Northeast Fisheries Science Center Reference Document 94-14

Identifying Potential Modifications to Sink Gillnet Gear to Reduce Harbor Porpoise Bycatch

Report of a Workshop held
September 20-23, Falmouth Massachusetts

Edited by

T. Frady, S. Northridge,
and T. D. Smith

NOAA/National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, MA 02543-1097

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INTRODUCTION

In response to the 1988 Amendment of the U.S. Marine Mammal Protection Act, the bycatch of marine mammals in fishing gear has been of increasing interest. Research programs conducted by the Northeast Fisheries Science Center have identified the likely range of bycatch in the demersal gill-net fishery in New England waters. Based on observations made aboard fishing vessels and during research sighting surveys, it appears that the bycatch of harbor porpoise has been on the order of 2 to 5 percent of the abundance of this species in the Gulf of Maine during the summer months.

Because the bycatch of harbor porpoise varies greatly by season and by area, one approach to reducing the bycatch is to restrict fishing activity in those areas and during those seasons when bycatch is the greatest. This approach is being explored by the New England Fishery Management Council as part of an amendment to the Multispecies Fishery Management Plan. As an alternative to or a longer term substitute for such restrictions, a workshop to determine methods of directly modifying gill-net gear to reduce the bycatch was held September 20-23, 1993, in Falmouth, Massachusetts. This is the report of that workshop (see Appendix 1 for the agenda).

The terms of reference agreed to by the workshop participants were:

1. Identify candidate approaches to directly modifying sink gill-net fishing gear to reduce harbor porpoise bycatch.
2. Rank all candidate approaches in order of priority for future development and testing, identifying relevant characteristics of each candidate approach.
3. Identify steps for needed development and testing of the highest ranking approaches.
4. Develop a list of basic research that will be needed to evaluate and/or further refine candidate approaches and their likely success.

The terms of reference did not include evaluating methods that use active acoustic devices to reduce bycatch. This approach was discussed to a limited degree because the U.S. Marine Mammal Commission and the NMFS plan to conduct a separate workshop to specifically address this approach.

The workshop was modeled after a similar meeting held by the International Whaling Commission in 1990[1] on cetacean bycatch in fixed gear fisheries. The present workshop focused on a single gear type as fished in a specific region, and involved fishermen actively participating in the fishery and scientists with broad experience with this and similar fishing gear (see Appendix 2, Attendees). No attempt was made to evaluate methods of modifying other types of fishing gear.

The report of the workshop is structured into three major sections, corresponding to the discussion within the workshop. In the first section, the fishing gear and its use were described by fishermen and individuals involved in collection and analysis of data on fishing activity. While primary emphasis was given to fishing in the Gulf of Maine, the sink gill-net fishery in the Bay of Fundy between New Brunswick and Nova Scotia was also discussed. To a lesser degree, the New England fishery was contrasted with those in California, Washington, and New Zealand. Although not discussed during the workshop, a recent study by Larrivee *et al.*[2] has revealed a similar fishery in the Gulf of St. Lawrence. Bycatch of harbor porpoise or other small cetaceans is characteristic of these fisheries.

The second section includes a review of previous scientific studies and fisheries experiments potentially relevant to bycatch reduction in the Gulf of Maine fishery. The discussion, and hence the report, were organized using Working Paper 4, "Mitigating porpoise - gill-net interactions: a selected bibliography of potentially useful research."[3] The manuscript summarizes existing relevant literature, divided into subtopics under two broad areas: acoustic methods and animal behavior.

Based on the information presented during the workshop (including the working papers, listed in Appendix 3), a list of all potential gear modifications, research needs, and data needs was developed by allowing each workshop participant to nominate candidates. These candidates were grouped subsequently into the three subject lists. The list of potential gear modifications and more general research needs were put in priority order by consensus. The third list, pertaining to data needs, was not ranked. All lists are found in Appendix 3.

Workshop participants agreed that future research and experimental studies should proceed along the priority order developed, and that the identified data needs should be considered especially in conducting the observer program.

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[1] IWC 1990. In press. Report of the Workshop on Mortality of Cetaceans in Passive fishing Nets and Traps, La Jolla, California, October 1990.

[2] Larrivee, M-L, M. C. S. Kingley, and C. Barrette. 1993. "Effect of fishery characteristics on bycatch of harbour porpoise in the Gulf of St. Lawrence (Canada)." Oral presentation at the 10th Biennial Conference on the Biology of Marine Mammals, Galveston, Texas, Nov. 11-15, 1993, sponsored by the Society for Marine Mammology.

[3] Northridge, S. 1993, ms. Mitigating porpoise - gill net interactions: a selected bibliography of potentially useful research. (Available from the author.)

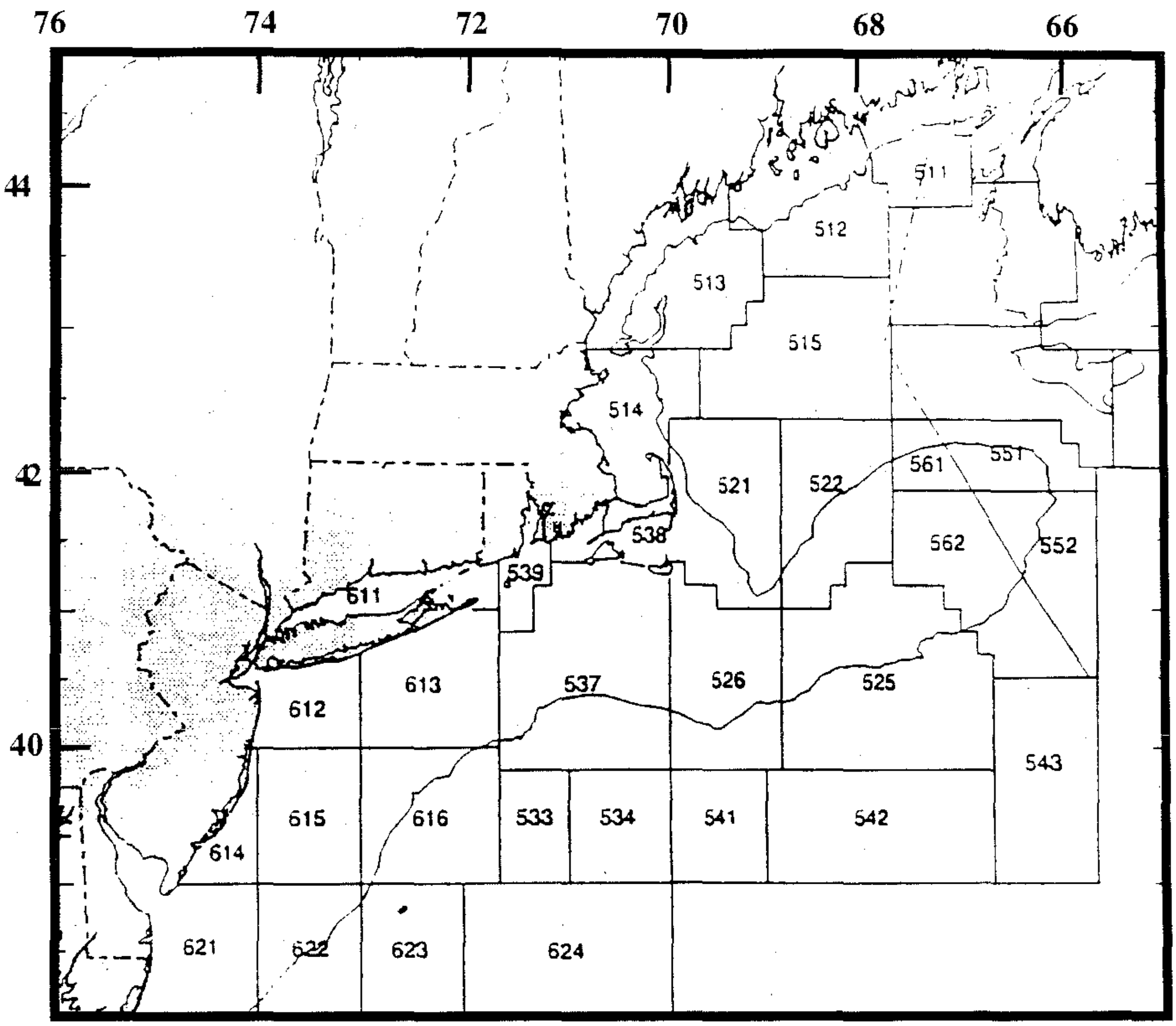

Figure 1. Fisheries Statistical Areas in the Northwestern Atlantic

DESCRIPTION OF GILL-NET FLEETS AND OPERATIONS

FISHING OPERATIONS

The New England Fishery

An overview of the New England gill-net fisheries was presented by Steve Drew (operations manager of the sea sampling/fishery observer program associated with this fishery) and Kathryn Bisack (NMFS data analyst working with the information collected by that program). Figure 1 shows the statistical areas (SAs) used for fishery management purposes in the Gulf of Maine.

Fishery observers have been sampling the Gulf of Maine (GOM) fishery for about five years. The information presented here was gathered from the Gulf of Maine fishery north and east of Cape Cod. The gill-net fleet operates in waters from close to the beach to 150 miles offshore in the Gulf of Maine. Recorded depths fished ranged from 5 to 140 fathoms in data collected since 1990, with the data on the deepest sets recorded only recently. Average boat size is between 35 and 55 ft, with some vessels as small as 25 ft and as large as 62 ft reported.

Drew noted that there is competition for bottom in the Gulf of Maine, both among gill-netters and between gill-netters and vessels using other types of gear. The gill nets are usually set on rough bottom where the trawlers won't go. Longliners will go out over the mud or use the same bottom as gill-netters. Erik Anderson (fisherman, New Hampshire Commercial Fishermen's Association) added that gill-netters are being forced to set in less and less desirable areas, because of increased competition for bottom with large otter trawl boats, and to attempt to avoid gear-conflict situations. These less desirable areas, he felt, were also the places that harbor porpoises frequent.

Most gill-netters in the GOM fishery use sink gill nets that are hauled with the assistance of a lifter. The net fishes on the bottom with anchors, usually a steel bar, on each end. The nets are set in 300 ft sections tied together in strings. Usually a string is 5 to 10 nets for a day boat, and 10 or 20 nets for a trip boat. Each end of the string is marked with a buoy, a high-flier, and a steel weight. Nets are rigged for demersal fishes in the year-round fishery. They are made of nylon monofilament or multi-monofilament, hung on the half.[1] Each net is 10 to 12 ft deep from headrope to footrope.

During discussion, fishermen reported great variety in strategy with regard to rigging, weight, and setting. Decisions depended on currents, bottom, and other boat traffic. Jim Homstead (offshore fisherman) noted that offshore boats rarely use anchors since they tangle, so he has to play the tide to compensate for that.

Day boats set in the afternoon, go home, return to pick up early in the morning, then reset and return to port. Weather permitting, day boats usually tend nets every day. The exceptions are some gill-netters targeting flatfish. They use a special net and a longer soak (3 to 4 days) because the flatfish can survive in the nets for a longer time than groundfish. Day boats account for about 80 percent of the GOM gill-net fleet.

Offshore, the vessels set overnight, pick up in the morning and set again. The subsequent sets soak 12 to 18 hours and the average trip lasts 3 to 8 days. Nets are hauled at the end of the trip and taken back to port. The time it takes to haul the net varies with the amount of fish in them and the experience of the crew in hauling and picking. Nets are generally set off the stern and hauled over the side. The anchors come up first and are reset each time. Anchors weigh between 20 and 80 lb and two are used on each string. The net is "flaked" (headrope separated from footrope) manually, or with the assistance of a flaking bar.

The method of haul has implications for attaching devices to the lines or mesh. Drew noted that instruments which are attached to nets hauled with a drum often end up on the bottom of the reel, making it hard to retrieve them during hauling. David Goodson (sonar engineer, Loughborough University, United Kingdom) noted that in the English fleet, drum reels were uncommon and gillnets are usually hauled using a belt hauler over the side and hang free when picked. This may make it easier to attach or recover instruments before the net is flaked into the storage pound. Drew noted that this was likewise often true in the New England fishery. There was also discussion of drum-type haulers used elsewhere.

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[1] Hung on the half means that they are rigged with a primary hanging ratio of 0.5, which is to say that the hung length of the net is half of the fully extended net.

The New Zealand Fishery

Steve Dawson (Otago University, New Zealand) discussed the gillnet fisheries of the South Island. Net type and fishing practices vary by region and target species. In the predominantly shallow Canterbury region, nets are typically about 1000 m long, and individual fishers set up to 6000 m of net. "Rig" nets are commonly used (mesh size 164 to 178 mm, 10 to 20 meshes deep; made of nylon monofilament, 0.7 to 0.9 mm diameter). In Kaikoura, nets are shorter, and are set in much deeper water (to 500 m). In all regions, nets are generally hauled and set over the stern, and are wound onto a hydraulically driven drum. Generally, nets are left in the water continuously and are not brought back to port unless bad weather makes net loss likely. Most gillnetting vessels are 30 to 45 ft long.

The California Fishery

Doyle Hanan (California Department of Fish and Game) described the gill-net fishery in California state waters, most of which was closed closed by a referendum banning gill nets. The fishery was primarily for halibut. Nets were fished at 12 to 30 fathoms and hauled using a drum reel over the stern.

GILL-NET GEAR

Most fishermen reported that their gear is similar in material and hanging ratio, and that their hauling techniques are similar. However, other characteristics of gear and fishing operations varied with season, fishery, size of boat, bottom fished, depth, and target species. Hanan remarked that this circumstance made for many different fisheries, not one, and that California research showed that bycatch of harbor porpoise varied quite a bit with the net rigging and use.

Ron Smolowitz (engineer, Coonamessett Farms) compared solving the problem of harbor porpoise bycatch in gill nets with gear development work conducted to improve fish catches with the same gear. Fishermen and scientists can alter most net characteristics: flotation, height, resistance, and so on. When mesh is stretched, he said, it affects the fish catch, whether the net gills or entangles fish. The uniformity of the set, the curve and bunching, can make a big difference in catch over the net; fish may pile up where there's a little bag. Smolowitz suggested that net characteristics which improve fish catches probably also increase chances of retaining a harbor porpoise.

Rigging

Robert MacKinnon (fisherman, Massachusetts South Shore Gillnetter's Association) brought some netting with him and demonstrated the typical New England gill-net rigging. For the leadline, he uses nylon wrapped lead core line. For flounder, he said, nylon wrapped poly-core line is used for the headrope (or floatline) and the net is fished inside the 30 fathom line. For groundfish, floats would be added to the headrope. The weight of the leadline varied from 50 to 90 lb, depending on the tide and how fast you want the net to sink. Homstead pointed out that another distinguishing characteristic of the flounder net was the number of floats, usually about 50 per half-net. If there are more, he said, the net is probably rigged for groundfish. Terry Stockwell (fisherman, Southport, Maine) noted that adding floats also prevents the net from being pushed down on the bottom by the tide.

Drew described another method for flounder rigging used by New England gill-netters. Ten feet of net are rigged into two feet of vertical space and "bagged" by tying the leadline to the floatline every few feet. Dawson asked if such a rig would capture fewer harbor porpoises. MacKinnon thought that if bagged, it would catch fewer porpoises and no groundfish. He suggested that when the height of the net was lower, it was a smaller target for the harbor porpoises to hit. He also described a rigging method used by Vietnamese fishermen out of Boston, a 20-mesh net with a polyfoam core floatline used for flounder and crustaceans. MacKinnon reported that the Vietnamese-type nets had no porpoise bycatch.

Flotation

Dawson reported that some New Zealand fishermen maintain that if they set the net more rigidly, they catch fewer dolphins because the animals "bounce off." There was no scientific evidence to support this claim, he said. Homstead asked if there were any holes in the nets that might have been caused by escaping animals.

Dawson said none were reported when interviewers asked about net damage.

There was some discussion of leadlines as opposed to lead sinkers and on other aspects of flotation as it related to harbor porpoise takes. Smolowitz noted that lead sinkers had been used, but were phased out in favor of leadline because line caused less tangling than sinkers.

Goodson reported that the headrope and leadline themselves can only be detected by the animal's acoustic senses directionally. Ellipsoidal shapes have proven good targets for the animal's acoustical detection senses. Floats so shaped, he said, might be more successful than sinkers as targets for porpoise sonar. If nets were rigged with more floats placed more closely together on the headline, the gear would be more buoyant, but it would be a better target for the animals to detect. In addition to being ellipsoidal in shape, the optimum float for detection would be the hard plastic type with an internal air cavity.

Bridle Characteristics

Discussion moved to the amount of space between nets on a string. Richard Turner (fisherman) said that bridle openings, the amount of space between nets on a string, varied in the fleet, but was customarily from 1 to 4 ft. Stockwell reported that he had added a 1-fathom piece of line between his nets to make the bridle opening bigger. In the limited time he used it, he said, it had not made much of a difference in harbor porpoise takes.

