in the greater extent of scale damage to soles caught by the beam trawler... General condition improved with increasing length and the extent of scale damage and wounding decreased, whereas the extent of bruising was greater in the larger fish."

"At least 70 per cent of...legal minimum size plaice were rejected on ENNIE EN APPIE when the observer was aboard (first two days of a six-day trip) because they were too small to be marketable in Holland and fish-hold capacity was left clear for the more profitable soles until nearer the date of landing."

"The extent of damage to different species of invertebrates by the beam trawler varied with both the quantity of the catch and its composition...In the hauls from the sandy area the extent of damage varied with the quantity of empty shells caught with them."

REFERENCE #: F022

Briggs, R.P., 1992. An assessment of nets with a square mesh panel as a whiting conservation tool in the Irish Sea *Nephrops* fishery. *Fish. Res.*, 13:133-152.

This study presents data on whiting discards in the Northern Ireland *Nephrops* fishery and examines the effectiveness of square-shaped mesh panels fitted to trawl nets in releasing juvenile whiting. Whiting, a target species for several countries in the Irish Sea, is also an important by-catch of the *Nephrops* fishery. Assessments of Irish Sea whiting stocks suggest that spawning stock biomass has been declining in recent years, and that the state of the stock is particularly dependent upon recruitment. Despite different mesh size regulations aimed at reducing losses of juvenile whiting, large numbers of juvenile whiting are still being discarded.

The use of square-shaped meshes versus conventional diamond-shaped meshes may minimize levels of by-caught whiting. At sea the performance of two trawl nets were compared during 22 hauls using a remote controlled television vehicle (RCTV). A 75 mm square mesh panel measuring 3 m in length and 30 meshes in width was inserted in the cod-end extension top-sheet 2.7 m in front of the lifting becket. An identical net of conventional diamond mesh throughout was constructed to act as a control in the sea trials.

Pictures obtained from the RCTV showed that the square-shaped meshes remained open during trawling whereas the traditional diamond-shaped meshes were closed. Different escape reactions of whiting, cod, saithe, scad, herring, flatfish (Pleuronectidae and Soleidae), and Norway lobster were observed. Mainly, whiting escaped when entering the square mesh window on the first attempt, though tended to become stuck tail first out of the cod-line meshes in the conventional diamond-shaped mesh. Lobster did not escape through the square mesh section.

Commercial fishing trials using a vessel rigged to pull two trawl nets simultaneously, one with a square mesh panel and one without, demonstrated significantly better whiting escapement from the net with the square panel than from the all-diamond net.

In summary, a high discard mortality of juvenile whiting continues to occur in the Northern Ireland *Nephrops* fishery, despite increases in the minimum allowable mesh size. The loss of immature whiting may be contributing to a decline in stock biomass, instigating conservation measures. A further increase in mesh size as a conservation option might incur *Nephrops* losses. A panel of square-shaped mesh fitted to a *Nephrops* trawl could be an important whiting conservation tool.

REFERENCE #: F023

Galbraith, R.D. and J. Main. 1989. Separator panels for dual purpose fish/prawn trawls. Scottish Fisheries Information Pamphlet No. 16.

A. Gear construction and operation

“...the capture of fish by trawls is not only a sieving process. Fish are herded for a time and are eventually captured when they become fatigued and enter the mouth of the net. The different species of fish react in characteristic ways when entering the mouth of a bottom trawl. When cod, skate, angler, plaice, lemon sole, dab and shellfish tire they enter the net close to the groundrope. When haddock tire they rise high ahead of the groundrig before turning back into the net. Whiting rise higher than the ground fish but lower than haddock. These differing reactions can be used to separate catches by species into different codends to the potential advantage of the fishermen. The escape of juvenile fish may also be enhanced by diverting them to larger meshed codends with meshes unobstructed by flatfish and Crustacea.

“Experiments have shown that it is possible to separate haddock and whiting from flatfish, cod and *Nephrops* by fitting a horizontal panel of netting inside the trawl. This pamphlet describes the design of proven separator trawls and emphasises the critical factors. It is important, for example, that the separating panel is rigged correctly by being fitted tight and not being allowed to flap. It is also very important that the fishing line of the panel is positioned directly above or slightly (less than 1 m) behind the footrope. The fishing line of the separating panel must never be rigged to fish ahead of the footrope because the haddock, whiting and saithe will be unable to rise quickly enough to enter the top net.” p. 1

C. Selectivity

The pamphlet describes 5 different trawl designs and provides diagrams of separator panels to be inserted in each. It also discusses several problems which may be encountered when fitting panels.

