FINAL REPORT

DEVELOPMENT OF THE WEST COAST FISHERY FOR PACIFIC HAGFISH

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Submitted by

Edward F. Melvin
Washington Sea Grant Program
19 Harbor Mall
Bellingham, WA 98225

and

Steven A. Osborn
Moss Landing Marine Laboratories
P.O. Box 450
Moss Landing, CA 95039

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I. EXECUTIVE SUMMARY

Skin quality defects and a lack of information on fishing gear, fishing techniques, and management tools threaten the development of the new fishery for Pacific hagfish on the Pacific Coast of North America. Solutions to these problems are likely to allow the development of both a profitable and a sustainable hagfish fishery from California to Alaska, as a supplement to highly regulated and harvest-limited traditional fisheries.

The objective of this project was to provide the seafood harvesting industry with the tools to fully develop a profitable and sustainable fishery for the Pacific hagfish on the West Coast of North America, and to provide an alternative or supplemental fishery for small coastal vessels, especially displaced gillnet vessels. Specific objectives were to: 1) develop gear and techniques that would select for more and larger hagfish, 2) characterize hagfish behavior around baited traps and improve trap designs based on these observations, 3) characterize and develop means to control skin quality problems, and 4) develop industry recommendations for capturing and handling Pacific hagfish.

Multiple experiments were completed in three general categories: fishing efficiency, trap design, and skin quality. Fishing efficiency experiments compared the number and size of hagfish caught as a function of trap size, gear soak time, bait concentration and type, fishing depth, and trap escapement hole size. The purpose was to develop means to select for large fish (>= 12 inches) without compromising overall production. Preliminary tests were also included on the extent of ghost fishing by lost traps . Trap design tests compared design features (single vs. double funnels and placement of escapement holes) that might select for more and possibly larger fish based on ROV observations of hagfish behavior in the presence of baited traps. Skin quality tests compared a suite of on-board handling techniques that might minimize or eliminate skin quality defects (bites and dorsal holes). All sampling was done in Monterey Bay, CA, using Moss Landing Marine Laboratories' R/V *Ed Ricketts*.

Mean number per trap and mean length did not vary significantly with trap size in comparisons of Korean traps, 5-gallon bucket traps, and 30-gallon traps. Because the relatively few hagfish caught with Korean traps (19.8 /trap vs. 29.6/bucket trap and 24.8/30 gallon trap) appeared stressed, and the 30-gallon traps were difficult to handle, 5-gallon bucket traps were selected for future comparisons. Using pooled data, the mean length of males (35.1 cm) was greater than that of females (34.1 cm), but this difference was not significant ($p=0.095$).

Comparing three soak times (4, 8, and 24 hours), mean number per trap increased slightly with increasing soak time, but results were not statistically significant. The mean length of hagfish caught in the 24-hour soak was significantly greater (34.8 cm; $p=0.000$) than for those caught in either the 4-hour (33.2 cm) or the 8-hour soaks (32.4 cm). Using pooled data from all soak times, males were significantly larger (35.2 cm) than females (33.5 cm; $p=0.000$); 13.5 % had undeveloped gonads and were labeled as immature.

In two experiments comparing the number and length of hagfish caught in traps with escapement holes of different sizes (range: no holes to 0.56 inch holes) and fished for 3 soak times (4, 8, and 24 hours), mean number per trap and mean length per trap varied significantly with trap escapement hole size and soak time. The number of hagfish increased with increasing soak time and decreased with increasing trap hole size. Hagfish length increased as trap hole size and soak time increased. Traps with 0.48-, 0.45-, 0.42- ,and 0.38-inch escapement holes and fished for 24 hours caught 44, 37, 65, and 104 hagfish/trap, respectively, with 90.3, 78.2, 74.1 and 51% of the hagfish 12 inches or greater in length.