Dawson asked if there were data on horizontal distribution of animals caught in the nets. Bisack indicated that quadrants of the net were recorded for takes, but not proximity of the animal to the bridle opening. How porpoises travel along the net is one of the questions being addressed in experiments conducted by Memorial University of Newfoundland (MUN) using active acoustic devices on gill nets. Thomas Jefferson (SWFSC) said he had observed that Dall's porpoise bycatch concentrated around bridle openings and near the net ends in the Japanese drift gill-net operations. These operations used strings about 9 miles long, comprising 3 nets each, with about 30 ft between nets. Chris Cooper (Department of Fisheries and Oceans, Canada) said Canadian trawl data showed that fish tried to escape after encountering some physical discontinuity in the netting, and speculated that it might be the same for porpoises. Homstead suggested that the most obvious discontinuity, besides the opening itself, was the height of the net at the bridle which could be 7 to 12 ft different from the rest of the net.

Mesh Size

Anderson reported that 5.5 in. mesh is not the best for catching larger cod. The larger individual fish, he said, seem to be taken around the bridle openings and in bags in the net. Stockwell said he thought seasons made more difference in bycatch than mesh size; more harbor porpoises were caught simply when they were around. In his case, that is in the fall during pollock season. For groundfish nets he reported that the minimum mesh size was 5.5 in., 10 in. for monkfish, and a variety of sizes for flatfish. MacKinnon reported that he fished 8 in. mesh because it retains the larger fish and he got less bycatch of nontarget species.

Set Direction and Current

Goodson asked if fish, when caught down tide of the net, were somehow reacting to flow of water through the net in detecting the gear. Smolowitz said that no one knows what the fish are doing exactly, but that they seem to feel some change around the vicinity of the net. There was no consensus on whether setting the net up from, down from, or across the tidal current made any difference.

Goodson asked if there was any evidence of porpoises being caught when the net is being set. Homestead replied that he had set right in schools of white-sided dolphins without a catch. Katherine Hood (Memorial University of Newfoundland) reported that bycatch in the Newfoundland fishery often occurred during the set. However, the faster the net sunk, the fewer animals were captured.

SEA SAMPLING DATA AND DATA ANALYSES RESULTS

Bisack reported on the data collected from the GOM gill-net fleet by observers from 1989 to 1992. She had arranged the data elements collected by observers into a table (Table 1). While explaining cumulative results for each element, she asked the group to make comments on how this preliminary data analysis might be improved.

Table 1. Summary of sea sampling data collected during observations of the New England groundfish gillnetting fleet

Netting	
Net material:	nylon, in 99% of observations
Number of strands:	monofilament, in 99% of observations
Mesh size:	Range: 5.5 to 10 in., mode at 5.5 to 6 in.
Twine gauge:	No. 12 and No. 14, in 96% of observations
Rigging	
Hanging ratio:	0.5, in 99% of observations
Net height:	Range: 1 to 12 ft, mode at 10 ft
Flotation:	Range: 1 to 300 per net, mode at 50 (68% of observations)
Anchor weigh:t	Range: 1 to 60 lb
Setting	
String length:	Range: 1000 to 8000 ft, mode at 3500 ft
Soak duration:	Range: 1 to 72 hr, mode at 24 to 36 hr
Depth:	Range: 2 to 130 fathoms, mode at 18 fathoms

Since 1989, 220 of the approximately 300 vessels in the gill-net fleet have carried observers on 2,200 fishing trips. Beginning in June 1989, roughly 1 percent of the fleet was sampled. Beginning in June 1991, 10 percent of the fleet was sampled. During the 2,200 sampled trips, 11,000 hauls were examined. Of these hauls, 99 percent were made with nylon mesh. Ninety-six percent of the nets were made with 12 or 14 gauge twine. Hanging ratio was most commonly 0.5, or "hung on the half." Stretched mesh sizes range from 5.5 to 10 in., with 6 in. being most common. Headrope to footrope measurements were generally 9 ft or more. Those less than 9 ft deep were generally for flatfish and monkfish, those 9 ft and deeper were for groundfish. Observers recorded a range of flotation, from 1 to 300 floats per net. When observers began working with the gill-net fleet, floating rope (poly-core) was entered as one float, but later, observers recorded it as zero. Anchor weights ranged from 1 to 60 lb, with nearly 50 percent of vessels using railroad rails. String length was most commonly 10 nets, each net 300 ft long, averaging 3500 ft in total length. Soak time averaged 24 hr.

Mesh Size

Tim Smith (NEFSC) asked if the group felt detailed information on mesh size was important to the problem of harbor porpoise bycatch, and if so, how could that information be better verified and reported. He was particularly interested in pursuing this question because preliminary analyses of the gill-net fishery sea sampling data presented in WP12 did indicate a correlation between mesh size and harbor porpoise bycatch and it was important to figure out why that seems to be the case if mesh size really doesn't make any difference.

Smolowitz felt the existing data would not yield much useful information because in many cases the observers are recording an average, not the actual, mesh size or mesh sizes in a net. He felt that there was enough mixing of mesh sizes within nets and strings to skew data that relies on an average mesh size as a descriptor for a set. Further, he said, there is no way to verify the range of sizes or ages of the fish.

Stockwell said that most skippers know what size mesh they are hauling before it goes in the water. The sea sampler usually asks what it is and they are told. The answer may not always be right, but he wasn't sure there was any better verification that could be made by an observer at sea during active fishing.

Anderson said that in his experience, harbor porpoises were caught in all mesh sizes and that he didn't think the mesh size really made any difference.

Hanging Ratios

With regard to hanging ratios, fishermen reported a great deal of variety depending on target species. However they agreed that for groundfish most nets are hung on the half. With regard to precision in constructing nets to a particular hanging ratio, Homstead pointed out that few nets are actually measured before they are fished. He noted, and others agreed, that skeins of netting that arrive from the manufacturer are not exactly measured; in practice, all nets are not the same length, even when they were constructed to be the same.

Soak Times

There was discussion of the recorded soak time. Fishermen were concerned that the observer data collected was far more detailed than that presented by Bisack. Also, Smolowitz felt observers tended to cover the day fleet more heavily than the trip fleet because the time commitment was smaller. However, the number of sets soaked for more than 72 hr seemed high. Fishermen said that a 72 hr soak indicated either a flatfish trip or bad weather. Smolowitz remarked that the data sheets he'd seen for sets longer than 72 hr were not flounder trips. Smith then asked if it was safe to assume that a soak for more than 72 hr was probably not made by design. Stockwell said it was a safe assumption for groundfish trips, because the fish were probably not marketable if they had been three days in a net before landing.

Fishermen said one thing that might improve soak time data would be for observers to accompany the vessel on successive days so that they were present when the gear was both set and hauled. Also, fishermen expressed interest in the census of fishing vessels and activity conducted by port agents. They felt this information was more specific with regard to fishing practices (particularly soak times) and might be very useful in trying to get a more precise fit between practice and the sea sampling data. Smith noted that this information was used to help verify the number of gill-netters and the number of nets being fished. Bisack noted that the census is not complete.

Depth

Bisack asked the group what characteristics of a fishery, if any, could be discerned from depth. For Maine trips, Anderson said that those at less than 18 fathoms are probably for flatfish, since that is too shallow for groundfish. Those trips at 40 to 50 fathoms are probably in eastern Maine. Those shoreward of 50 fathoms are most likely off mid-coastal Maine. Vessels fishing shoreward with gill nets are most likely targeting dogfish. Stockwell asked if the depth data had been broken down by target species. Bisack said that it had been for species alone, but not for species combined with depth. She noted that cross-checking shallow depth trips with target species might confirm relationships such as the correlation between shallow depth and dogfish trips suggested by Anderson.

Set Direction

Discussion revealed that fishermen's strategies for setting varied with fishery, tide, wind conditions, and location of the fish. Simon Northridge (NEFSC) said that 65 to 70 percent of the trips in the data were set along Loran lines. MacKinnon noted that in crowded areas, people set on the Loran lines so they wouldn't cross gear; further offshore, he said, fishermen set on the fish, which may or may not be on a Loran line. Homstead indicated that he also set to make sure he didn't have to haul into the tide or the wind, if possible. It was generally agreed that if a set were made on a Loran line, that revealed the location of the set, but no additional information.

Entanglement Data

At this time, observers only record the quadrant of the net in which animals are entangled. Since there had already been discussion from both fishermen and scientists about the prevalence of animals entangled around the bridle ends, Bisack questioned whether further refinement of this data element would be useful and/or possible. Drew noted that sometimes the animals are so wrapped in the net that it is not possible to untangle them and still tell where they were caught in the net. All agreed that getting more precise information on where in the net porpoises become entangled is important, but there was not good agreement on how that could be done efficiently at sea by observers.

Trip Target Species

There was further discussion about how to discern or confirm the target species of a trip from data already collected by observers. For example, further examination of the data may find correlations between takes and target species that are not now apparent. Stockwell, among others, indicated that he had fished alongside vessels using nets rigged for dogfish and observed those nets taking harbor porpoises while his groundfish gill nets, fishing at the same time, did not take any. Hanan said that the California fishery logbook program was divided by target species, and that he felt it yielded some valuable information about bycatch. All seemed to feel that target species of the gill-net trip could probably be cross-checked by comparing the gear rigging with the stated target; and this could show correlations between fishing operations and bycatch that could be used to modify operations to reduce bycatch.

Gear Attributes and Entanglement

John Wang (University of Guelph, Ontario) indicated that work in the Bay of Fundy revealed little difference in harbor porpoise bycatch with mesh size. Smolowitz reiterated that hanging ratio is very important, since a net could be made to gill only, but wouldn't catch as many fish as a net that is rigged to entangle. Smith added that size selectivity experiments that have been done with fish in gill nets of varying material and rigging might provide some insights. However, Wang indicated that he had found it difficult to get useful information on selectivity of gill nets. Experiments on size selectivity have used perfectly hung nets, he said, but that's not what happens in the fishery. Wang noted that size selectivity information in the sea sampling data may indicate either targeting for large individuals or a set in an area with a lot of large fish.

MacKinnon said he he targets larger individuals by adjusting mesh size and hanging ratio, not by moving into a particular area. Wang added data from the Bay of Fundy fishery showed that the gill-net fleet was using area, not adjustments in gear attributes to target various sized individuals. Rollie Barnaby (Sea Grant Program, University of New Hampshire) said that Bay of Fundy fishermen may not have enough experience with the gill nets to realize that a larger mesh would catch larger individual fish. Cooper said that his work showed gill nets to be size, but not species, selective.

Stockwell asked if anyone had done work with underwater cameras watching nets fish in real fishing operations. Dawson said he knew of work where divers observed the nets *in situ*. They found that different species behaved differently around nets and that some were better than others at avoiding the nets. Stockwell said that he fishes a 6 in. mesh and gets all sizes and all species. He said that while steaming he was looking for forage fish (such as herring or mackerel) and he suspected that harbor porpoises may be doing the same thing. Smith asked if fishermen used sonar to target different sizes of fish. Stockwell said he preferred to set on forage fish and in a position to avoid other gear. He also may change the position of the gear with each set, zigzagging or doing a circle set if he thinks it will catch more fish.

Hanan described a study of size selectivity of gear in the California halibut fishery. Researchers found a difference in the size composition of fish catches made with 8 and 8.5 in. mesh nets. Pat Gearin (NMFS, AFSC) noted that the Bay of Fundy, where Wang's work was conducted, is a very high tidal area. In other Canadian fisheries there is probably more selectivity than Wang found in the Bay of Fundy. Gearin said this might be an important contrast since Wang's area is one of apparently higher harbor porpoise bycatch rates.

Smolowitz reported on some experiments with salmon gill nets in observation tanks. In these tests, the nets bundled as they were filled with fish. He described a study reported by Girard on how the change from natural fibers to nylon affected gill-net retention. Girard reported that the nylon nets gilled fish, but also entangled many more fish than the natural fiber nets. Fewer salmon were captured by more rigid nets. Smolowitz concluded that selectivity is relative, and that there are good data available on selectivity of gill nets for fish.

Oceanographic and Weather Factors

MacKinnon noted that he doesn't catch any fish in slime and wondered if it was also true that harbor porpoises would not be caught. Drew replied that observers tried to note slime conditions when possible, but almost nobody fishes in slime, so observations are sparse. That kind of observation, he said, might only be recorded in the comments section of the observer's log.

Goodson noted that sea state and wave height, which are recorded by observers, may affect the harbor porpoise's acoustic ability because of the entrainment of air bubbles at the water's surface during sea states greater than Beaufort 3 or 4. Smolowitz asked Goodson whether an animal's ability to use sonar is affected by the depth of the water. Goodson replied that in shallower inshore water there is more background noise, but most of this is well below the operating frequency of the animal's sonar. He suspects that for the purpose of gill-net detection, depth probably doesn't make any difference unless the animal is in very shallow water.

Jefferson asked whether anyone had seen any evidence of cetaceans changing behavior with sea state. Goodson said that bottlenose dolphins have been observed to alter (shorten) their sonar foraging range in shallow water when reverberation levels are higher.

REGIONAL AND SEASONAL STRATEGIES

Fishermen from the major gillnetting fleets operating off New England were represented at the meeting. Each gave a short presentation of describing the fishery, gear, and operations in his fleet. To help with discussion of the Sea Sampling Program data, the presenters also compared their operations with that shown as average in Table 1.

Northern Gulf of Maine
Richard Turner, Stonington, Maine

Net material:	nylon
No. of strands:	1 (monofilament)
Mesh size:	5.5 - 6.5 in.
Twine gauge:	mostly 14, some 16
Hanging ratio:	0.5
Net height:	9 - 12 ft
Flotation:	50-55 floats per net
Anchor weight:	15-25 lb mushroom each end
String length:	4,500 - 6,600 ft
Soak duration:	16 - 18 hr
Depth:	50 - 100 fathoms

In areas 511 and 512, Stonington and Jonesport are the major gill-net ports. There are 10 gill-netters in Stonington, and almost all of them are day boats, fishing primarily one-day trips. Their fishing style is roughly similar to that of other ports, but they fish longer days and deeper water on average, sailing around 1 AM and returning to port around 4 PM.

The fishing season in the area used to extend from March to November. In recent years the season has started later, in response to the availability of fish, and runs roughly from May to November. Currents in the area are stronger than in many areas to the south and west. The target species are cod and white hake. The fleet used to fish in shallower water. In recent years, it is rarely found in water less than 50 fathoms deep because of high catches of dogfish in shallow waters.

With regard to takes, it seems that when porpoises are seen swimming, they are not taken in gill nets. When porpoises are taken, they most often appear to be tangled by the dorsal fin, with a few tangled by the tail. Few seals are caught in nets. At times, fish in the nets have been bitten by predators, but it is uncertain whether they are bitten by seals or blue sharks.

Central Gulf of Maine
Terry Stockwell, Boothbay Harbor, Maine

Net material:	nylon
No. of strands:	1 (monofilament)
Mesh size:	5.5 - 6.0 in.
Twine gauge:	14
Hanging ratio:	0.5
Net height:	9 - 12 ft
Flotation:	50-55 floats per net
Anchor weight:	(old leadline sometimes used)
String length:	3,600 - 6,000 ft
Soak duration:	18 - 24 hr
Depth:	40 - 80 fathoms

In Boothbay Harbor there are about eight gillnet vessels. They fish mostly one-day trips, and occasional trips of two to three days' duration. They have fished traditionally in area 513, but in recent years during the summer they are more frequently in area 512. They used to start fishing in March, but in recent years the fishing season has started in April in response to availability of fish, and goes through the first part of December. The target species is usually cod, although there has been some directed fishing for dogfish. (This year the dogfish are too small for the market.) They fish at least 60 nets per day, with some boats fishing 80 to 120 nets per day.

There are often several boats fishing in a concentrated area, setting their gear on Loran lines to avoid entanglement with other fishermen's nets. The fishing is very variable, with conditions changing daily. Seals are numerous in the area, and seal damage to the catch is not uncommon.

Harbor porpoise takes are most likely to occur in April-May and in November. In the autumn, takes often follow the passage of schools of mackerel through the area. Takes may be associated with the presence of herring. It is not uncommon for fishermen to see porpoises swimming, but not taken in nets. When taken, it often appears that they have been tangled by the pectoral fins, then the dorsal fin, with very few apparently wrapped by the tail.

New Hampshire North of Portsmouth, Statistical Area 513

Erik Anderson, New Hampshire Commercial Fishermen's Association Portsmouth, NH

Fleet: 25 vessels
Trips: Duration: half day boats, half off shore boats. Days are to Jeffreys Ledge
Season: Feb to March: Offshore boats, no day boats
April to May: groundfish gearing up, Spring flounder fishery is in the day fleet
June to Aug: Peak for groundfish and dogfish
Oct-Dec: Active groundfish time
Netting: Net Material:
No. of strands:
Mesh size: 5.5 in.
Twine gauge:
Rigging: Hanging ratio:
HR to FR distance:
Flotation:
Anchor weight:
Setting: String length: day boats, 5 to 25 nets trip boats, 20-25 nets
(Driven by size of vessel. Day boat operators probably fish 60-90 nets; larger boats fish 80 to 120 nets)
Soak duration: 16-18 hours, accomplished in one day.
(Extended soak times not advantageous because it affects the quality of the product delivered.)
Depth: Whole length of Jeffreys Ledge is 40 fathoms and above. At more than 40 fathoms, the fleet runs into trawlers

Anderson noted that the vessels in this fleet have higher harbor porpoise bycatch rates. The depth of water does seem to make a difference in bycatch rate. Anderson himself fishes inside of Jeffreys Ledge more than offshore of it. He reported that his bycatch used to occur in spring, but in recent years has been much more likely in the fall.