“There are definite advantages in fitting a separating panel in a trawl net. The fish caught in the top codend are in better condition than those in the bottom which have been subject to damage from skate, dogfish, shells and crustacea, etc.... The separation of species into two codends will reduce the sorting time on deck and therefore the length of time before the fish are on ice.

“If the belly of the net is badly torn the top panel will continue to fish as before for cod and whiting. In a separator trawl flatfish and *Nephrops* are caught in the bottom codend, and so masking of the meshes by these species in the top codend will not occur and small unwanted fish will be allowed to escape.” p. 7

Summary data are presented which show that, in daylight trials in two areas, almost all haddock and most whiting are caught in the top codend whereas virtually all groundfish (cod, skate, flatfish, monkfish) and *Nephrops* end up in the bottom net.

It is estimated that the addition of a separator panel and second codend would increase the cost of the net by a quarter to a third.

REFERENCE #: F024

Branton, R. 1994. Reduction of bycatches in the Scotian Shelf silver hake fishery. Industry Services and Native Fisheries Project Summary No. 47. Fisheries and Oceans Canada.

B. History and statistics

Silver hake winters off the shelf edge and moves into the shallower waters of the Scotian Shelf in late spring to spawn. Russians and others have traditionally fished for this species using smaller mesh gear (40-60 mm) than the Canadian groundfish fishery (120-140 mm). During the 1970s and 1980s, time and area restrictions were imposed on these fleets to limit bycatches of cod, haddock etc.

D. Incidental fishing mortality

Following the groundfish crisis in eastern Canada, concern increased about bycatches in the silver hake fishery, and the Department of Fisheries and Oceans reanalyzed the extensive data on this fishery which had been collected by observers. By plotting the percentage of bycatches of cod, haddock and pollock with respect to depth and longitude, it was found that most catches of cod and haddock occurred in depths of 100-190 m and east of longitude 60° W. Pollock catches were more variable. It was estimated that if the silver hake fishery were restricted to fishing in waters deeper than 190 m and west of longitude 60° W., catches of haddock would be reduced to about 1/3 of the then-current catches and cod to about 1/2 or less. Pollock catches would be reduced also, but to a lesser extent. Silver hake catch rates would not be affected.

However, the fleet did much of its fishing in the summer months in waters of 100-190 m depth, so changing the boundaries of the fishing area would disrupt the fishing pattern of the fleet. It was thought that some of this disruption could be avoided by allowing the fishery to begin earlier in the year, while the silver hake were still in deeper waters off the Shelf.

F. Management issues

Regulations in effect in the silver hake fishery also required the use of a sorting grid to allow the escape of cod, haddock and pollock, but these were not very effective in protecting small haddock (see Annotated References F025 and F026) . However, observer data showed that much of the haddock which was caught in the 100-190 m waters were juveniles (under 35 cm), so restricting the fishery to deeper waters would greatly reduce the catch of small haddock. Revising the time and area closures would thus be complementary to the mandatory use of a separator grate.

REFERENCE #: F025

Cooper, C. 1992. Experiment with a rigid separator grate in a silver hake trawl. Industry Services and Native Fisheries Project Summary No. 37. Fisheries and Oceans Canada.

A. Gear construction and operation

Silver hake harvested on the Scotian Shelf are generally 15-40 cm in length, which is considerably smaller than other groundfish species such as cod (40-110 cm) and haddock (35-60 cm). Silver hake are thus fished with smaller meshed gear (40-60 mm), which can result in bycatches of these other species.

In an attempt to reduce this problem, experiments were conducted with a sorting system based on a separator grate which was already in use in the Eastern Scotian Shelf shrimp fishery. The system tested consisted of rigid steel grate which, when installed in the trawl, allows the silver hake to pass through into the codend while diverting the cod, haddock and pollock through a fish release opening above the grate. A funnel was installed in front of the grate to direct the fish towards the bottom of the grate. The grate measured 1.37 m by 1.98 m with vertical bars spaced 40 mm apart and it was installed at an angle of 45-50°. During the experiments, a second codend was installed to collect the fish which would normally escape.