The group noted that high takes have been on the edge of Jeffreys Ledge. Anderson said that the fleet has been forced inside by the mobile fleet since 1991, which was the year of the highest recorded take. Anderson said that happened when he and others in the fleet moved to the 50 to 55 fathom line. He noted that five miles from that line he didn't have any problem.

The gear used is fairly standard. Anderson reports seeing differing patterns with harbor porpoise entanglement and fish takes. He sees no pattern *per se* in how harbor porpoises are entangled, although pectoral fins seem to be the place they are first snagged.

Although it seems logical that both fishermen and harbor porpoises are looking for bait, sometimes there is bait and no harbor porpoises or groundfish. Sometimes the net plugs up with bait and sinks. In spring of 1993, Anderson caught a harbor porpoise in a short (6 hr) soak. The group noted that the only solid data on what bait fish are present during takes is extrapolated from landings data and comparison of activity in shoreside processing of herring. Also, Anderson noted that in Area 513, there was some success with fishermen warning each other of harbor porpoise activity, since Stockwell reported seeing the animals about three weeks before they arrived in the area Anderson fished.

In discussing the affect of gear on harbor porpoises, Homestead remarked that although the groundfish gill-net fleet had lost a lot of bottom to trawlers in the recent past, there was also encroachment of gill-netters into deeper water, traditionally the grounds of trawlers. "Using monofilament line and small floats, we wouldn't normally go past 60 fathoms. Now we're out to 120 to 150 fathoms and that is traditionally their water," he said.

Discussion was inconclusive regarding whether this spatial shift in fishing effort might have an affect on porpoise takes. The data have only been collected for three years, not long enough to show a trend. There was a significant drop in takes for the spring in SA 513-514, but the reason for it is not known.

Offshore Fleet

Jim Homstead, South Portland, Maine

Area: SA 515 with a few boats also using SA 522
Fleet: 20 vessels
Trips: Offshore, trip boats

Season: Year-round
January to March: pollock and hake in eastern part of area
April to June: groundfish and dogfish
Summer: hake, pollock, a few cod
Fall: pollock

Netting: Net Material:
No. of strands:
Mesh size: 6.0, a few at 6.5 to 7 in.
Twine gauge: 14 for 6.0, 12 for bigger mesh

Rigging: Hanging ratio: 0.5
HR to FR distance:
Flotation: 60 floats per net
Anchor weight: Not used offshore

Setting: String length: 20 to 30 nets
Soak duration: first set usually over night and pulled after 12 to 14 hours, reset and soaked for 18 to 20 hours.

Depth: 75 to 125 fathoms, 130 fathoms in January and February for pollock

Homstead described his fishing operation. He sets his gear on Loran lines or edges at depths of 75 to 130 fathoms, where he occasionally fishes alongside trawlers. His first set is hauled in 12 to 14 hours. In the summer, the boat operates with a crew of five and in other months with a crew of four. Target species include pollock, hake, dogfish, and groundfish. In SA 515 during the winter, he estimates there are 9 or 10 regular gill-netters. More boats operate in summer, coming mostly from Gloucester and Portsmouth, making up the 20 or so boats that fish year-round in the area.

Homestead remarked that in years past he had fished SA 513, where he caught harbor porpoises at a higher rate over the season. This was inside the 50 fathom curve, never taking more than one or two animals in a day. Since he has been fishing SA 515, he sees only white sided dolphins and does not know of any vessels catching these animals in their gear. He reported taking only one harbor porpoise and three seals in the past three years.

Fishermen present reported that they did not capture harbor porpoises when they could be clearly seen traveling in groups. Smith summarized sighting survey data, noting that the animals travel together in small groups. That is important, he said, if they are present in noticeable groups and not being taken. Anderson remarked that if the fishermen can see harbor porpoises they try to avoid them, so the resulting reduction of effort or hesitation in resetting gill nets might affect takes.

Southern New England, SA 521 to 515, 522

Robert MacKinnon, Massachusetts South Shore Gillnetter's Association
Marshfield, Massachusetts

Fleet: Small day boats, mostly out of Scituate, 38 to 42 ft

Trips:

Season: Winter: cod at 20 to 50 fathoms
Spring: flounder at 80 to 125 fathoms (bycatch of lobster)
June: monkfish, dogfish
July-August: trip fish offshore in 521 on the backside of Cape Cod
Fall: pollock, cod on the East side of Stellwagen

Netting: Net Material:
No. of strands:
Mesh size:
Twine gauge: inside waters, 13 when other gears are around

Rigging: Hanging ratio: 0.5
HR to FR distance:
Flotation: cod, 50 floats per net
Anchor weight:

Setting: String length:
Soak duration: flounder, haul every 48 hours; otherwise try to fish every day.

Depth:

MacKinnon represents approximately 20 boats from the port of Scituate. He reported that some boats have shifted to Point Judith (R.I.) to catch monkfish, at least one boat currently fishes for dogfish on the Outer Banks of North Carolina, and many boats go offshore to longline in December and February.

MacKinnon reported that most harbor porpoise takes occurred off Stellwagen Bank, generally in shoal water (less than 30 fathoms deep). He observed that when the herring move into the area, the harbor porpoises follow them. MacKinnon associates the lack of herring in the area over the last two years with fewer harbor porpoise takes in the last two years. The harbor porpoises that he caught in earlier years were taken in flounder nets with 5.5 in. mesh, and the animal's tail seemed to be the first thing wrapped in the net.

Gearin reported that the gill-net fishery he worked with uses 7 to 8 in. mesh in 10 to 30 fathoms; most animals are head-caught, after which they wrap or twist and the flukes and pectorals are entangled. He has seen 360° net marks on the heads of harbor porpoises. This phenomena was also reported by Cooper. Gearin had theorized that takes happened when mothers and calves were foraging near the bottom of nets, since mature females and juveniles were taken together. However, DNA fingerprinting tests showed that the animals in multiple-take sets were not related. Work is now underway to determine if relatives are taken during the fishery, but not in the same haul or on the same day. Jefferson reported that similar tests done on mature females and calves taken in the California gill-net fishery did not reveal family relationships. Bisack reported that approximately 10 percent of the observed takes in the Gulf of Maine were multiple takes of two or three animals.

Bay of Fundy

John Wang, University of Guelph, Ontario

Area: Bay of Fundy, 10 to 15 minutes out from North Head/Campobello; 2 to 2 1/2 hours to the basin in the Bay

Season:	mid-July to mid-September (peak) July- to October (complete) Refers to times when porpoises are caught
Fleet:	22 boats out of North Head, Grand Manan Island, 35 to 45 ft boats
Netting:	Net material: monofilament No. of strands: Mesh size: 6 in. Twine gauge:
Rigging:	Hanging ratio: 2/3 HR to FR distance: 33 meshes Flotation: 80 to 100 floats per net, 45+ lb lead line plus a leaded rope for extra weight threaded with the footrope Anchor weight: 40 to 60 lb admiralty-style anchors
Setting:	String length: 3 to 4 nets per string, 900 to 1600 ft per string, 5 to 6 strings per boat Soak Duration: 18 to 72 hours depending on weather
Depth:	20 to 80 fathoms

The gill-net fleet consists of 22 vessels on Grand Manan Island. Twelve boats fish from North Head and ten from the southern part of the island. There are six gill-netters located on nearby Campobello Island. Gill-netters are also located in Nova Scotia, but their interactions with harbor porpoises are not well documented and are believed not to be as detrimental as those in the fleet operating from New Brunswick.

The Bay of Fundy vessels are rigged with stern rollers for hauling the nets. They raise the net to the surface with floats before hauling. There is little tension on nets when hauling. One net (or "web") in a string is approximately 400 ft long, and 9 to 15 ft high. More floats are used on these nets than on nets in the U.S. Gulf of Maine and the hanging ratio is quite different.

The day fleet travels about 10 to 15 minutes from North Head to the fishing grounds, or about two hours to the basin in the Bay of Fundy. It is an area of very high tides. Tidal flow can be anything from slack to racing, and an average tidal flow has not been calculated. Set netters don't go some places because the tides are too high. The fleet targets pollock, cod, and hake. Average crew size is two.

A high concentration of harbor porpoises occurs from July to September near the northern portion of Grand Manan Island to the Wolves Islands. A large number of porpoises are caught in gill nets and weirs during this period each year. Many gill-net entanglements are thought to occur during daylight, when herring are demersal. Herring compose 85 percent of porpoise stomach contents. Porpoises may also become entangled while trying to take hagfish caught in the nets during long soaks. Previously, harbor porpoise bycatch estimates were derived from the number of animals returned by fishermen, who receive a bounty for each animal. A report of 30 animals taken in one day was confirmed, and the fisherman involved estimated takes by other vessels were similar over a period of three weeks.

An observer program was initiated this year (August to mid-September, 1993). Four technicians were employed at four locations: North Head, Whitehead (Southern part of Grand Manan), Campobello, and Nova Scotia (Meteghan). There was discussion about whether the concentration of animals in the Bay of Fundy was higher than on U.S. Gulf of Maine fishing grounds and if so, might that result in the allegedly higher takes by gill-netters than are seen in the U.S. part of the fishery. Ed Tripple (Department of Fisheries and Oceans, New Brunswick) noted that although actual density of harbor porpoises in the area was not known, there was no question it was high.

Smolowitz asked if any differences had been observed in animal behavior in the Gulf of Maine and the Bay of Fundy. Smith has not seen any work showing major differences in animal behavior in the two areas reported.

Stockwell asked what Canadians were doing about the high kill rates. Tripple reported that when the 1993 observer data are ready it will be presented to managers. He predicted that since the area concerned is relatively small with only a few fishermen, the problem could be addressed a little more easily than that of the United States.

Newfoundland

Katherine Hood,
Memorial University of Newfoundland
St. Johns, Newfoundland

Area:	Newfoundland
Fleet:	
Trips:	Day trips
Season:	
Netting:	Net Material: Monofilament
	No. of strands:
	Mesh size: 5.5 in.
	Twine gauge:
Rigging:	Hanging ratio:
	HR to FR distance:
	Flotation:
	Anchor weight:
Setting:	String length: Ranges from 5000 to 900 fathoms, 3 to 10 nets per string
	Soak duration: hauled daily
Depth:	offshore: 50 fathoms, kept about 1 fathom off bottom.
	inshore: 12-20 fathoms, 1 to 3 mi. offshore

The fleet leaves port around 4:30 AM, hauls the nets, resets, and returns to port at 3 to 4 PM. In 1992, the east coast of Newfoundland was closed to cod fishing. Recently, SA 3PS was also closed. This is where Hood has been working with an observer-based research project, an area that traditionally has been both a big fishing and a high bycatch area. The target species is primarily cod with an inshore capelin fishery. Estimated average landings ranged from 6000 to 51,000 lb per day. For the boats included in the study, the average was 5000 lb. Fishermen in St. Brides were offered a buy-out, and only one family chose to continue fishing.

In 1992, 90 harbor porpoises were reported as bycatch. Fourteen of these were retrieved and used for study. The fleet also has a bycatch of seals, with 800 to 1000 taken in 1992, primarily in the inshore capelin fishery. Harbor porpoises seem to be following the capelin in that instance, and appear to follow herring as well. She estimates an annual bycatch of about 3000 harbor porpoises and many more seals.

The study used CTDs and observers. Oceanographic data were collected at the nets in 15 minute transects: during haul, pre-, and post-storm conditions. Data were obtained for nets that did and did not capture harbor porpoises. At each station and net, CTD data were recorded to see if there were any correlations.

Observers collected daily haul numbers from fishing vessels and daily numbers from the fish plant to determine total catch. Information was also collected by observers on all bycatch during fishing operations. Stomachs from both captured harbor porpoises and from the fishing target species were examined.

Gear varies much more within the fishery in Newfoundland than it does in the New England fishery, particularly with regard to number of nets per string and strings per boat. Most nets are fished with the leadline off the bottom. Data were collected on net construction, color, age, and other descriptors. At the conclusion of fieldwork, Hood reported that the fleet was going from 5.5 to 8 in. mesh and to hooks for longlining.

Observers recorded where harbor porpoises were found in the nets. A great percentage of them were found by the bridle, or skirt, rolled up in the net. On two occasions, a harbor porpoise was taken along with seals (mostly young harp seals).

SEASONAL BYCATCH PATTERNS IN NEW ENGLAND

Smith briefly outlined the areas and seasons during which gill nets take harbor porpoises. The information was based on observer data gathered over the past three years. In 1989-1990, 1 percent of gill-net trips were covered; in 1991 and 1992 10 percent were covered. The Gulf of Maine fleet was covered in all years, and in 1992 areas to the south of Cape Cod were also covered.

Reported harbor porpoise takes are shown by geographical area in Figure 2. Conclusions about takes and movements are inconclusive because not enough sampling has been done to provide a statistically sound basis for comparison. Takes generally correspond with seasonal movements of animals, but those movements do not fully correspond with migratory data. For example, in Massachusetts Bay in 1990, 10 percent of porpoise takes occurred in March and 5 percent in April. In 1991, no porpoises were taken. In the more northerly areas, the bycatch has varied from year to year.

Dawson asked how much information there was on fishing effort, harbor porpoise movements, and fleet changes over the years. Smith said that

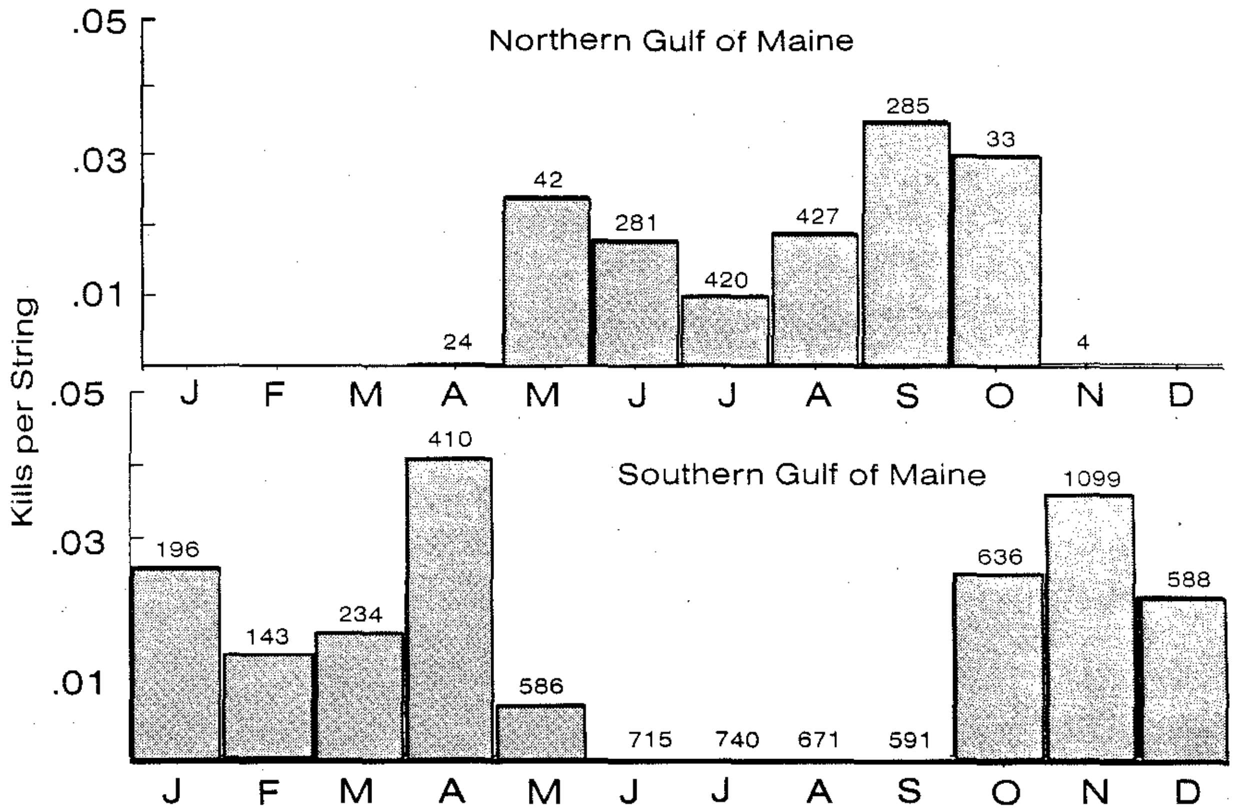

Figure 2. Harbor porpoise takes in the gill net fisheries (kills per string for observed strings) by geographical area, June 1989 to December 1992. Northern Gulf of Maine comprises Statistical Areas 511 and 512. Southern Gulf of Maine comprises Statistical Areas 513, 514, and 515. Numbers over bars are the total number of strings observed

there was not enough information on the seasonal distribution of harbor porpoises to make any correlations with those characteristics. In some areas, he noted, harbor porpoises were clearly present and there was no take.

The problem does seem to be seasonal, although the season varies with area. In the mid-coast fisheries, 20 to 45 percent of takes occur between October and December. Off eastern Maine, harbor porpoise bycatch occurs throughout the summer months. In Massachusetts Bay it is more prevalent in the spring.

Drew suggested that additional scrutiny of areas where there were harbor porpoises and no takes might be useful. For example, the area east of Cape Cod has high observer coverage and no reported takes. He said that the nets fish in strong tides with a lot of floats and lead. MacKinnon countered that the net fishes only during slack tide, and that in the tide the net lays down. David Wiley (International Wildlife Coalition) suggested that the strong tidal current through the net might help animals escape the nets, or wash dead animals from the nets before they are hauled.

Wang added that in the Bay of Fundy, with some of the world's highest tides, no correlations have been found between takes and tidal current. Correlations have been found however, with area, depth, and aggregations of individual porpoises. The nets in the three areas with highest takes are fishing in less than 50 fathoms of water where there are a high number of individuals. All three areas have similar tidal flow. Wang reported that time-depth recorder data from tagged animals indicated that they were spending a lot of time near the bottom in high-risk areas, and are suspected to be foraging, since 80 percent of stomachs examined contained herring.

Doug Beach (NMFS, Northeast Region) asked if fine-scale distribution of forage fish was known for any of these areas. Northridge indicated that there was little information, and that most data collection was centered on groundfish rather than herring or other forage fish.

TECHNICAL PRESENTATIONS ON MITIGATING PORPOISES - GILL-NET INTERACTIONS

This portion of the meeting was meant to take advantage of the attendees' areas of expertise in cetacean biology and behavior, gear technology and research, and *in situ* knowledge of commercial fishing operations and incidents of harbor porpoise bycatch during those operations. Several working papers were distributed at the meeting (listed in Appendix 2) in order to familiarize participants with recent research. The goals of the discussion were twofold:

1. **To review work in the field** of mammal bycatch reduction and draw out the gathered experts' knowledge of new information not covered in the working papers

2. **To discuss this gathered knowledge and begin to evaluate possible modifications** to gear and the research and data collection/analysis that would support those or other methods for reducing mammal bycatch.

In order to structure the discussion, the group worked from an outline supplied by Working Paper 4 (WP4), "Mitigating porpoise - gill-net interactions: a selected bibliography of potentially useful research." Working from that paper, the discussion was divided into several areas of discussion:

1. **Acoustic methods of bycatch reduction**

   Porpoise sensory abilities
   (the porpoise's acoustic emissions and/or acuity of acoustical perception)
   Net detectability
   (acoustic or other properties of netting material and how cetaceans perceive them)
   Passive acoustic experiments
   (principally the addition of acoustically reflective material to netting to make the nets more detectable by animals with acoustical perception ability)
   Active acoustic experiments
   (sound-emitting devices attached to gear in order to alert animals to or scare them away from nets)

2. **Animal behavior and net design**

   Behavior in relation to nets
   Mechanics of entanglement
   Gill-net design and use in relation to entanglement
   Nonacoustic modifications to gear

Active acoustics were not considered in depth because a workshop is planned for Fall 1994 dedicated to that topic. Discussion tended to be far ranging and discourse often strayed from the main topic at hand. Most of the comments are recorded here nonetheless, since it was during this discussion that the group deliberated on mitigation strategies, needed research, and data improvements, eventually culling out those that had the best chance of immediately making a positive difference in harbor porpoise bycatch.

ACOUSTIC METHODS OF BYCATCH REDUCTION

Porpoise Acoustics and Net Detectability

The technical discussion was summarized by Jim Hain (NMFS, Northeast Fisheries Science Center) as follows:

Source level:	160 dB (maximum of 177 dB re 1μPa at 1 m)[2]
Transmit beam:	9° azimuth (estimated value), 18° elevation
Pulse approximately 10 cycles:	(gated sine wave, narrow band)
Central frequency:	approximately 120 to 140 kHz (100-150 kHz)[3]

[2] Akamatsu, T., Y. Hatekeyama, Y. Kojima, and H. Soeda. 1992. The rate with which a harbor porpoise uses echolocation at night. *In* J. Thomas *et al.*, eds., Marine Mammal Sensory Systems, p. 299-315. New York: Plenum Press. Hatakeyama, Y., and H. Soeda. 1991. Studies of echolocation of porpoises taken in salmon gill net fisheries. *In* J. A. Thomas and R. A. Kastelein, eds., Sensory Abilities of Cetaceans: Laboratory and Field Evidence, p. 269-281. New York: Plenum Press.

Pulse duration:	approximately 20 to 100 microseconds
Reception resolution:	approximately 3°
Typical slow click rates:	10 to 500 clicks per second
Audiogram peak sensitivity:	4 to 40 kHz, with rapid fall-off above 140 kHz and below 4 kHz.
Estimated Detection range:	Rope/leadline: 9 m Monofilament mesh: 2m

Acoustic Capabilities of Harbor Porpoises

Goodson described the beam of sounds as emitting from the melon of the animal and said that the porpoises seem unlikely to be able to perceive small targets outside the narrow transmitted (18°) beam width. In his opinion, they have little chance of detecting the headropes or leadline (except when they are at right angles to them), or webbing. They have a better chance, he said, of detecting floats, because the floats have a large enough acoustic cross-section to create a specula acoustic "glint" that the animal's sonar can detect. The pronounced giant glint from ellipsoidal floats can be detected over a wider range of approached angles than that from cylindrical floats. Metal or air-chambered hard plastic floats are likely to produce the best reflections. Webbing is difficult to detect, first because the material is very transparent to sound, and second because the webbing fiber/filaments are much smaller in cross-section than the wave length of the incident sonar signal. To get good detection potential there has to be a marked difference in the reflectively of the two masses, as one would find between water and air.

Goodson suggested that animals may "see" webbing as they would algae or air bubbles: as something they can swim through. When they are foraging, they may detect a mass (such as a string of nets with floats and line) and objects beyond it (fish aggregating behind the net), but once they are locked on a target fish, they may not notice anything else. Bottlenose dolphins in captivity don't like to go through apertures less than 1.5 m or so, he reported. He suggested it might be useful to increase significantly the length of the bridle openings between nets in a string, or to eliminate the openings altogether. He also noted that in some U.K. bottom set nets, the foot rope is maintained a few inches off the bottom (to reduce crab interactions). This technique might usefully make the bottom of the net more detectable to the porpoise's sonar, especially on soft bottom in which the leadline may sink.

Yoshimi Hatakeyama (National Research Institute of Fisheries Engineering, Japan) measured sound pressure of "clicks" emitted by harbor porpoises held in concrete pens and animals held in enclosed nets in the open sea. The sound pressure measured was lower in the animals in the pens than it was in animals in the enclosed nets. This experiment and others have led him to believe that animals are selective about when they are echolocating and that, at times, they may not be echolocating systematically.

Dawson suggested that net modifications will only work if the animals are echolocating at the time they encounter a net. Further, he said, animals are also captured in nets that they are technically capable of detecting. Goodson noted that more information is needed to determine the distance at which harbor porpoises can detect an object. The sonar beams that cetaceans emit are relatively narrow, he said, and a small target needs to be within the beam width if it is to be detected. He continued that harbor porpoises, when apparently foraging near the surface, had been observed to zig-zag rather than swim in straight lines; a potentially hazardous behavior if repeated near a gill net.

Harbor Porpoise Behavior

Several researchers reported on behavior noted during their work with dolphins. Dawson reported that dolphin sonar clicks increase in rate and the animal "wags" its head back and forth when locating a school of fish. Goodson reported that in his observations, a dolphin did not swing its head at all once it was locked on a target, which it follows with its beak. Goodson noted that the head wagging is characteristic of foraging behavior and that could be what the animals are doing around the net. They are very good at classifying objects as prey, and perhaps the fish's strength as a target is induced by the regular variations in its tail beat rate. Hatakeyama added that the frequency of a dolphin's acoustic signal is very high and its beam narrow while the animal is searching.

[3] Mohl, B. and S. Andersen. 1973. Echolocation: high frequency component in the click of the harbor porpoise (*Phocoena phocoena*, L.) *J. Acoust. Soc. Am.* 54:5:1368-1372.

Harbor porpoises, said Hatakeyama, also have a low frequency click, but they don't use it for echolocation. (There are some data on harbor porpoises making sounds at 2 kHz. The source level is also very low, about 120 dB. They may use this frequency range for orientation, and possibly for a communication mode.)

Hatakeyama also reported on his work with a harbor porpoise in aquarium tanks with nets present. During observations, the animal approached the net eight times, making a u-turn just before touching the net. Nine times it passed by the end of the net and into the water on the other side of it. After about 2 minutes, the animal swam vertically toward the net and made contact with it. Hatakeyama concludes from this that the headrope and floats are very obvious to the animal and that after the animal is used to it, the harbor porpoises will be less concerned about avoiding it.

Gear Modifications Related to Harbor Porpoise Echolocating Ability

Reflectors. Goodson said that floats are detectable by harbor porpoises and the best shape is one that will reflect the animal's beam from any direction. The actual reflection, he explained, is of first air surface encountered. In foam floats, it is the air bubble that act as reflectors. The optimum float for acoustic detection, he has found, is one with a small volume of air trapped inside a rigid plastic shell to form a curved reflecting surface; the "target strength" of such a float is determined in large measure by the curvature. For dolphins, the curvature would need to create a target strength of -35dB (for a sphere with a 2 m radius). For porpoises, a smaller target strength may be adequate, as their maximum prey size is smaller. In that case, a spherical target of the same diameter (target strength approximately -41dB) may be appropriate. (The minimum size reflector to give this target strength is about the same dimension as a table tennis ball.) Such reflectors would need to be distributed across the webbing face of the net at 2 m intervals or less. The reflection, he said, is from the mismatch in density between the water and the float. For float material, Goodson noted that metals such as tungsten and lead have a significant mismatch in density with water, but they are not appropriate for fishing gear; synthetic foam doesn't stand up to water pressure; and hollow glass balls are good.

MacKinnon asked about threading polyline though the net parallel to the headline or floatline and the leadline to make the net more detectable. Goodson said it was an inefficient way of getting sound back to an animal, but a 1/4 to 5/16 in. poly rope would be much more detectable than the webbing alone. However, the animal would only detect this when approaching from a perpendicular angle. Hatakeyama reported that this had been tried in his work with various reflective materials attached to nets. In one experiment, vertical ropes were attached to the net every 3 m. He also tried using sheets of plastic blister wrap (a packing material) and horizontal vinyl rope on the nets. In these small scale experiments, porpoises still became entangled. Also, reflectors tended to tangle the nets during hauling. Hatakeyama noted, however, that more data would definitely be required before any conclusions could be drawn.

Jefferson reported on an experiment in Monterey Bay using vertical lines anchored in shallow water on sandy bottom. Porpoise behavior around the strings was tracked from a cliff. The strings varied in materials: plastic blister wrap, nylon, and bead chain. The animals did appear to have better success detecting some materials, but no gear was completely avoided. There was no conclusion about what the animals were reacting to that made detection success better in some cases.

Hain returned to the question of the low-frequency sound emitted by the animal and whether an animal would get any return using that near a net. Dawson said he doubted it, since at 2 kH the hearing ability of the harbor porpoises is very low. Goodson agreed, saying that its directivity is also poor at that level, and even if it did use the low frequency band, the sound would go straight through the net. Hatakeyama explained that low frequency sounds are emitted at very low sound pressures. The animal's hearing is not good enough to detect it. Jefferson noted that some have suggested that this is simply an artifact of high frequency sound production.

Animal communication. Dawson indicated that there is little solid information on harbor porpoise communication. Goodson noted that in his experience, bottlenose dolphins are echolocating while in a group, but nothing is known about their cognizance of signals. Smolowitz asked about circumstances where individuals are scattered on either side of a net and sending out signals. Dawson reported that there is evidence from bats and dolphins that animals in groups do use each other's sonar signals. Goodson agreed, arguing that if we can read their signals on our equipment it is likely they can read those of one another. Hatakeyama noted that the bottlenose dolphin whistles in communication mode, but the harbor porpoise uses high frequency clicks.

Communication among the animals was discussed at some length, particularly with regard to whether animals would stay away from gear that broadcasts a harbor porpoise "distress call." Dawson felt that although little was known about harbor porpoise communication, it probably was not relevant to management. Further, he said, no one seriously thinks they have a symbolic language. They don't use sounds in sequences or with a syntax, he said, although they may be "eavesdropping" on other animals' sonar signals. He suggested that the communication was probably passive rather than active. Wang indicated that there may be some communication between mothers and calves. Dawson said that those were probably distress calls, and reminded the group that there is no specific answer to this question for any cetacean. All cetaceans make sounds when they are highly motivated, he said; dolphins and porpoises make sounds that indicate not only danger, but other states as well.

Goodson recalled an anecdotal observation (attributed to Jacques Cousteau) of dolphins reacting to prerecorded sounds from an injured (harpooned) dolphin. The injured dolphin's close associates reacted to the playback, but dolphins encountered later did not.

Jefferson noted that there was good evidence that killer whale pods, subgroups, and individuals exhibit differences in call structure and that the frequency of their calls increases when they are excited. It is not clear, he added, whether animals hearing a distress call would be attracted or repelled from the area.

Nonacoustic Sensory Abilities of Harbor Porpoises and Related Gear Modifications

Hearing and chemoreceptivity. Beach suggested that the animals may not be echolocating near an aggregation of prey simply because they can hear or otherwise detect the fish without using sonar. Dawson said that it appears that dolphins can gather a lot of information about their surrounding environment without echolocating. Goodson added that there may be nonacoustic factors that the animal can use to follow and locate a school. For example, he said, a dolphin following a herring group may be locked onto a trail of excreta. They can also detect fine changes in salinity.

Smolowitz proposed soaking nets in something that would repel the animals. He said there was research that indicated some dips affect fish catches. However, it is not known whether this is caused by a chemosensory or mechanical factor. Goodson noted that there had been some work on chemoreceptivity by researchers in the Ukraine. Kusnetzov demonstrated that bottlenose dolphins possess acute sensitivity to "odorant" solutions and that "common dolphin detected the feces extract solution diluted in proportion 1 on 10 millions" (Kusnetzov, V. B. 1990. Chemical sense of dolphins: quasiolfaction. *In* J. A. Thomas and R. A. Kastelein, ed., Sensory Abilities of Cetaceans, Laboratory and Field Evidence. Proceedings of a NATO advanced research workshop and symposium of the Fifth International Theriological Congress on Sensory Abilities of Cetaceans, held August 22-29, 1989, in Rome, Italy. New York: Plenum Press). Goodson also noted that traditionally, fishing net materials were treated with tar oil, alum, and bark extracts to prevent rotting, and these treatments would leach out of the water with time. The increasingly concentrated taste in the water at short range would be detectable to the animal. He felt that if a suitable repellent treatment could be found, it would be a good candidate deterrent. Northridge reported, however, that there was evidence that tarred nets that were used in the North Sea did have harbor porpoise takes.

MacKinnon reported that new gill nets are sometimes soaked in fabric softener to loosen them, but there weren't any other dips in use in New England that he was aware of. Russell DeConti (Center for Coastal Studies) asked about the status of research into the chemoreceptive abilities of the animals.

Color/light detection and reaction. Fishermen indicated that they had tried all colors of nets without any success in deterring harbor porpoise bycatch. Dawson said that cetacean eyes generally have a high proportion of rods, which detect contrast, and very few cones, which detect color. For this reason, it is currently believed that they don't have good color perception. Hatakeyama reported on work with beluga whales that indicates they do detect red and black string more easily than green. If the cell density in the retina of the harbor porpoises were examined, he felt it would reveal quite a bit about the animal's color perception.

The role of available light in net detection was also discussed. Smith pointed out that in 50 fathoms of water it is probably always too dark to visually detect a net. Smolowitz noted that more animals would be caught at night than during the day if they were only using visual cues when encountering nets, and said that this was the case with fish. That would make it important to know the amount of available light at the time of entanglement. However, he thought most entanglements were the result of the animal being startled or were accidental, because turbidity or some other intermittent factor was obscuring the net. Experiments with fishing gear have repeatedly shown, he said, that even at night you still have to make the net invisible to the fish's eye if you want to catch it.

Hatakeyama reported that the animals had better success recognizing nets made of thicker, darker colored twine. They would approach it and react to it. In one experiment, food was put about 10 cm behind the net. Porpoises on the opposite side approached within 5 to 30 cm of the net using echolocation. About 40 seconds later, it rushed into the net using its head and was entangled. In a night experiment, food was placed next to a drift gill net. The animals recognized the danger and did not approach the food. He concluded that the reaction of the porpoises depended on how hungry or nervous it was.

Bisack asked fishermen to describe the range of webbing colors they used. They reported using pink, red, and a range of green and blue webbing for most trips, and often fishing more than one color in a string. Over the years, MacKinnon has purchased white webbing and dyed it with household fabric dye. He reported that light green always worked, drab was reliable, and that purple was the best for flounder. He hasn't tried orange, but noted that the Icelandic fishermen use it. Hood said that in her Newfoundland study, the fishermen preferred green and light blue. They hoped to correlate web color with takes in analyzing data collected in the study.

Wang said that his studies with tagged animals indicated that they were not diving deeply at night, and it is assumed that's either because they are not foraging or because the prey (herring) is at the surface at night. Stockwell added that he felt the harbor porpoise feed drops off at night and that's when the animals approach gear that is actively fishing and become entangled. Turner confirmed that he had never caught an animal during the day. Anderson reported that he caught one during the day in 45 fathoms of water on a shallow, short (6 hour) soak.