C. Selectivity

A total of 33 tows were made in three locations, under conditions of very low (0.09 tonnes/hour) to moderate (1.27 tonnes/hour) catch rates. Generally, about 95% of the silver hake passed through the grate into the codend while over 90% of the cod, haddock and pollock escaped through the opening above into the second codend. In one series of five tows, only 90% of the silver hake passed through the grate, but an underwater camera showed this was probably due to the presence of spiny dogfish in front of the grate. Variable results were obtained for herring, which are close in size to silver hake: from 38-76% escaped into the second codend.

A further four tows were made without the funnel in place. Only 64% of the hake passed through the grate, showing that the funnel is essential for the proper operation of the sorting system.

About half of the pollock and haddock which were small enough to pass through the grate actually escaped through the opening and were retained in the second codend. This suggests that the behaviour of those species is different from silver hake. It also shows that the grate can reduce the capture of both juvenile and adult pollock and haddock.

No differences were evident in the effectiveness of the sorting system between small tows of 300 kg and large tows of five tonnes.

REFERENCE #: F026

Cooper, C. 1993. Experiment with different grate designs in a silver hake trawl. Industry Services and Native Fisheries Project Summary No. 45. Fisheries and Oceans Canada.

A. Gear construction and operation

Earlier work showed that a sorting system using a rigid separator grate and a funnel in a silver hake trawl was effective in reducing the bycatch of cod, haddock and pollock (see Annotated Reference F025 for background). Further experiments were conducted to evaluate the effectiveness of changing the design of a system.

C. Selectivity

The original design had a grate with vertical bars spaced 40 mm apart and set at an angle of 45-50°. In one experiment, using a 50 m Canadian trawler, that configuration was compared with two others: horizontal bars spaced 40 mm apart and vertical bars spaced 50 mm apart. The angle of attack was left at 45-50°. A total of forty tows were made. Both the 40 mm grates allowed about 95% of the silver hake to pass, while deflecting 85-99% of the pollock and haddock out the escape opening; not enough cod were caught to draw any conclusions for that species. Underwater video images showed that the silver hake had a greater tendency to hit the grate and possibly suffer damage. The 50 mm vertical grate retained 99% of the hake in the codend, but fewer haddock and pollock escaped (62% and 32% respectively). In six tows, the angle of the 40 mm vertical grate was reduced from 45-50° to 24° to test a "worst-case scenario". While more haddock and pollock escaped with this configuration, the amount of silver hake which escaped also increased, from about 5% to over 40%.

In three tows, large quantities of small haddock (<35 cm) were encountered, over 90% of which passed through the grate and were retained in the codend. This demonstrates that the grate is not effective in areas with very small haddock. On the other hand, no problems were observed with dogfish, monkfish or skates blocking the grate, and the silver hake did not seem to suffer any damage by passing through the funnel and grate.

In another experiment, a 100 m Cuban trawler was used to test a grate mounted at 60°. During 14 sets (five with the grate and nine without), catch rates ranged from 100 to 6,000 kg/hour. Consistent with the other design, 95% of the silver hake was caught in the codend while 92% of the haddock and 97% of the pollock escaped into the second codend.

The author concluded:

- the most efficient grate design for harvesting the current size distribution of silver hake, haddock and pollock is a grate with vertical bars spaced 40 mm apart and set at an angle of 48° in the net, which will retain 97% of the silver hake and release 85-95% of haddock and pollock;
- the spacing of the bars is extremely important to the effectiveness of the grate in separating haddock and pollock from silver hake. Increasing the spacing by 10 mm decreased the efficiency by 40-50%;
- the grate was effective in both small and large tows, there was no difference in catch rates between the trawl with the grate and without and there was no difference in the quality of the fish caught.

REFERENCE #: F027

Cooper, C. 1992. Cod and haddock separator trawl. Industry Services and Native Fisheries Project Summary No. 38. Fisheries and Oceans Canada.

A. Gear construction and operation

Scottish work had shown that groundfish differ in their behaviour as they tire in front of a trawl. Cod tend to turn at a low height and enter the bottom of the trawl, while haddock tend to fall back in a high arc into the top of the trawl. This information was used to develop a panel which could be inserted horizontally in the trawl to separate haddock from cod.

This study reports upon Canadian follow-up work testing a separator panel. The height of the panel could be adjusted by means of two ropes, varying in length from 2.5 feet (0.77 m) to 4 feet (1.23 m), which connected the panel to the footrope. Separate codends collected fish which entered the trawl above and below the separator panel. Ten tows were performed at each of four heights and data were collected on each species caught in the codends.

C. Selectivity

The tests showed that 88-96% of the haddock were retained in the top codend; higher percentages tended to collect in the top codend with the panel installed at 2.5 feet than at 4 feet. The percentage of cod in the bottom codend varied from 27-59% as the panel was raised in the trawl, showing that cod are highly sensitive to panel height. Virtually all of the pollock and mackerel (99-100%) were found in the top codend while American plaice, yellowtail and winter flounder accumulated in the bottom. There was no pattern for silver hake or halibut, but it was noted that larger halibut tended to enter the top codend and the smaller ones entered the bottom.

The author notes that it was quite difficult to ensure the proper insertion of the panel in the net and that visual inspection was very important.

Fish Catch in Shrimp Trawls

REFERENCE #: G001

Kenney, J., A. Blott, and J. T. DeAlteris. 1991. Shrimp separator trawl experiments in the Gulf of Maine shrimp fishery. Proc. Fish. Conservation Engr., Workshop. Rhode Island Sea Grant. p. 6-11.

A. Gear construction and operation

"The concept of selective shrimp trawls is not new. Trawl design modifications have been evaluated in shrimp fisheries for separating finfish from shrimp, with varying degrees of success (West et al. 1984; Averill 1988; Watson 1989; Watson and Taylor 1990). The techniques utilize behavioural and size differences between shrimp and finfish, and include horizontal separator twine panels, large mesh escape panels, deflecting grids, accelerator funnels, and others. The basic modifications to the nets evaluated in this project were: large mesh in the belly area and a funnel accelerator ahead of the trawl cod end." p. 6.

D. Fishing mortality

"The discard of finfish bycatch in the Gulf of Maine northern shrimp trawl fishery is considered a serious problem. The species-specific discard rate varied from 17 percent for winter flounder to 95 percent for silver hake in 50 tows made by commercial trawlers during the period 1985-1989 (Howell and Langran 1990). Studies by Jean (1963) and Howell and Langren (1987) suggest a very high mortality for discarded finfish in the western North Atlantic fisheries. The discard problem has two major facets; direct wastage in throwing fish back into the sea and loss of future catches of larger animals through the mortality of small individuals (Saila 1983)." abstract

"...compared to the tropical shrimp fisheries where 10 kg of finfish bycatch is captured and discarded for each 1 kg of shrimp captured, the Gulf of Maine shrimp fishery is not nearly as wasteful. The results of this project indicate that an average finfish bycatch for the control trawls is 0.43 kg of cod and dab per 1 kg of shrimp, and for the experimental trawls, 0.35 kg of cod and dab per 1 kg of shrimp. For the composite catches of all control trawl tows, approximately 73 percent of the cod catch was undersize (<19 in, 48.3 cm) and discarded; additionally, 98 percent of the dab catch was undersize (<14 in, 35.6 cm) and discarded."

"...it appears that large mesh (30 cm) in the lower belly, shorter legs (9 m vice 28 m), and an accelerator funnel can result in significantly reduced catches of either cod or dab." p. 11.

REFERENCE #: G002

Watson, J. W. and C. W. Taylor. 1991. Research on selective shrimp trawl designs for penaeid shrimp in the United States. Proc. Fish Cons. Engr. Workshop. Rhode Island Sea Grant. p. 50-59.

B. History and statistics

"Investigators have reported finfish catch rates between 2.8 and 18.0 kg for each kilogram of shrimp caught (Blomo and Nichols 1974, Chittenden and McEachran 1976, Bryan 1980, and Juhl et al 1976). The most recent study by Pellegrin et al (1985) estimated fish bycatch for the Northern Gulf of Mexico penaeid shrimp fleet at more than 510,000 mt."

D. Incidental fishing mortality

"The incidental catch of finfish by shrimp trawling gear is a significant source of mortality affecting the conservation, utilization, and management of finfish stocks in the southeastern United States."