Drew said that he had the impression that takes were fewer on trip boats, and that gear is definitely in the water at night. For day boats, he suggested, you would think the nets are on the bottom during more daylight hours than those of trip boats. Turner added that the primary difference between trip and day boats is distance from shore and he felt that was a more significant factor in bycatch than available light. Wang noted that in the Bay of Fundy study they found that the longer soak times (24 to 48 hours) had higher takes of porpoises. Northridge added that currently one can determine how long the nets are in the water, but not the time during the set when animals are caught. Also, he noted that since most sets in the data are longer than 16 hours, you can't discern the time of day.

Process of Entanglement

Dawson noted that although the animal's acoustic perception of floats was highly directional, its optimum direction was perpendicular to the net. As such, one would think that close and perpendicular to the net would be where the animal was most aware of the mesh. Anderson reminded the group that the net wasn't hanging uniformly in the water, that the animal may have a number of positions relative to a float while swimming more or less in a straight line and could easily entangle a pectoral fin in mesh that is bagging in the water. Goodson reiterated that anything placed 1 m to either side of the narrow beam will not register enough to stop the animal from trying to move forward. Dawson reported that almost all the gill-net caught animals he examined had a clear mark around the snout where they apparently first encountered the net. This may indicate, he said, that the animals are swimming into the net.

Barnaby stated that white-sided dolphins are often present during gillnetting and yet they don't often become entangled. Goodson noted that their acoustic source levels are probably more similar to those of the bottlenose dolphin, and may be expected to be higher than a harbor porpoise's source level. Jefferson added that dolphins more frequently travel in larger groups, so there's a good chance that at least one individual will alert the others to an obstacle. Also, dolphins stay together longer, essentially having a longer learning period before traveling alone. Dawson thought foraging behavior might explain their lower rate of entanglement. A similar animal, the dusky dolphin, forages at night off New Zealand in mid-water (about 100 m) where it encounters squid and lanternfish. If the white-sided dolphins are doing something similar off New England, they wouldn't encounter many bottom-fishing gill nets.

Passive Acoustic Experiments

Detecting Gill Nets with Side-Scanning Sonar

Goodson described his experiments testing the sonar image of a gill net in the ocean. In the first experiment, 100 kHz side-scan sonar images were made of gill nets in calm water. The images showed the head and foot ropes clearly at a range of 45 m. The experiment, described in Report No. 408 from the Sea Fish Industry Authority (Hull, U. K.), also demonstrated an opaque, fine, bubble "fog" or "cloud" effect caused by either the wake of the sonar-towing vessel or a fishing vessel passing close to the net. The cloud of microscopic bubbles tended to obscure much of the gear. However, the headrope/floats and reflector-enhanced mesh remained detectable to the (100 Khz) side-scan sonar through this cloud, to at least a 30 m range. The bubbles were driven some tens of meters below the surface and persisted for several minutes. In sea states greater than Beaufort 4, a similar effect occurs as air becomes entrained at the surface and is drawn into the water column to considerable depths. Goodson likewise suggested that in any raised sea state, the strong headrope image could be obliterated by wave troughs masking this target from a horizontally projected cetacean sonar. In such conditions, the detection range of a cetacean's sonar is severely impaired.

Goodson concluded from this work that the most detectable part of gill-net gear is the headline/floats and the leadline, although the latter is difficult to detect except when the sonar beam is projected on its length at a perpendicular angle. Vertical ropes can also be detectable, but in sink gill-net gear these are usually tilted or bowed by tide effects. The webbing remains completely invisible to sonar at any practical range (greater than 2 m). Harbor porpoises are unlikely to detect even the strongest component (submerged headline/floats) at ranges much greater than 9 m, and the animal's beam width at this range was less than 3 m. Goodson also pointed out that the side-scan sonar took several minutes to acquire the complete image, and that an approaching porpoise could only perceive the small sample of the net structure detectable inside the narrow cone of sound projected ahead of it. Even at short range, the weak, diffused echoes returned from webbing appeared little different from those caused by natural volume scatters (for example, from bubbles or algae), and may be assumed to be penetrable.

There is some disagreement, however, about range of detection. Au and Jones (1991, *Marine Mammal Science* 7:258-273) calculated that Dall's porpoises should be able to detect webbing at ranges of at least 7.5 m (170 dB signal) to 15 m (180 dB signal). In their words (p. 269), "echolocating *Tursiops* and other odontocetes including Dall's porpoises should be able to detect gillnets at long enough ranges to avoid entanglement." Dall's porpoise signals are very similar to those of harbor porpoise.

Bottlenose Dolphin Sonar-Based Detection of Simulated Fishing Gear

Goodson reported on a series of three annual field trials held in September of 1991, 1992, and 1993 in Scotland's Moray Firth. These trials have been used to examine the effectiveness of passive acoustic net reflectors designed to match the dolphin's sonar characteristics. The researchers first determined the regular swimming patterns of a local population of approximately 150 bottlenose dolphins (most of which had been photographically identified in a long-term study by Aberdeen University). The chosen site is a coastal area with a kelp bed near shore and a flat, hard, sand bottom seaward of the kelp line. On average, 30 to 40 dolphins passed through the study zone each day. The cliffs are 53 m high, and from them, in good weather, dolphin could be accurately tracked using electronic theodolite equipment. Typically, most of these animals pass in two strung-out aggregations (spread out over an hour or so), with pairs and occasional solitary animals intermittently passing during the rest of the day. Some of these groups are believed to include the same animals returning.

For two weeks in 1992, two strings of simulated surface-tending gill nets were placed across the path that the dolphins normally traveled. The simulated gear was made of a headline and an 8 m long, vertically suspended 3 mm twine that carried test reflectors, spaced apart at 2 m intervals. The two strings were anchored about 100 m apart. No webbing was used. Both strings were first set with reflectors spaced at 2 m intervals, although the outer string was modified late in the trial to increase the reflector horizontal spacing to 6 m. The experiment was conceived to determine the range at which the enhanced "net" became detectable to a dolphin's sonar, and to examine the swimming and acoustic behavior of the leading animals as they interacted with the "net." (A subsidiary task was to develop new tracking technologies that would permit similar studies to be undertaken in an offshore environment.) The animals' underwater sonar behavior was monitored using moored (modified) sonobuoys deployed on each side of these simulated nets.

From the cliffs, researchers tracked the lead animals with theodolites and recorded their underwater vocalizations detected by the sonobuoys. A camcorder also recorded the scene of each interaction. Typical swimming speeds of the passing animals were on the order of 0.8 to 2 m/sec and in general, although some foraging behavior was observed nearby, these animals were in a travel mode. Leading animals tended to be alert, and detection of the simulated nets by echolocation consistently occurred at ranges greater than 50 m and occasionally from as far as 170 m. In all cases, the detection induced a positive avoidance behavior. After safely passing clear of the simulated nets, several animals made sonar investigations of the back of the "net," but again from no closer than 50 m. On a few occasions, an isolated non-echolocating straggler was observed traveling out-of-line from a main group. Such animals are believed to be most at risk. On a single occasion in the 1992 trial, a lone animal traveling at 3 m/sec crashed through the reflector enhanced "net" while swimming directly toward a group that had already safely passed around the "net." This interaction occurred without the animal using its sonar.

In 1991, a similar straggler was initially seen at 50 m range, and was observed retreating from the simulated net before eventually turning at the 170 m range to follow the "safe route" used by other animals. In this case, analysis of the sonar signals, which first appeared 7 sec before the 50 m observation, suggests that this animal "woke up" and suddenly detected the barrier at the 20 m range before retreating.

Reducing the number of reflectors from one simulated net to 6 m horizontal spacing continued to induce avoidance behavior, but the detection appeared to occur at much shorter ranges.

In 1993, the two simulated net strings were set in line with approximately 250 m separating them. This gap between the "nets" was placed across the predicted travel path of the animals, and a number of animals used the gap to pass between them. Adding a floatline to close the gap caused a few animals to balk and pass either inshore or offshore. But, several animals were still observed to pass through the gap even when a leadline was suspended below the floatline. In all cases, the animals avoided the strings supporting suspended reflectors.

As the site for these tests had originally been used for a salmon bag-net fishery (this closed about five years before the first of these trials), it had been assumed that the tests would naturally force the animals offshore if any memory of these old, staked-net obstructions existed. Interestingly, the very first interactions induced an inshore avoidance behavior, causing the animals to pass slowly (and silently) along the edge of the kelp line, although this behavior was not sustained after the first few days. As the trial progressed, more animals chose to pass offshore.

In all the trials so far, 170 m is the maximum detection range of the strings of reflectors when the dolphin's pronounced echolocation behavior clearly indicated detection by sonar. In one case, two leading animals slowed to a stop while echolocating before making a sharp turn to seaward, causing a 100 m "sidestep" in their travel path. In this example, as later animals in the group caught up with them, they joined in a slow repetition rate, very loud, echolocating chorus. The behavior was first observed late in the 1991 trial, and it may well be that these particular animals had made previous encounters and had learned to anticipate the obstruction to their passage at that location.

Goodson reported that dolphins should benefit from an increased sonar range as the water gets deeper and reverberation ceases to restrict them. Bottlenose dolphins probably search for prey out to 80 or 100 m maximum range in good conditions.

Cooper noted that in Canadian experiments, side scan sonar will pick up gill nets on sandy bottom, but on harder bottom there's too much scatter to do so.

Jefferson reported that there is abundant evidence that dolphins may be herded using the bubble walls created by moving vessels. Goodson added that the water disturbed by a vessel with even a little cavitation on the hull left a bar that persisted on the sonar screen for several minutes. He reported that after a storm, it took 4 to 5 hours for the water's acoustic conditions to return to normal.

Dawson remarked that not much is known about how harbor porpoises integrate spatial parameters. Animals with sonar that have been better studied, like bats, are known to have passive spatial senses. The only cetaceans that are known to have similar abilities are freshwater dolphins, which integrate sonar information onto a spatial map.

Jefferson reported that there is some work with bottlenose dolphins that indicates they have a good memory for acoustical data.

Passive Acoustic Gear Modifications

Reflectors. Dawson pointed out that the central weakness of Goodson's dolphin experiment for the purposes of this workshop was the lack of controls. The important thing, he said, is to get results under both modified and unmodified conditions. Goodson added that to get a true picture of what the animals were reacting to you needed underwater observation. He had done some work with divers (but this was an intrusive method of study) and the development of passive tracking tools to localize and track individual animals underwater was a specific 1993 task. Goodson reiterated that the present focus of the work was development of suitable study techniques that could eventually be applied at sea, close to commercial fishing nets. The development and assessment of efficient reflectors that might eventually be used in the reduction of cetacean bycatch require such an approach if the dependence on body count statistics was to be reduced in the development stages. The dolphin/net interaction rate, as well as the quality and quantity of data obtainable in such experiments, are many orders of magnitude greater than can be obtained at sea in an actual fishery. The research to date suggests that the reflectors tested so far are very effective in attracting attention and generating avoidance behaviors in this inshore environment. Smith noted that while the experiment did not reveal a definitive answer, the question for the group was whether it was promising enough to suggest some candidate gear modifications.

Dawson said that testing the reflectors in a real situation was the only way to get information that was useful for the problem at hand. The only difference in control and experimental gear should be the addition of reflectors. For harbor porpoises, the gear would have to be set and hauled as real gear would be, not left in place for days. In general, tests of passive acoustical gill-net modifications have produced small, insignificant changes in catch rate.

Hatakeyama reported that Dall's porpoise, when moving around unmodified gear, would u-turn and avoid it, attempt to go under it, or travel along it, apparently reacting to the net within 5 to 10 m of it. Goodson's experiment suggested a detection by bottlenose dolphins from much greater distances.

Smolowitz pointed out that there could be significant behavioral differences between the bottlenose dolphin and the harbor porpoise. Their acoustic capabilities are different and Goodson's study involved animals that were resident in the area. In the Gulf of Maine, harbor porpoises appear to be migrating though an area, he said, not remaining resident at a forage site.

Goodson said that the moored strings supporting reflectors could be expected to generate some very low frequency (strumming) noise with the tidal flow, but it was unlikely that the dolphins would hear this. He suggested that in the presence of predator noises, such as killer whale sounds, he expected dolphins to stop echolocating as a defensive strategy, since the echolocating sounds would indicate the dolphin's location.

Acoustic vs. mechanical/strategic modifications to gear and fishing practices. Smolowitz argued that examining the mechanical aspects of the gill netting might result in reduced bycatch. He felt that twine size, shape, color, and methods of constructing nets could all make a difference in harbor porpoise behavior that would reduce bycatch.

Wang wondered whether the animals were foraging on what's caught in the nets or on scavengers around the nets. If it is used as a feeding area, wouldn't making the net more obvious tend to advertise it rather than deter the animals from approaching it? Goodson noted that if that were the case, then clearly they can detect the net and we could then work on ways to use whatever is attracting them (blood, excreta, the larger target provided by fish in the net) to get them to avoid it. He pointed out that the single thing we know for sure at this time is that the inert materials themselves as configured to make fishing gear are not detectable from long ranges by the porpoises.

Smolowitz summarized this discussion, saying that there were many factors that could affect chances of entanglement. Net characteristics such as straightness of the string and distribution of netting are possible modifications that might reduce the gear's capability to entangle. Of course, fish catches might also be reduced as well. But since the fishery also has to look at reducing fish catch over time because of other management plans, Smolowitz suggested it was a good time to look at harvest reductions that are caused by built-in gear inefficiencies that might reduce harbor porpoise bycatch. Anderson agreed, saying that catching less fish was preferable to catching no fish. Homstead argued however that management plans required him to reduce effort, not catch, so the last thing he wanted was a less efficient net.

The group discussed the bridle openings in net strings at some length as a possible gear modification. Goodson said his experiments put the "personal space" of the dolphin at about 2 m. In Hatakeyama's experiments, harbor porpoises traveled though spaces of 1 to 2 m. Wang reported data showing that porpoises in fish weirs would try to go through an opening that was less than 1 m wide, and that they would go under a bottom-tending net.

At-Sea Gear Research Using Passive Acoustics

Smith noted that there are many designs for improving the passive acoustic signal of a net, but existing fieldwork with the devices has been inconclusive. If the group felt testing these options in real conditions with some kind of combined scientific/fishing fleet cooperative experiment, that would be expensive and you might only get one opportunity to conduct a test of that magnitude. In view of this, perhaps this meeting's time would be best spent trying to select the modifications most likely to work, rather than planning to test all the options.

Goodson agreed, noting that before acoustic reflectors, for example, could be used in experiments at sea, the mechanical problems of hauling gear fitted with them would have to be solved. There was general agreement that floats suspended in the mesh of gill nets in the Gulf of Maine represented a treatment that warranted consideration. It was noted that a better understanding of the methods for the experiment should be acquired because additional experiments may be difficult to justify after making a substantial investment in one that fails. It was suggested that a small-scale effort be considered to address the mechanisms for deploying floats in meshes as acoustic reflectors.

Data Collection

The group noted that data collected during sea sampling might need modification to provide information on nonacoustic factors that might be related to bycatch mitigation. The specific data collection done in the Newfoundland study described by Hood provided a good example of how to devise a program for specific research needs in an operating commercial fishery. A similar dedicated research project on New England gill-net fisheries might be the fastest and most efficient way of collecting this information, rather than attempting to append more data collection to the sea sampling program. Drew noted that for every day at sea, 1100 to 1200 bits of data are collected by a sampler. To increase the detail collected on net characteristics, something else would have to be eliminated.

Tracking and Observing Cetacean Behavior

During the meeting, many people had commented on the need to observe and describe porpoise behavior in order to determine their reactions to various modifications and whether the modification is causing the animal to change its behavior around a net. Jefferson reported that in the British Columbia gill-net fishery, he had observed Dall's porpoises 20 m or more away from the net respond to it by traversing it or going under it. This kind of observation can be made optimally from high ground surrounding an inshore area where both active gill nets and cetaceans are present and cetaceans can be tracked with a surveyor's theodolite. Wang asked if foraging behavior around the net could be observed from the surface. Goodson said that was one of the things they were trying to discover in his experiment by attempting to track echolocating, vocalizing, or tagged animals.

Hatakeyama suggested that there are ample data to indicate the animals are capable of detecting the gear, even if we don't know why they sometimes avoid it and sometimes don't. The information most lacking is that explaining the mechanics of their entanglement, and that would have to be observed or tracked.

Active Acoustic Experiments

The Workshop did not consider this topic in detail, but did try to identify what has been done in this area and shows promise. Smith reminded everyone that an extensive workshop considering active acoustic mitigation of bycatch was being organized in the next several months.