"...the turtle excluder device (TED), was developed by NMFS to reduce the incidental capture of endangered sea turtles by shrimp trawls...Research during the development of the TED led to new finfish separator designs based on modification of water-flow characteristics in the trawl. The design uses webbing funnels to accelerate water in the cod end of the trawl, and leading panels and openings to exclude finfish. The separation technique utilizes the differences in swimming ability and behavior between shrimp and finfish to reduce the finfish catch. Separation rates of as much as 78 percent during daytime fishing and 50 percent during nighttime fishing, with no significant difference in shrimp catch rates, were achieved during evaluation of the technique."

This paper contains a review of selective shrimp trawl research in the United States since 1973.

REFERENCE #: G003

Thorsteinsson, G. 1992. The use of square mesh in the Icelandic shrimp (*Pandalus borealis*) fishery. Fisheries Research 13: 255-266.

C. Selectivity

Before 1967, the Icelandic shrimp fishery was conducted by low powered boats on inshore grounds using small trawls with short bellies. Small gadoids and herring were able to out-swim the slow gear and were thus not subject to capture. The discovery of offshore shrimp grounds in 1967 introduced bigger trawl designs into both inshore and offshore fisheries. The larger trawls caught 2.3 times more shrimp than the smaller trawls but also increased the catch of small fish. In one experiment the small trawl caught 22 fish per hour versus 314 fish per hour for the larger trawl.

Attempts to reduce bycatch included "...the use of shorter bridles, longer chains between fishing line and footrope, and the hauling of the trawl with the engine disconnected from the propeller. Very soon the conventional footrope was replaced by bobbins which were originally considered to reduce the bycatch of young fish but actually resulted in shrimping on harder ground where small fish were often more plentiful."

Other methods to reduce fish bycatch and catch of under-sized shrimp included closing areas, increasing cod end mesh size, and providing extra slack in the net side panels.

Square mesh cod ends were found to decrease the catch of 0-group fish drastically and reduce undersized shrimp significantly. There was also a 10-20% loss of legal shrimp but these were usually of the smaller, less valuable size.

D. Incidental Fishing Mortality

In 1974 management guidelines based on economic considerations were adopted. "In these calculations the prices of shrimp and fish species were taken into consideration (Palsson and Thorsteinsson, 1985). The guidelines indicate the number of small gadoids and other fish species allowed per 1000 kg of shrimp."

In 1974 "... the shrimp fishery in Isafjardardjup...had killed small gadoids which would have yielded a catch of 1600 tons some years later." This represented 40% of Iceland's shrimp catch for that year.

REFERENCE #: G004

Andrew, N.L., K.J. Graham, S.J. Kennelly, and M.K. Broadhurst, 1991. The effects of trawl configuration on the size and composition of catches using benthic prawn trawls off the coast of New South Wales, Australia. *ICES J. mar. Sci.*, 48: 201-209.

This study compares the catch rates of fish and crustacea in triple-rigged trawls, and in single trawls with and without sweeps of 40 m and 140 m length, off the coast of southwestern Australia. Other studies have shown that the number and size composition of catches are influenced by the length of sweeps. Most trawlers in the eastern king prawn fishery off Australia formerly towed single trawls but most are now triple-rigged. Consequently, there has been an increase in incidental catch, mostly demersal fishes and invertebrates. Fishermen profit from some by-catch, and species such as red spot whiting are often targeted.

The catch per swept area and size selectivity of four configurations of prawn trawls were assessed during night-time trials; trawl configurations compared were: single trawl with 7 m bridles, single trawl with 40 m bridles, triple-rigged trawl, and single trawl with 140 m sweeps. Catch comparisons were made between Australian red spot whiting, sand flathead, shovelnose lobsters, Eastern king prawn, and brown tiger prawn.

Results are discussed in terms of operational and catch differences between trawls. Mainly, sweeps were found to herd Australian red spot whiting and sand flathead but not prawns and shovelnose lobsters. Single trawls with long sweeps caught significantly larger red spot whiting and sand flathead than any other trawl configuration. Triple gear caught more smaller red spot whiting than other configurations but this effect was not evident for sand flathead.

The relationship between catch rate and sweep length should be known in order to compare assessments of stock abundance and species composition drawn from trawls with different sweeps. If incidental catch is to be monitored in prawn trawl fisheries then the use of long sweeps should be regulated.

REFERENCE #: G005

Andrew, N.L., and J. G. Pepperell, 1992. The by-catch of shrimp trawl fisheries. *Oceanogr. Mar. Biol. Annu. Rev.*, 30, 527-565.