Although many approaches have been explored (Working Paper 4, page 3), few have been extensively tested for cetaceans. The exploratory studies in South Africa were not encouraging, due to accommodation by the bottlenose dolphins.[4]

Studies in the Japanese high seas fishery were more promising. There, some bycatch reductions were obtained in a limited number of trials using a 20 to 50 kHz sound source. However, Dawson suggests that the picture is somewhat less clear than this. Studies examining effects of adding sound emitters to gill nets have proven to be inconclusive. In a report in press (The potential for reducing entanglement of dolphins and porpoises with acoustic modifications to gill nets. Report of the International Whaling Commission, Special Issue), Dawson concludes that sound emitters appear to be a marginal

[4] Peddomors, V. M., V. G. Cockcroft, and R. B. Wilson. 1991. Incidental dolphin mortality in the Natal shark nets: a preliminary report on prevention measures. In S. Leatherwood and G. P. Donovan, eds., Cetaceans and Cetacean Research in the Indian Ocean Sanctuary. *UNEP Marine Mammal Technical Report* No. 3.

benefit, if any. This conclusion is based on a survey of published data on cetacean entanglements in nets fitted with emitters.

Lien (1993)[5] reported an experiment in which active acoustic devices were test-fished on four vessels. Anderson participated in the study and reported that he fished in a normal pattern. There were no takes in strings with the devices and 10 takes in strings with no devices. During the tests, he observed harbor porpoises around the nets with the devices and none were caught or entangled. He reported that the devices were large and awkward to handle, a little bigger than a softball. However, he also reported that the nets fished and hauled successfully with them attached. The devices were attached to the headrope when the gear was set, clipped onto the headrope manually just as the net was going over the setting bar. The hauls took about 5 to 10 minutes longer as the crew attached and detached the devices. The instruments were placed on alternate nets within a string of 8 to 10 nets, using 4 per net. As equipment was lost during the tests, the devices were then placed on the entire string, about 15 per string. Because of the experimental design, sample size, and the lack of data for comparison, the results of this test were statistically inconclusive.

Lien has been working to modify the devices so they can be used more easily on gill nets, and hopes to test them in 1994. A redesigned experiment with the modified devices was tentatively scheduled for this year, but Lien's modified instruments were not available in time. Some of the instruments will be tested in a limited experiment on fishing vessels during the New England gill-net fishery in fall, 1993.

Barnaby reported that Lien had described tests with his devices in Australia. Lien described putting the devices on shark nets to deter another cetacean and said he got the same results as in the New England gill-net fishery: takes in unmodified nets and no takes in modified nets. Sample size, however, was unreported.

Goodson noted that noisemakers are potentially both deterrents and attractants. But he noted that if they are attractants, they may be a useful supplement to reflectors. Hood reported that in experiments in St. Johns, Newfoundland, results indicate that alarms may be useful in deterring some large whales from fish traps. Hanan reported that in California acoustical devices were used to keep sea lions away from gill nets: they worked at first, but then the animals got used to them and ignored them.

ANIMAL BEHAVIOR AND NET DESIGN

Behavior in Relation to Nets

Hatakeyama reported on Akamatsu *et al.'s* work with two harbor porpoises in a net enclosure, described in WP13. In Figures 3 and 4 (from WP 13) he describes the behavior of a captive harbor porpoise around a gill net. The animal was kept in a net enclosure, roughly 21 m x 15 m, and 13 m deep, constructed with a bag. A 13 m (length) x 6 m (depth) gill net was introduced and set in such a manner that the net enclosure was roughly divided in half (sections A and B). There was enough space below (approximately 7 m) and to one side (4 m) of the gill net for the porpoise to pass from one section to the other. The porpoise remained in section A although it made several approaches to the net; the closest approach to the net was 3 m (with an average of 8 m). After 45 min., the porpoise became entangled in the gill net. The animal was entangled by the flukes and Hatakeyama indicated that the animal's entanglement would probably have been fatal if it had not been freed by the researchers. Injuries to the flukes, flippers and head were sustained. The animal did struggle energetically and attempted to surface to breathe. These observations were made during the daytime.

Observations were made 26 hr later. The porpoise was observed to pass between sections A and B frequently (12 passes as compared to zero in the initial trial) without becoming entangled. The average distance of the porpoise to the gill net was reduced to 7 m. Initially, the porpoise was very cautious and swam slowly. After the porpoise became accustomed to the net, the porpoise activity increased. The net was then left overnight. The porpoise did not become entangled. Entanglement or contact with the net was observed four times and the porpoise did not exhibit avoidance behavior towards the net. Entanglement occurred with the fin, and the body was in an oblique position relative to the net.

Introducing food into the net enclosure increased the activity of the porpoise; frequent

[5] Lien, J. 1993, unpublished. Field tests of acoustic devices on groundfish gill nets: assessment of effectiveness in reducing harbor porpoise bycatch.

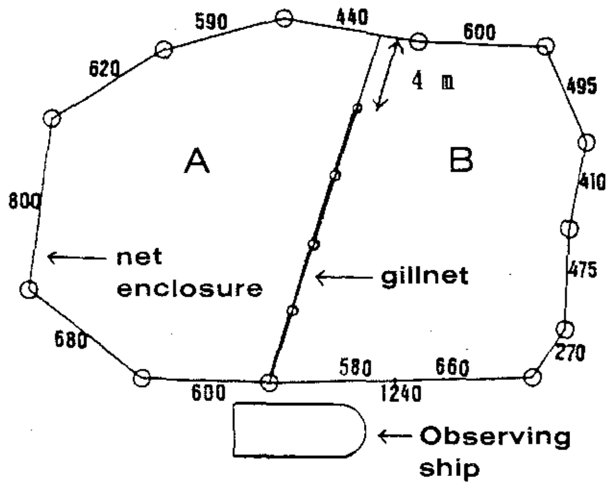

Figure 3. Top view of the experimental net enclosure (a bag net of the set net). The net enclosure was roughly divided in half (sections A and B) by a gill net. Figures along the perimeter of the net enlcosure are distances (in cm) between floats.

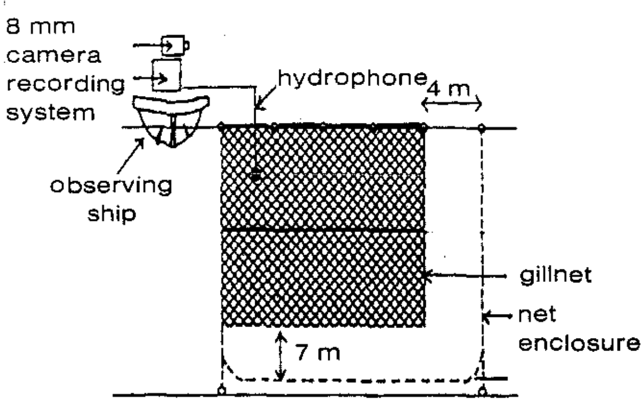

Figure 4. Side view of the net enclosure. There was enough space below (about 7 m) and to one side (4 m) of the gill net for the porpoise to pass from one section to the other.

movement between sections was observed. However, when food was hung in front of the net, the porpoise did not approach the net to obtain the food.

Attempts were made to scare the porpoise into the net by hitting the surface of the water in the section of the net enclosure that the porpoise occupied. The porpoise swam to the opposite section without getting entangled each time. There was no contact with the net. It appears that once the porpoise recognized ("learned") the danger of the net, the researchers were not able to induce an entanglement.

Hatakeyama *et al.* observed the behavior of a captive harbor porpoise toward a gill net in a 5.5 m x 2.5 m pool, 1.2 m deep. A gill net that was deep enough to reach the bottom of the pool was introduced. There was room on one side to allow the porpoise to pass between sections. The porpoise approached the net, and then made u-turns away from it. The net was then pulled to one end of the pool, and food was hung 10 cm from the net, on the side opposite the porpoise. The porpoise approached the food in 3 sec and remained 5 to 30 cm from the net while frequently echolocating. After 40 sec, the porpoise charged into the net at high speed (head first).

Age/Sex Composition of Takes

Wang reported that during his study with Read, they noted the age and sex of bycaught animals, but the data have not yet been fully analyzed. Also, the data samples in some cases were collected by fishermen, and bias may have been introduced in selection of animals.

Dawson reported on age and sex data collected during study of entangled Hector's porpoises. There were many one- to three-year-olds and few older porpoises. The investigators attributed this to "teenaged driver syndrome": the juvenile animals were less cautious and less experienced than the older animals. They knew the sample was biased, however, because there weren't enough mature females in the sample to have produced the reported number of juveniles.

Several participants reported on data from other fisheries with harbor porpoise bycatch. Gearin reported on the harbor porpoise/salmon gill-net interactions in Washington. In studies of harbor porpoises collected in set nets targeting Chinook salmon, researchers found that the porpoises were feeding on the same species of fish that the fishery was targeting. This suggested that they were actively foraging at the time they were captured. There were more one- to three-year-olds than other ages, but that was consistent with the overall population structure. Northridge reported that of the animals measured in North Sea captures, the modal length of captured individuals was 120 to 130 cm in gill nets and 150 to 160 cm in trawls. In Jefferson's work, about 200 Dall's porpoises were collected from drift nets and examined, and he felt that the sexes and ages present were more or less representative of the overall population. Wang noted that the weirs in the Bay of Fundy tended to capture smaller animals, but there are no age composition data for those takes.

Bisack reported that for the 135 observed animals killed in the New England gill-net fishery, age was determined for 76. Of these, 18 percent were calves, 47 percent were one- to two-year-olds, and 34 percent were adults. With regard to feeding, 79 percent of the stomachs examined contained herring, 5.1 percent contained silver hake, 5 percent contained hagfish, and 0.5 percent contained lanternfish. Stomachs also contained gadoids and squid beaks.

Harbor Porpoise Detection of Gear/Behavior Around Nets

Development of Sonar Capabilities

Hood asked if there was any information on the physiological development of sonar capabilities of harbor porpoises with age. No one was aware of any. Goodson pointed out that some cetaceans continue to depend on their mothers for 18 months, but Dawson indicated that *Phocoena* may not do so. Jefferson reported that there was some good information on the reactions of captive dolphins and porpoises to structures with age. What's lacking, he said, is *in situ* data. He thought that it would be possible to get *in situ* data by observing inshore fisheries, and from TDRs and sonar buoys as already discussed. Goodson reports that since the workshop, some additional data have come to light from Harderwijk Aquarium in The Netherlands. A five-week-old harbor porpoise, rescued from stranding, was fully weaned at less than 8 months and proficient at catching live fish. This animal was found to be clicking and apparently able to use its echolocation sense even at five weeks of age.

Observation of Harbor Porpoise Behavior

Stockwell thought it unlikely that there was any location where New England gill-net fleet operations could be observed from shore. Smith asked whether harbor porpoise activity around gill nets could be observed from the surface of the water using an appropriate platform. Jefferson felt that if the nets were not deep in the water column or in shallow water, it could be seen. Wang noted that in Grand Manan, the fishery is close to shore, but the water is deep and there are so many animals that it would be hard to track just one. Smolowitz noted that underwater cameras have successfully recorded fish behavior around submerged nets and that might be the way to proceed. He suggested that a low light camera in an area with high harbor porpoise/gill-net activity would record valuable information.

Goodson said that he eventually wanted to place a sparse array of hydrophones on, or close to, fishing nets, to sense the presence of foraging cetaceans by their own sound emissions. One could get an accurate fix on direction, distance, and orientation of dolphins over at least 300 m with this technique. For harbor porpoise, however, the ranges may be reduced to less than 100 m.

Homstead asked if there was any difference in harbor porpoise behavior (diving, swimming, and so on) in relation to water depth. No one was sure, but part of what was needed to find out was a way of tracking and observing the animals under various conditions. Jefferson noted that to get precise plots with a theodolite, one needed a stable platform. Dawson asked if there were TDRs that could fix on satellite signals. Smith reported that during observations from the *R/V Able J*, electronic range detectors were used. If the vessel is within 0.5 mi of the animal, a rifle-mounted device and a compasser can be used to locate the animal. Blimps would be useful, but its hard to get them in the right place at the right time, with good weather for observation. Goodson noted that sonobuoys moored in fixed positions could give good detection of cetacean sounds in quite reasonable sea states, provided these devices were first modified to reject low frequency sea-state noises and made sensitive only to the high frequencies. Rifle-mounted devices are more difficult to use in higher sea states.

Mechanics of Entanglement–Improving the Sea Sampling Database

Discussions focused on Northridge and Bisack (1993; WP12), which constitutes an exploratory analysis of entanglement data by aspects of gear, environmental parameters, and fish catch based on the NEFSC Sea sampling program. The authors went over the analysis in detail with the collected workshop in order to get more insight into data bias and how collection might be improved to address the gill-net/harbor porpoise interaction problem.

Current analyses are of data combined from different regions within the Gulf of Maine area, and from different times, seasons, and fisheries. This "lumping" scheme was necessary to gain first impressions from the database, but also constitutes a significant weakness as it obscures differences in entanglement rates occurring within and between the seasons and areas combined. A consistent theme of the discussion was that entanglement rates are probably driven by seasonal and areal factors and that it is simplistic and misleading to concentrate on any single gear-related factor without careful stratification of the data, particularly by area.

During lengthy discussion of the data collection program, other themes emerged:

- Data should be reanalyzed after stratification of areas and fisheries with clearly differing bycatch rates. The trade-off in such stratification is lower statistical power resulting from fewer entanglements in the sample analyzed. Stratification may provide particularly useful insights into the effect of depth, mesh size, and association with pollock.

- Data from another gill-net fishery that has been studied in detail would be useful for comparison, and for protocols used in stratification and analysis. One source of such data would the work by Hanan and his co-workers on harbor porpoise bycatch in California gill nets.

- Discussions indicated that some data gathered by the Sea Sampling program appear to be of uncertain accuracy and others of dubious utility. Concern was expressed that the large amount of data observers are required to collect emphasizes quantity rather than quality, and inhibits accurate recording of some important data. Some adjustment of data collected at sea seems desirable.

Anchor Weights

Entanglement rates differed significantly across seven categories of anchor weight (ranging from 10 to 60+ lb), with highest catches associated with anchor weights of around 50 lb. However, no clear trend of increasing catch with increasing anchor weight was evident. Indeed, it was not clear at the workshop that anchor weight was related to bycatch. Factors that restrict the conclusions which may be drawn include:

- The weight of anchors constructed by fishers is estimated rather than measured, and may be very approximate, although the weight of "store bought" anchors is likely to be known precisely

- Because anchors can be lost, fishers buy the least expensive ones available, rather than those that may best suit the species targeted

- The statistically significant relationship between catch rate and anchor weight might be caused by correlations between anchor weight and other factors

- Anchor weight is determined partly by the extent of tide in the area fished.

Slope of the Net on the Seabed (Angle of Net)

Observers record the maximum and minimum depths of each string set. These data are obtained either by asking the skipper, or are observed directly from the echosounder. The analysis revealed significant differences in catch rate according to slope of seabed, however trends are absent and the meaning of the result is unclear. It was considered that the result may be unreliable because:

- The terrain may undulate, rather than have a consistent +ve or -ve slope. It is not known whether an average slope calculated for the set would reveal anything useful for *in situ* use.

- As with anchor weight, differences could be driven by a factor unrelated to slope

However, Smith noted that in other fisheries, animals have been found to forage more in

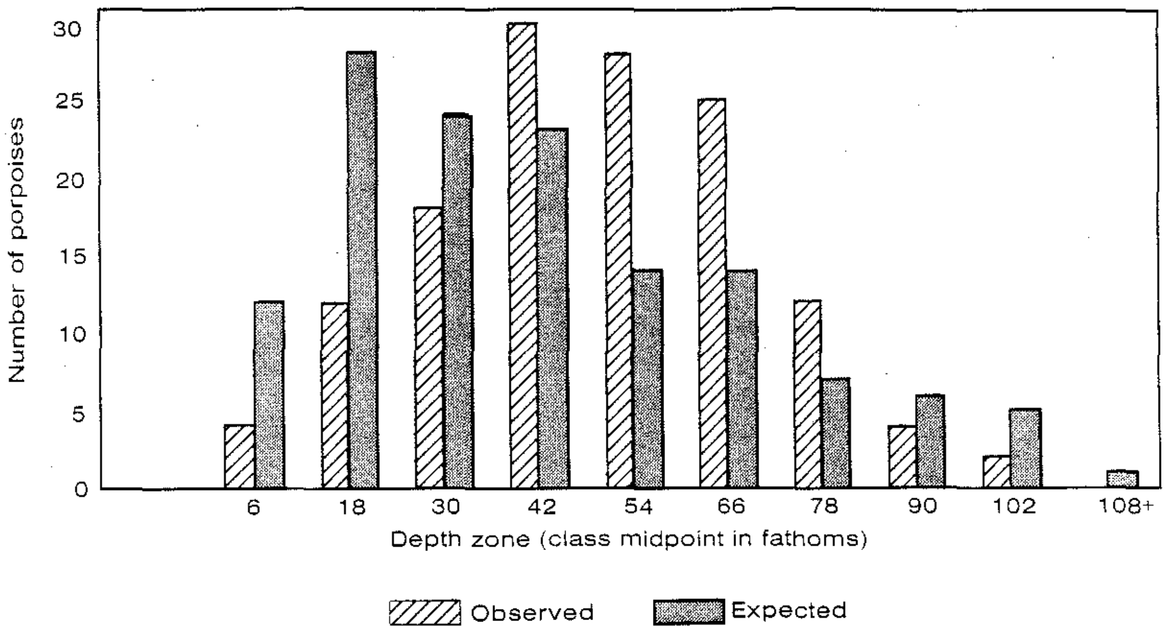

Figure 5. Expected frequency distribution of number of animals captured at each depth zone plotted with actual distribution from observed trips in the Sea Sample data.

areas of high relief, so knowing the characteristics (such as slope) of the bottom may eventually correlate with harbor porpoise bycatch in a way that is useful.