This report draws together the literature on shrimp by-catch and reviews the state of research on by-catch estimation, utilization, efforts for reduction, and impacts of trawling on ecosystems. Shrimp trawl fisheries make an important contribution to the total catch of the world's marine fisheries, and in so doing generate a tremendous amount of incidental mortality to other fishes, particularly fin-fish. In the great majority of the world's shrimp fisheries more by-catch is caught than shrimps.

There are several reasons to minimize by-catch reported in the literature. Killing commercially important species or protected animals, disrupting the food web, contaminating the catch via rotting organic material on trawl grounds, and conducting inefficient trawl tows are all drawbacks to fisheries with a large amount of incidental catch. A direct approach to avoiding by-catch is to design fishing gear that allows by-catch, particularly turtles and fin-fishes, to escape. These devices, known as TEDs, allow non-targeted species to pass through panels while allowing target species to pass through to the codend. TEDs have been used mainly for turtles, though also for fin-fish and in other fisheries (for pandalid shrimps in New England, for example, and for groundfish in Norway).

Selective trawl designs have been used which incorporate chutes, pockets and covers, as well as 'skylight' panels, to allow by-catch to escape. Trawls have also been designed to retain by-catch in a second codend, while electric fields have been used to avoid by-catch all together.

Trawling is considered to affect directly the stocks of species caught as by-catch. It also has indirect effects by possibly changing the abundance and composition of community assemblages. Differential mortality of predators and prey can lead to changes in food-web dynamics. The physical impact of trawling may change trawl grounds so they are suitable to different types of species. Moreover, discards from trawl fisheries make food available to surface predators, and have been shown to influence the behaviour and numbers of scavenging species. The structure of benthic communities (abundance and species composition) also has been shown to change after trawling.

REFERENCE #: G006

Broadhurst, Matt K., Steven J. Kennelly, and Gerard O'Doherty, 1996. Square-mesh panels in codends and the effects of haulback-delay on by-catch reduction in the New South Wales oceanic prawn-trawl fishery, Australia. *Fish. Bull.* 94(3): pp xx-xx.

This study addresses the effectiveness of square-mesh panels in reducing by-catch from the New South Wales oceanic prawn-trawl fishery and assesses the effects on catches from haulback-delay using the panels. Incidental capture and mortality of animals other than the targeted eastern king prawn in NSW may reduce the yield of stocks that form the basis of other fisheries. Square-mesh panels in codends have been successful in reducing by-catches. Other studies have not addressed behaviour patterns of escaping fish nor the period during tows that escape occurs.

In the NSW prawn fishery there is a delay of up to 15 seconds between slowing the vessel and engaging the winch to haul in the trawl (haulback-delay). During this time, the degree to which fish escape varies per species. The effects of the haul-back delay on fish behaviour needs to be addressed in order to interpret adequately the effectiveness of the square-mesh panels.

Two codend designs with panels inserted in different configurations (length-wise versus width-wise) were compared against a conventional design. Both of the modified codends significantly reduced the weight of discarded by-catch, and one significantly reduced the number and weight of red spot whiting. Neither reduced the catch of prawns.

A second experiment testing the effects of haulback-delay showed that juvenile whiting, an important commercial finfish, escaped from square-mesh panels in the trawl during a 10-15 second delay. There was no significant reduction in the number or weight when there was no delay in haulback, unlike other species which escaped continually throughout the duration of the tow. If fish which remain in the codend experience greater stress as other studies have shown, those fish escaping at the end of the tow may suffer greater post-trawl mortality than those which escape continuously.

Unless most of the escaping fish survive, square-mesh panels in codends may be of little value. Mortality of red spot whiting may be reduced by lengthening the panel or increasing its mesh-size. Not all species to be excluded behave in a similar manner and the effects of operational procedures can significantly influence the rate of exclusion of some species.

REFERENCE #: G007

Coale, J. S., and R. A. Rulifson, 1994. Comparisons of shrimp catch and bycatch between a skimmer trawl and an otter trawl in the North Carolina inshore shrimp fishery. *North American Journal of Fisheries Management* 14:751-768.