Depth

Figure 5 (from Figure 7, Northridge and Bisack) indicates an interesting mismatch of depths at which fishing effort is concentrated and depths at which most entanglements occur. Depths between 42 and 78 fathoms appear to pose a significantly elevated risk of entanglement. It is possible that these results are biased by:

- Data from geographic areas of high entanglement rate (*e.g.* Jeffreys Ledge) that contain a limited range of depths
- Possibility over-sampling of the 18 m depth category

This analysis did not break out depth by area and correlate it with kill rates. Although the group seemed to feel this would be very beneficial, it may only be possible in theory. For example, even in a high catch area like Jeffreys Ledge, there are not enough dead animals collected to get a statistically sound result about kills related to depth.

Flotation

The majority of nets were made with 1.66 floats per 10 ft of headline. However, the analysis shows that nets with fewer floats appear to have significantly higher entanglement rates. It was noted that:

- There are problems in the classification of the number of floats. For example, flounder nets with a headrope of foam-cored floating rope are recorded variously - the current protocol is to record them as having one float. This biases the number of floats low.
- Flounder nets, which are considered to catch porpoises at a much lower rate than those for groundfish, often have fewer floats. Removal of these nets from this sample would have the effect of increasing the kill per haul calculated for other nets with fewer than 1.6 floats per 10 ft of headline.
- Fishermen noted that there is geographic variation in the number of floats used, hence differences seen in this analysis may be driven by differences in entanglement rates among areas.

- Removal of nets known to have low catch rates, *e.g.* flounder nets and those groundfish nets set far offshore, would sharpen the comparison of entanglement rate among categories of flotation.

- The result that nets with fewer floats appear to catch more porpoises could imply support for the hypothesis that increasing the number of floats makes the net more detectable, and hence easier for porpoises to avoid. Countering this are the Grand Manan nets, which have many floats yet very high bycatches. However, this fishery is not considered to be directly comparable with that in the Gulf of Maine.

Net Types

Broadly, participants felt that four net types are used in the Gulf of Maine (flounder, dogfish, groundfish and monkfish). Fishermen present were confident that they could reliably identify each net type, but that target species cannot always be precisely determined from the net type. For example, old groundfish nets are frequently used to target dogfish, but would still be identified as groundfish gear.

In order to clarify Sea Sampling data, Smith asked if there were a set of gear characteristics for each gill-net target species that the industry would agree provided a clear cross-check of the target species recorded at the beginning of the trip. Fishermen felt that would be possible.

Net Height

No significant differences in bycatch were apparent using either of the measures of net height. This may seem surprising as a low net would appear to offer less area for entanglement. For flatfish nets, it was noted that the actual height of the headline varies according to the number of tie-downs used. With fewer tie-downs the headline bows upward more, and mean height is increased. A possibly compounding factor is introduced by the bag of mesh formed by tying the headline to the groundline. This may increase the chance of entanglement if a porpoise reaches that part of the gear.

Some discussion focused on whether the bag was necessary to catch flounder. Opinions were divided, but it was noted that Vietnamese fishermen in the Boston area used nets that were 3 ft high to target flounder effectively. These nets had no bag, and were set at .5 hanging ratio, with 6 in. mesh and 8 gauge twine, in about 15 fathoms of water. Fish were tangled in these nets rather than gilled. MacKinnon felt that the nets would fish and such a modification would be preferable to the industry over closure of the fishery.

Length of String

No significant differences in bycatch were evident here, though it was noted that the kill rate of nets in the 4500 ft class appears higher. No explanation was offered for this. This analysis, like the others, is confounded by the fact that net length differs by geographic area. As Stockwell put it, "The nets with high takes in your graphs are consistent with gear in the gill-net fishery for groundfish during the seasons when you have big takes: 24 hour soaks in the fall and spring. I'm the guy who's catching it and this is my gear you're describing. And that's geographic, not gear."

Mesh Size

Porpoise kills vary significantly by mesh size, with the mesh sizes of 5.25 and 5.75 in. having kill rates nine times higher than the 7.5 and 9 in. categories. As discussed earlier, geographical variation confounds the relationship. Larger meshes are used offshore where catches are typically low. Other points noted were:

- Since Federal law stipulates a 5.5 in. minimum mesh size, the validity of the 5.25 in. category was questioned. It is possible that these nets are from the west and south side of Cape Cod, where the smaller mesh size is legal.

- Recorded entanglement rates of large mesh nets (8 in.) could be artificially low if porpoises drop out of these nets more frequently than they do from smaller meshed nets.

- It may be possible to look at the effect of mesh size in one area of high bycatch (*e.g.* Jeffreys Ledge). This would control for differences between areas.

- Some participants felt that larger mesh sizes posed less risk to porpoises, because they are less likely to become entangled upon contact with the net. However, it was noted that porpoises and dolphins get killed in nets of a very wide range of mesh size, including the swordfish driftnets in the Mediterranean (mesh sizes 36 to 52 cm) and the directed gill net fishery for dolphins and porpoises in Peru (mesh sizes 3 to 44 cm).

It is clear that all mesh sizes pose some risk, and that a quantitative evaluation of relative risk is not currently possible. Smolowitz noted that the size of fish caught in the nets might have something to do with the harbor porpoises attracted to the net and there might be a valuable correlation with the probability of an encounter.

Soak Time

Kill rate (per hour) appears to decline with extended soak times, but the relationship fails to reach statistical significance. The problem is that flounder soaks are longer: lower catch rates in longer soaks may be caused by gear characteristics or fishing method.

Twine Gauge

Again, differences are not significant and trends are unclear. Data are confounded by the fact that small twines are used in fisheries that, apparently for other reasons, have low porpoise takes (*e.g.* flounder). However, the data suggest that the hypothesis that twines of larger diameter catch fewer porpoises is likely to be incorrect.

Some discussion followed on whether porpoises may break out of the nets if the twine was sufficiently weak. Dall's porpoises have been observed to break through drift nets at high speed, however nets of extraordinarily fine twine catch small cetaceans in other parts of the world. Fishermen present said they frequently encounter holes in their nets, but felt that those could be made by sharks or rocks. The consensus was that a net sufficiently weak to allow porpoises to break out would probably be unworkable.

Wind Speed

The result of this analysis was not significant, but a weak trend towards higher kills in higher winds was noted. This result might be interpreted as tentative support for the hypothesis that net detection is made more difficult by entrainment of microbubbles in the water column during high winds. That the wind speed recorded is that during hauling, not during entanglement, is confounding.

Fish Catches

No associations between fish species in the net and whether an entanglement occurred in that net were consistent over the three years. However, observer coverage levels were low in the 1989-1990 year, so the power to detect an association in that year is poor. The most consistent associations are with pollock and redfish. Pollock catches (in lb) *vs* porpoise catches (Figure 16, WP12) show an interesting, generally positive, relationship. No significant association is seen with cod, because they are caught in almost every net. The following points were noted:

- The analysis is confounded by area, season and fishery. For example, most fishers in area 514 in summer were targeting dogfish.

- The analysis suffers from the problem of determining significance when making multiple unplanned comparisons. One in 20 tests will be significant by chance alone. An analysis protocol to deal with this problem is given by Rice (Rice, W.R. 1989. Analyzing tables of statistical tests. *Evolution* 43(1)223-225).

Gill-Net Gear Characteristics and Modifications to Alter Entanglement

Smolowitz gave a general description of gill-net gear research results. Old natural fiber gill nets caught fish by gilling only. When monofilament came into use, the selectivity curves became irregular, suggesting that entanglement was occurring at a higher rate. It is not clear why, said Smolowitz, but monofilament stretches more than multifilament, but what more commonly affects catches is the slack in synthetic line. In addition, synthetic nets are often hung loosely to increase entanglement. Nets are set on a zigzag or at angles to create bags and dead-end areas that increase entangling effectiveness. Smolowitz reported that with fish, there appears to be increased capture near the bridles where the net height is shorter on average that of the rest of the net, making a loose bag. Also, work with underwater cameras shows that twine contrast with the surrounding background is more important to detectability than twine color, and that may be equally true for marine species that are more sensitive to contrast than color. Monofilament is the most effective material for catching and retaining fish. Some data suggest that water turbidity causes a drop in efficiency. Some data show greater bycatch in multifilament line. Multifilament is easier to use, less expensive, and more durable. Monofilaments mark the fish the most.

A gill net is set over time, and saturation with fish is a function of their availability . Once fish aggregate in the net, the net begins to fish less efficiently. The diminishing return over the time of set is more pronounced when more fish are available. When there are fewer fish around, it is more advantageous to set for a longer time. Saturation may also cause changes in the configuration of the net.

Smolowitz suggested a combination of modifications that would decrease the entangling characteristics of the nets both for fish and for harbor porpoises. These included modifying bridle openings, hanging ratios, net material, flotation, and net height to make a less efficient net. These modified nets, he argued, would only be used during the highly migratory part of the season when harbor porpoises are omnipresent.

During discussion it became obvious that the physical characteristics of gill-net gear vary not only among the vessels, but within a string. The characteristics that change the gear's efficiency in capturing harbor porpoises may also change the gear's efficiency in capturing and retaining target species.

Tying Methods

MacKinnon explained several different methods of tying down the net: tie headrope and footrope, weave the rope through the meshes to increase bagging, and/or create bags with rope around the nets. Also, irregularities over the bottom area where the net is set will cause different heights and slack along the net. Also, everywhere there is a fish, there's a ball in the net. MacKinnon suggested a straight net, rather than one hung on the half, might entangle at a different rate. Dawson reported that in New Zealand, gillnetters claim that they use twice as many floats and twice as much weight as the average in New England, and the nets have very little slack.

Turner said that the customary hanging ratios used in the fishery are the result of years of experimentation by fishermen. Hanging on the half is the most efficient ratio, and changing it would make a big difference in catch. He did not believe it would make much difference in harbor porpoise bycatch.

Bridle Changes

There were many suggestions about bridle changes. Wider openings (10 m), more openings (shorter net sections), and closing the openings were discussed. Goodson reported that in the drift gill-net fishery he worked with, openings were widened to 10 m. Observations indicate that sharks found the openings and shark bycatch dropped. When the nets were hauled, a school of dolphins passed through the gaps without entangling. Jefferson reported however that the high-seas salmon nets have wide gaps between the nets and still catch many porpoises. He indicated that the bycatch of Dall's porpoises was concentrated within 50 m of the opening.

With regard to shorter nets within a string, Homstead said that the industry was somewhat at the mercy of manufacturers. Experimental nets could be constructed, but shorter nets are not currently available from manufacturers.

Mesh Size

Mesh size modification was discussed without agreement on whether it affects harbor porpoise interactions with the nets. Some of those present felt mesh size was not as important as slack in entanglements.

Some data indicated that large mesh gill nets caught fewer porpoises. Hanan reported however, that the larger the mesh in the California fishery, the more cetaceans were caught.

Smolowitz indicated that over the season when there is the most concern about interactions (in the mid-coast area where there is the most bycatch) the size of the mesh varies from 5.5 to 6 in. Mesh size may be limited by a number of factors and may not be anything that can really be changed.

Leadline Modifications

Drew wondered about using metal rings on the leadline as weights to increase the acoustic detectability of the net's bottom. In the cod fishery it might be useful to get the net to hang off the bottom. Jefferson noted that the British Columbia gill-net fishery has a small bycatch. He wondered if it had anything to do with the fact that they use separate weights at the bottom of the net rather than a solid leadline. Goodson suggested that metal objects attached to the footrope would scrape on a hard or sandy bottom with any movement or vibration of the net, and would generate low level, but very detectable, high frequency sounds.

Adding Floats as Reflectors

Anderson asked Goodson if the reflector floats used in the Scottish experiments had ever been used on real fishing gear. Goodson reported that he had used them in a tuna drift gill net, attached to strings hung at intervals from headrope to footrope. The method of attachment needed some improvement as when shot, part of the test string did not deploy properly. The initial excess buoyancy of the braided strings supporting reflectors caught across the headline, and held a part of the net near the surface. Given this, there was a potential for entanglement, and perhaps the reflectors are optimally attached directly to the mesh.

Twine Modification

Smolowitz suggested paying more attention to contrast over color in twine, and using breakaway twine. Turner noted that animals frequently became wrapped in 50 or more meshes where weak twine would do no good. Weak twine would reduce net durability, he said, increasing the likelihood that the net might be dumped.

Dawson reported that fishermen in New Zealand have a low net and use a very fine twine that does retain dolphins. When the animal hits the net, it is caught by several strands. Dawson felt that a "break-away" twine would have to be very weak indeed and would probably not be fishable. Stockwell agreed, saying that much bycatch is taken during pollock season and pollock are strong enough that they would tear through such netting.

Other Modifications

There were two additional suggestions: to hang balloons from the headrope and/or to mark it with brightly colored tape.

WORKSHOP RESULTS

Once presentations were completed, the group turned its attention to sifting through the workshop for the nonacoustic or passive acoustic modifications of gillnetting gear or changes in fishing strategies that would reduce the bycatch of harbor porpoises in the New England gill-net fisheries. In selecting candidate modifications, it was clear that additional research and data collection would also be required to fully grasp possible solutions to the bycatch problem.

A description of the process by which modifications, data, and research needs were listed and ranked is presented in Appendix 4.

Based on the discussion, a list of 78 items was compiled. Each of these was broadly categorized as a possible gear modification, an area requiring research, or a data need. The master list was not ranked. It is presented in Appendix 4 as Table A1. It was clear that the group was not going to have enough time to rank all three categories by consensus. It was agreed that ranking the suggested gear and operational modifications was most critical, followed by needed research, and finally the data needs. The group did rank gear and operational modifications.

RANKING GEAR/OPERATIONAL MODIFICATIONS

The suggestions for gear modifications fell into two broad categories: making the net more detectable to the animal and reducing its entangling characteristics. The 24 suggested modifications listed in Table A1 were voted on by each member of the group. The results are presented in Table 2 for modifications to improve detectability of the nets, and in Table 3 for reducing the gear's ability to entangle. Active acoustic deterrents rated highly during this exercise, even though they were not addressed by the workshop, largely because fishermen felt it was the surest route to immediate results.

RANKING RESEARCH NEEDS

The research items in Table A1 were categorized further by rapporteurs (Table A2). Since the group's time was limited, the ranking was not as detailed as in the case of gear and operational strategies. Once the group had reviewed the categories, items under each were selected by consensus as the most crucial or the most immediately promising avenues of inquiry. Those results are presented in Table 4.

RANKING DATA NEEDS

The group did not have time to rank data needs. The master list was categorized by rapporteurs into subject areas, presented in Table A3. The group was presented with the listing, but no action was taken. Items on the list may be either new data requirements or suggested modifications to the existing sea sampling effort.

Table 2. Candidate modifications for improving gill net detectability (acoustic, visual, chemoreceptor) to harbor porpoise[1]

Rank	Number of Votes	Modification
1	21	Floats in mesh
2	19	Active acoustics
3	16	Passive noise makers
-	-	Lead sinkers instead of lead line on footrope
-	-	Use metal clips instead of twine to tie mesh to selvages
4	14	More and smaller floats on headrope
-	10	Horizontal ropes strung through nets (acoustic and visual signal)
5	-	Increase net visibility (ocular) using things hung on net(mylar, floats, balloons)

[1] Items with dashed lines are separate in the master table (Table A1), but the group felt they were similar enough to the main item that they could be combined with it

Table 3. Candidate modifications to reduce gear entangling capabilities[1]

Rank	Number of Votes	Modification
1	19	Operational modification (string length, set time, number of nets, soak time)
2	16	Increase tension in net to reduce entanglement chances
-	-	Adjust net hanging ratio (horizontal)
-	-	Twine characteristics (color, material, elasticity)
-	-	Increase tension with more floats and more leadline
-	-	Use different hanging ratio at headline and leadline on a single net
-	-	Increase bridle height so it's more similar to that of the rest of the net
-	-	Try net dipping (stiffness)
3	16	Adjust net height (HR to LL, vertical) (bagging)
-	-	Try Vietnamese net (half-net)
4	15	Bridle openings (make wider, or close up)
5	12	Shorten nets, increase number of bridle openings
-	-	Increase bridle height so it's more similar to that of the rest of the net

[1] Items with dashed lines are separate in the master table (Table A1), but the group felt they were similar enough to the main item that they could be combined with it

Table 4. Ranking of research needs by category

Porpoise Acoustics

Measure wild harbor porpoise echolocation/sonar use around net

Determine response of harbor porpoise to sound

Net Acoustics

Determine how much noise a net makes underwater

Evaluate passive noise makers

Other Detection

Measure ambient light around net (visibility)[1]
  How it affects behavior
  How it affects net detectability

Animal Behavior Fine Scale

Assess food habits of harbor porpoise and fish in (& around?) nets

What is the fine scale distribution of forage fish around net

What are the age, size, probable familial relationship among porpoise entangling?

Document fine scale (baseline) behavior of harbor porpoise in GOM under natural conditions

Animal Behavior- Large Scale

Develop tools to track individual animals

Track animals (coarse scale)

Monitor porpoise migration to identify times of vulnerability

Nets[1]

Examine the mechanics of nets in situ and in models

Examine the differences between fishing operations with & without takes (in areas of high takes)

Determine the time of entanglement (time of day, actual time of entanglement)

Observe net deployment and retrieval underwater

Record bottom temperature (profile-CTDs) around gear (relate to entanglement, movements, acoustic conditions)

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[1] Subitems were so closely related to the main entry that the group could not reach a consensus about eliminating them from the list.

APPENDIX 1

Agenda

AGENDA

Identifying Potential Modifications to Sink Gill Net Gear to Reduce Harbor Porpoise Bycatch

A Workshop held September 20-23, 1993
Sea Crest Resort and Conference Center
Falmouth, MA

Introduction

Welcome — Allen E. Peterson, Jr.
Science and Research Director, NEFSC

Workshop Process — Tim Smith
Chief, Marine Mammal Investigation, NEFSC

Organizational Details
Terms of Reference
Review and Adoption of Agenda

Description of Gill Net Fisheries

Overview of New England Gill Net Fleet	Steve Drew Manomet Bird Observatory Kathryn Bisack NEFSC
Northern Gulf of Maine	Richard Turner Stonington, ME
Central Gulf of Maine	Terry Stockwell Southport, ME
New Hampshire North of Portsmouth	Erik Anderson New Hampshire Commercial Fishermen's Association
Offshore Fleet	Jim Homstead South Portland, ME
Southern New England	Robert MacKinnon Massachusetts South Shore Gillnetter's Association
Bay of Fundy	John Wang University of Guelph
Newfoundland	Katherine Hood Memorial University of Newfoundland

Technical Presentations	Simon Northridge, Chair NEFSC
Acoustic Methods of Bycatch Reduction	
Porpoise Acoustics and Net Detection	Jim Hain, Rapporteur,
Passive Acoustic Experiments	David Goodson Loughborough University Yoshimi Hatakeyama National Research Institute of Fisheries Engineering Simon Northridge, Rapporteur
Active Acoustic Experiments	Tim Smith, Rapporteur
Animal Behavior and Net Design	
Behavior in Relation to Nets	Yoshimi Hatakeyama National Research Institute of Fisheries Engineering John Wang, Rapporteur
Mechanics of Entanglement	Simon Northridge Kathryn Bisack NEFSC Steve Dawson, Rapporteur
Gill Net Design and Use	Ron Smolowitz Coonamessett Farms Doug Beach, Rapporteur
Identifying Candidate Gear and Fishing Practice Modifications, Research Needs, and Data Collection	Tim Smith, Chair

APPENDIX 2

Attendees

Attendees

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APPENDIX 3

List of Working Papers

Working Papers

WP1

Smith, T.D., D. Palka, and K. Bisack. 1993. The biological significance of the bycatch of harbor porpoise in the Gulf of Maine gill net fishery. Woods Hole, MA: NOAA/NMFS/NEFSC. NEFSC [Northeast Fisheries Science Center] Ref. Doc. 93-23.

WP2

IWC [International Whaling Commission]. 1990. Report of the Workshop on Mortality of Cetaceans in Passive Fishing Nets and Traps. IWC SC/43/ Rep. 1.

WP3

Coe, J.M. 1990. Discussion paper on management options to control marine mammal mortality in passive fishing gear. IWC [International Whaling Commission] Working Paper SC/090/ G39.

WP4

Northridge, S. 1993, ms. Mitigating porpoise - gill net interactions: a selected bibliography of potentially useful research. (Available from the author.)

WP5

Drew, S. 1990. The groundfish gill net fishery in the Gulf of Maine: fishing gear and methods. IWC [International Whaling Commission] Working Paper SC/090/G39.

WP6

Au, W. and L. Jones. 1991. Acoustic reflectivity of nets: implications concerning incidental take of dolphins. *Marine Mammal Science* 7:258-273.

WP7

Dawson, S. 1991. Modifying gill nets to reduce entanglement of cetaceans. *Marine Mammal Science* 7:274-282.

WP8

Hatakeyama, Y. and H. Soda. 1990. Studies on echolocation of porpoises taken in salmon gill net fisheries. In J. Thomas and R. Kastelein (eds.), Sensory Abilities of Cetaceans. New York: Plenum.

WP9

Jefferson, T.A., B. Wursig, and D. Fertl. 1992. Cetacean detection and responses to fishing gear. In J. Thomas et al. (eds.), Marine Mammal Sensory Systems. New York: Plenum.

WP10

Fridman, A.L. 1986. Calculations for Fishing Gear Designs. (Revised by P.J.G. Carrothers.) London: Fishing News Books.

WP11

Prado, J. and A. Smith. 1990. Possibilities of reducing incidental catch and mortality of marine mammal in drift net fisheries. IWC [International Whaling Commission] Working Paper SC/090/ G14.

WP12

Northridge, S. and K. Bisack. 1993, ms. Gear and catch characteristics affecting harbor porpoise kill rates in the Gulf of Maine sink gill net fishery. (Available from the authors.)

WP13

Hatakeyama, Y. 1993, ms. Sensory capability and behavior characteristics of harbor porpoise relative to modifying fishing to reduce bycatch. (Available from the author.)

APPENDIX 4

Selection and Ranking of Candidate Gear Modifications, Research Needs, and Data Needs

THE PROCESS OF SELECTING CANDIDATE MODIFICATIONS

One goal of the discussion was to devise a list of possible nonacoustic or passive acoustic modifications of gillnetting gear or changes in fishing strategies that would reduce the bycatch of harbor porpoise in the New England gill net fisheries. In selecting candidate modifications, it was clear that additional research and data collection would also be required to fully grasp possible solutions to the bycatch problem.

Because managers are considering restrictions on gillnetting to reduce harbor porpoise bycatch and because the fishing season in which interactions are most prevalent was about to start, fishermen persent were very concerned about having some modifications to test in 1993. They agreed that the acoustic devices tested by Lien in 1992 were useful deterrents and regretted that they were not available for use in 1993. However they wanted to leave the meeting with suggested modification to test this year.

Smith said that if fishermen wanted to try modifications outside of a formal experiment, then it was crucial that the results be observed by sea samplers or other trained observers. Currently, there is no money for a small scale experiment such as Lien's had been. However, additional money is not needed to help industry develop a way to document a field experiment with gear modifications. Smith cautioned that such experiments would be useful for testing methods, but probably not for estimating catch rates. If more formal results are to be obtained then the additional funding for a full research project would have to be obtained.

Smith chaired the final day's chore of sifting through the rapporteur's notes, culling all of the suggestions from discussion into a master list, then winnowing it down based on two factors: the likelihood that the measure would make a difference in bycatch and the likelihood that it was a modification, research inquiry, or data element that could be obtained in the short term, that is, in enough time to make a difference in helping industry address the bycatch question before a closure was required.

Based on the discussion, a list of 78 items was compiled. Each of these was broadly categorized as a possible gear modification, an area requiring research, or a data need. The master list was not ranked. It is presented as Table A1. It was clear that the group was not going to have enough time to rank all three categories by consensus. It was agreed that ranking the suggested gear and operational modifications was most critical, followed by needed research, and finally the data needs. The group succeeded in ranking the first two categories.

RANKING GEAR/OPERATIONAL MODIFICATIONS

Most of the suggestions for gear modifications fell into two broad categories: making the net more detectable to the animal and changing gear characteristics to reduce its success in entangling animals. The 24 suggested modifications for this category listed in Table 3 were voted on by each member of the group. The results are presented in text Table 2 for modifications to improve detectability of the nets, and in text Table 3 for reducing the gear's ability to entangle. Active acoustics were rated highly during this exercise, even though it was not a workshop topic, largely because fishermen felt it was the surest route to immediate results.

RANKING RESEARCH NEEDS

The items listed in Table A1 were categorized further by rapporteurs to make ranking easier. These results are found in Table A2. Since time remaining to the group was very limited, the ranking was not as detailed as in the case of gear and operational strategies. Once the group had reviewed and more or less approved the categories, items under each were selected by consensus as the most crucial or the most immediately promising avenues of inquiry. Those results are presented in text Table 4.

RANKING DATA NEEDS

The group did not have enough time to rank data needs. The master list was categorized by rapporteurs into subject areas, presented in Table A3. The group was presented with the listing, but no action was taken. Recall that items on the list may be new data requirements or suggested modifications to the existing sea sampling effort.

Table A1. List of needed research, needed data collection or analyses, and candidate gear/operational modifications for reducing harbor porpoise bycatch in New England gill net fisheries[1]

RESEARCH NEEDS

1. How do animals behave around gear?
2. Does entanglement at surface or bottom?
3. What is the cue to porpoise when they successfully avoid net?
4. How many animals encounter the net, yet avoid capture?
5. What is the fine-scale distribution of forage fish around net?
6. What is the age, size, and probable familial relationship among porpoise entangling?
8. What are the behavior differences when animals are seen but not caught?
21. Conduct work to improve acoustic profile of floats
23. Monitor porpoise migration to identify times of vulnerability
31. Develop tools to track individual animals
32. Track fine scale behavior near nets
33. Tracking coarse scale behavior near nets
34. Assess noise the net makes underwater
35. Investigate passive noise makers
36. Measure wild harbor porpoise echolocation/sonar use around net
44. Determine the time of entanglement (time of day, actual time of entanglement)
48. Measure ambient light around net (visibility)
    a. How it affects behavior
    b. How it affects net detectability
49. Determine specific visual sensitivity/acuity of harbor porpoise
51. Evaluate role of chemosense in detectability

52a. Test usefulness of net dips for chemoreception

53. Take bottom temperature (profile-CTDs) around fishing areas (relate to entanglement, movements, acoustic conditions)
54. Assess food habits of harbor porpoise and fish in (and around?) nets
55. Observe mechanism of entanglement with ROVs or underwater cameras
56. Examine stomach contents of the harbor porpoise to find largest prey species they are pursuing (for acoustic information--how far away can HP see that prey)
58. Determine harbor porpoise bycatch rate by depth
59. Use sector or side scan sonar to look at bubbles walls and net deployment during fishing
60. Conduct underwater observation of net deployment and retrieval
63. Describe fine scale (baseline) behavior of harbor porpoise in GOM under natural conditions
65. Determine senses other than sonar used by GOM harbor porpoise while migrating
66. Determine what factor(s) trigger(s) migration response (physiological, feed, magnetics)
67. Determine response of harbor porpoise to sound
68. Study animal sounds made during entanglement
72. Improve understanding of GOM harbor porpoise biology/ecology
73. Describe the physics of harbor porpoise sonar (beam width, dimensionality)
77. Describe the mechanics of nets *in situ* and in models

DATA NEEDS[2]

7. Determine the differences between fishing operations in with & without takes (in areas of high takes)
9. Indicate mixed mesh size nets within a string
10. Distinguish floatropes versus separate floats

[1] The items were numbered as they came up in discussion. As we began to categorize, they were useful as identifiers. They do not indicate any kind of rank. Those that are out of sequence were moved to other categories through group discussion.

[2] May be either new required data or suggested additions or modifications to sea sampling effort

Table A1. Continued.

DATA NEEDS (Continued)

11. Record more specific on soak times
12. Note where within nets the animals are entangled
13. Note location of animals in net/string when multiple porpoise killed in a set
14. Record how porpoise are entangled (head, pectoral, dorsal, fluke)
15. Define four gear classes: groundfish, flounder, dogfish, monkfish
16. Define "fisheries": includes gear and target species?
17. Determine size selectivity of gear for fish: rigging, mesh, species of fish
18. Relate porpoise catch rate to trip target species, caught species, depth
19. Note damage to net that may have been caused by porpoise breaking through nets (any?)
22. Relate bycatch by mesh size
28. Review observer data elements for collectability & utility
29. Continue analysis of observer data with geographic/seasonal strata
50. Compare our Sea Sampling data with that from the California halibut fishery, and that collected in Newfoundland research
61. Take body temperature of retrieved dead animals
70. Calculate a standardized unit of effort to use in analyzing effort data
71. Select field study sites (for example, the November pollock fishery)
74. Record bottom type (maps, interviews w/skipper)
75. Determine bottom type for historic data
76. Design an experiment for testing gear modifications

GEAR/OPERATIONS MODIFICATIONS

20. Modify bridle openings (make wider, or close up)
21. Improve acoustic profile of headrope floats
24. Increase tension in net to reduce entanglement chances
25. Change net material to increase acoustic and/or nonacoustic detectability
26. Adjust net hanging ratio (horizontal) to decrease entangling ability
27. Try lead sinkers instead of leadline on footrope
30. Put floats in mesh to improve acoustic target
37. Modify twine characteristics (color, material, elasticity)
38. Modify net height (HR to LL, vertical) to reduce bagging
39. Try Vietnamese net (half-net) described by MacKinnon
40. Increase tension with more floats and more leadline
41. Try different hanging ratios at headline and leadline on a single net
42. Increase bridle height so it's more similar to that of the rest of the net
43. Increase leadline weight to increase sinking speed
45. Shorten nets, increase number of bridle openings
46. Increase net visibility (ocular)
47. Try horizontal ropes strung through nets (acoustic and visual signal)
52. Try net dipping-for stiffness
57. Raise footrope slightly off bottom 3-4 in.
62. Try operational modifications (string length, set time, number of nets)
64. Active acoustics
69. More and smaller floats on headrope
78. Use metal clips instead of twine to tie net to selvages

Table A2. Research needs for understanding harbor porpoise - gill net interactions, categorized by subject area[1]

Porpoise Acoustics

36. Measure wild harbor porpoise echolocation/sonar use around net
56. Examine stomach contents of the harbor porpoise to find largest prey species they are pursuing (for acoustic information--how far away can harbor porpoise see that prey)
67. Determine response of harbor porpoise to sound
68. Animal sounds made during entanglement (distress call?)
73. Physics of harbor porpoise sonar (beam width, dimensionality)

Net Acoustics

21. Improve acoustic profile of floats
34. Net self-noise assessment
35. Passive noise makers
59. Sector or side scan sonar looking at bubbles and net deployment

Other Detection Cues

48. Ambient light around net (visibility)
    a. How it affects behavior
    b. How it affects net detectability
49. Determine specific visual sensitivity/acuity of harbor porpoise
51. Determine role of chemosense in detectability
52 a. Test net dips for chemoreception

Animal Behavior-Fine Scale

55. Observe mechanism of entanglement with ROVs or underwater cameras
1. Document behavior around gear
31. Develop tools to track individual animals
32. Track fine scale behavior near nets (fine scale near nets)
54. Assess food habits of harbor porpoise and fish in (& around?) nets
63. Document fine scale (baseline) behavior of harbor porpoise in GOM under natural conditions
3. What is the cue to porpoise when they successfully avoid net?
4. How many animals encounter nets and avoid capture?
5. What is the fine scale distribution of forage fish around net
6. What are the age, size, probable familial relationship among porpoise entangling?
8. What are the behavior differences when animals are seen but not caught

Animal Behavior-Large Scale (Migration, *etc.*)

65. Determine senses other than sonar used by GOM harbor porpoise while migrating
66. Determine what triggers migration response (physiological, feed, magnetics)
72. Improve understanding of GOM harbor porpoise biology/ecology
23. Monitor porpoise migration to identify times of vulnerability
33. Track animals (coarse scale)

RESEARCH-Nets

44. Determine the time of entanglement (time of day, actual time of entanglement)
2. Does entanglement occur at surface or bottom?
53. Record bottom temperature (profile-CTDs) around gear (relate to entanglement, movements, acoustic conditions)
58. Determine harbor porpoise bycatch rate by depth
60. Observe net deployment and retrieval underwater
7. Examine the differences between fishing operations with & without takes (in areas of high takes)
77. Examine the mechanics of nets *in situ* and in models

[1] Numbers in the first column are the item's number from the master list in Table A1.

Table A3. Data needs categorized by subject area[1]

Gear and Operational Information

9. Account for mixed mesh size nets within a string
10. Distinguish floatropes versus separate floats
16. Define "fisheries": includes gear and target species?
11. Be more specific on soak times
17. Note size selectivity of gear for fish: rigging, mesh, species of fish

Harbor Porpoise Entanglement Information

12. Note where in net animals are entangled
13. Note animal location in net/string when multiple porpoise killed
14. Determine how porpoise are entangled (head, pectoral, dorsal, fluke)
19. Note damage to net that may have been caused by porpoise breaking nets (is there any?)
22. Relate bycatch to mesh size (gear question if there is a difference)
61. Take body temperature of retrieved dead animals

Auxiliary Data Information

15. Define four gear classes: groundfish, flounder, dogfish, monkfish
74. Note bottom type (maps, interviews w/skipper)
75. Determine bottom type for historic data

Observer Data, Analyses, and Indexes

18. Relate porpoise catch rate to trip target species, caught species, depth
28. Review observer data elements for collectability & utility
29. Continue analysis of observer data with geographic/seasonal strata
50. Compare our sea sampling data with that from the California halibut fishery, and Newfoundland fisheries
70. Calculate a standardized unit of effort to use in analyzing effort data
71. Select field study sites (for example, November pollock fishery)

Experimental Design for Testing Gear Modifications

[1] Numbers in the first column are the item's number from the master list (Table A1). This table is not ranked by priority.

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