Researchers compare skimmer and otter trawl fisheries in North Carolina and the different fishing methods used with these gears. Amount of bycatch, amount of shrimp caught, bycatch composition, bycatch survivability, and length-frequency distributions of finfish species collected in each gear are compared. The purpose of the study was to determine if skimmer trawls can be used in North Carolina to reduce bycatch and improve bycatch survivability.

Brown shrimp, *Penaeus azetecus*, pink shrimp, *P. duorarum*, and white shrimp, *P. setiferus*, make up the commercial shrimp fishery in North Carolina. Fishermen typically use the otter trawl, an unselective type of gear which generates a considerable amount of bycatch. One and a half to eighteen kilograms of finfish may be caught for each kilogram of shrimp.

The skimmer trawl may reduce bycatch because it is pushed in pairs alongside the vessel, as opposed to behind the vessel like the otter trawl. Towed beside the vessel, each skimmer trawl tailbag can be retrieved every 30 minutes without stopping the vessel. Bycatch survival should be greater because the catch is dumped more frequently.

Results showed that on average, the skimmer trawl caught less bycatch (mean, 0.47 kg/min) than the otter trawl (mean, 0.66 kg/min), and had the lower bycatch rate (mean, 0.30 kg/min) and fish-to-shrimp ratio (mean, 1.38) during peak season for white shrimp. Organisms in the skimmer trawl showed greater survivability than those in the otter trawl. Skimmer trawls proved more effective in catching white shrimp, and otter trawls in catching brown shrimp. The strength of statistical comparisons was limited due to the two different methods of operation.

The lower bycatch rate of the skimmer trawl may be attributed to the reduced net spread compared to the otter trawl. Lower mortality observed in the skimmer trawl may be due to frequent retrieval of the tailbag and shorter culling time, the gear itself, or a combination of these factors. The skimmer trawl does not require use of a TED because the frequent tailbag retrieval should increase survival rates of captured sea turtles. Finfish bycatch may be reduced even further when Florida fish excluders are sewn into skimmer nets. Use of the skimmer trawl in the North Carolina shrimp fishery may increase white shrimp catch and reduce bycatch and mortality of most other species.

REFERENCE #: G008

Henwood, T., W. Stuntz, and N. Thompson, 1992. Evaluation of U.S. turtle protective measures under existing TED regulations, including estimates of shrimp trawler related turtle mortality in the wider Caribbean. NOAA Technical Memorandum NMFS-SEFSC-303 15p.

This study evaluates sea turtle catch and mortality by U.S. shrimp trawlers under current sea turtle conservation regulations, and provides a gross estimate of turtle catch and mortality for the wider Caribbean. Sea turtles are caught incidentally by shrimp trawlers in U.S. and foreign waters. Since 1987 turtles have been protected by Federal Sea Turtle Conservation Regulations (Federal Register, Vol. 52, No. 124, June 29 1987), otherwise known as Turtle Excluder Device (TED) Regulations, in the Gulf of Mexico and southwestern North Atlantic. Opposition to TEDs has been based on the argument that regulations are an economic burden and sea turtle mortality is negligent.

Inshore and offshore shrimping effort, turtle catch rates, turtle mortality rates, effectiveness of TEDs and tow time restrictions, and compliance with existing regulations, were analysed in order to evaluate sea turtle catch and mortality in the United States. Several assumptions needed to be made in the analysis which may under or overestimate sea turtle mortality. Based on the analysis, approximately 4,360 turtles suffer mortality each year in the inshore and offshore U.S. Atlantic and Gulf of Mexico waters despite current TED regulations. This compares to a total of 13,112 turtles taken without TED regulations.

This mortality rate before TED regulations is approximately equal to that taken by the Mexican shrimp fleet (11,324), though this number could be higher because Mexican fishermen do not release turtles, and turtles may be more abundant in waters off Mexico. In Central America roughly 3,500 turtles are taken (and die), and in South America, roughly 10,600.

The mortality estimate in U.S. waters (4,360) is probably an underestimate. Current TED regulations have resulted in a 67% reduction in annual turtle mortalities. The authors note that, "annual shrimp landings have not changed despite alleged high shrimp loss rates associated with TED utilization. Expansion of TED requirements to all areas at all times of the year would result in a total reduction in shrimp trawler related sea turtle mortalities of 97%." It is essential to enforce conservation measures beyond U.S. waters in order to ensure that turtles are protected throughout their entire range.

REFERENCE #: G009

Isaksen B., J.W. Valdermarsen, R.B. Larsen, and L. Karlsen, 1992. Reduction of fish by-catch in shrimp trawl using a rigid separator grid in the aft belly. *Fisheries Research*, 13: 335-352.

This study describes the design, implementation, and effectiveness of a rectangular grid installed in a shrimp trawl to avoid the by-catch of fish. Designed in Norway, the aluminum grid with longitudinal bars is placed in the extension piece in front of the codend, angled 48°, with a fish outlet on the top. In front of the grid a funnel guides fish and shrimps toward the lower part of the grid.

Countries such as Norway and the USSR consider by-catch of fish in shrimp trawls in the Barents Sea and along the Norwegian coast undesirable. Major by-catch includes undersized cod and haddock, as well as small redfish and Greenland halibut. Since 1984, a separator panel of netting had been used in those coastal shrimp fisheries which exceed minimum by-catch levels. Redfish are difficult to separate with net panels; however, a rigid separator grid, the 'Nordmore'-grid, proved more successful. Using the separator grid, fishermen are able to fish on grounds that otherwise would have been closed due to the high by-catch of cod and haddock, while at the same time they are able to decrease the amount of sorting work on deck.

In evaluating the effectiveness of the grid, researchers investigated various distances between bars, dimensions of the grid, location and angles of the grid mount, grid materials, guiding devices, and sizes of the fish outlet. Installation, practical aspects, speed and angle measurements, and underwater observations of the grid are described.

In experiments using the separator grid, shrimp loss was low, (around 2-5%), and a higher percentage of large fish were released relative to small fish. The size at which fish were released varied per species. (Species included cod, haddock, Greenland halibut, redfish, and polar cod.)

Other by-catch prevention devices have been evaluated, though the separator grid has been the most optimal in terms of separating fish and avoiding shrimp loss. To get the best results, the grid must be designed and installed properly (aspects described in study). The authors recommend "coastal shrimpers (40-60 feet) use aluminum grids at least 0.7 m wide and 1.35 m long, while the bigger offshore trawlers use a 1.0 m wide and 1.5 m long grid, both with a bar separation of 19 mm and mounting angle of 48°, which gives an acceptable shrimp loss below 5%."

Following these experiments, the separator grid was made compulsory in the northern coastal shrimp fishery from 1 March 1990, in the offshore fisheries from 1 January 1992, and in the Barents Sea and Spitsbergen waters from 1 January 1993.

REFERENCE #: G010

Larsen, Roger B., 1996. Experiments with a new, larger type of fish/shrimp separator grid and comparisons with the standard Nordmore grid. ICES FTFB W.G. Meeting, Woods Hole, 15-18 April.

Not to be cited without prior reference to the author

This study compares use of the standard Nordmore grid and a new and larger type of fish/shrimp separator grid in reducing bycatch and increasing escapement of juvenile fish. Successfully used by shrimp fleets internationally, the Nordmore grid (standard off shore) measures 1.5 m in length and 1.3 m wide with a maximum bar distance of 19.0 mm, and is operated at an angle between 50° and 45°. More effective separation of the smallest fish (0-group) needs to be achieved.

The new type of fish/shrimp separator grid, with a longer grid and a lower angle of attack, was tested during a cruise along Svalbard in July/August 1995. The purpose was to test whether the new style improved escapement of juvenile fish (0-group), as well as typical bycatch species like redfish and flatfish, and maintained a low and acceptable loss of shrimps comparable to the Nordmore grid.

The installation of the new type of grid is similar to the standard Nordmore grid, but the construction differs in the length (2.5 m versus 1.5 m), and the way the crosswise strengthening bolts are fastened to the lengthwise bars. The large grid was tested at angles of 18° and 23°, while the Nordmore grid was tested at 48°.

Only two hauls were compared, though all species of fish (cod, redfish, Greenland halibut, and Long rough dab) seem to escape more easily with the new grid. Average loss of shrimps by weight was smaller with the new grid than with the Nordmore despite the large difference in angles of attack. The numbers of juvenile fish during this experiment were too high with both types of grids. Even at the lowest angle of attack (18°), the numbers of small fish retained exceeded the legal limit of 1 juvenile/kg shrimp catch. "It is therefore necessary to encourage work that can solve the bycatch problem of the smallest fish in the northern shrimp fisheries."