In two further experiments designed to identify an optimal trap escapement hole size and confirm results, traps with 0.42-vs. 0.45-inch, and traps with 0.45- vs. 0.48-inch escapement holes fished for 24 hours were compared using larger sample sizes. Mean length varied significantly with escapement hole size (range: 35.9 to 38.2 cm), but mean number per trap (range: 60.4 to 73 hagfish/trap) did not. Percent >=12 inches ranged from 80.6% (0.42) to 96.5% (0.48). We conclude that larger fish can be selected by using larger escapement holes and longer soak intervals. Specifically, traps with 0.48-inch escapement holes fished for 24 hours best select for hagfish >=12 inches in length.

In a comparison of traps baited with three concentrations of chopped mackerel, 4 pounds of mackerel caught significantly more hagfish (110.8/trap) than one (65.4/trap) or 2 pounds of mackerel (42.3/trap). Mean length did not vary with bait concentration. The optimal bait concentration for 5-gallon traps is near one pound of bait per gallon of trap volume. Increasing bait concentration does not retard the escapement of smaller hagfish.

In a test designed to determine if Pacific hagfish are more vulnerable to night fishing (nocturnal), and if they prefer a specific bait, mean number per trap did not vary significantly with fishing period (12 hour/daytime , 12 hour/nighttime, and 24 hours) or bait type (chopped mackerel (44.8/trap) and rockfish carcasses(59.5/trap)). Mean length did not vary significantly with fishing period. Given that both daytime and nighttime 12-hour soaks produced more hagfish on average (50.2/trap and 66.2/trap, respectively) than the 24-hour soak (39.8/trap), the lack of statistically significant differences, and the tremendous variation in catch among traps within the same soak interval, we can not determine if greater catches observed in 24 hours vs. 4 and 8 hours in our earlier experiments were a function of longer soak time or of increased nocturnal activity. Further, it appears that 12-hour soaks produce at least as many hagfish of a similar size as 24-hour soaks. Production fishing might produce more definitive answers regarding possible advantages of nighttime fishing verses daytime fishing.

In two experiments in which a total of 12 traps were baited with dead hagfish and fished for 24 hours, one hagfish was captured. We speculate that lost hagfish traps do not appear to continually catch more hagfish; however, to conclusively address the ghost fishing question, extended experiments should be conducted in which traps are fished and monitored for weeks as opposed to 24 hours. A degradable escapement mechanism is advisable on hagfish traps to protect other species.

Mean number per trap and mean length varied significantly among traps fished at five depths, 50, 112, 175, 238, 300 fathoms (100, 225, 350, 475, 600 meters), but showed no consistent trends in either variable. Significantly more hagfish were captured at the 475-meter depth (43/trap), and hagfish caught at the 100-meter (37.1 cm) and the 475-m (36.5 cm) depths were significantly larger than hagfish captured at other depths.

ROV observations of hagfish in the presence of transparent baited traps provided a variety of insights on hagfish trap design. Hagfish demonstrated difficulty in finding and entering the trap through the entrance funnel and attempted to enter the trap through escapement holes. It appears likely that a more efficient trap could be designed by increasing the number of entrance funnels, restricting escapement holes to the area surrounding the entrance funnels, shortening the entrance funnels, and constructing the funnels from a solid rather than a perforated material.

Experiments were completed comparing hagfish number and length caught in four trap design variations derived from ROV observations: 1) the standard bucket trap (holes in the sides, bottom and lid) with a single entrance funnel fitted into the lid; 2) the standard trap with holes throughout and a second funnel fitted into the bottom of the bucket; 3) a trap with a single funnel but with holes drilled in the bottom and lid only (without side holes); 4) a trap with two entrance funnels as described above, but without side holes. Because results from the first and second experiment conflicted, probably due to damage to the entrance funnels, the experiment was repeated. Traps with two funnels caught significantly more hagfish per trap (53.9/trap) and significantly larger hagfish (38.4 cm) than traps with single funnels (20.52/trap; 35.1 cm). Traps without side escapement holes caught more hagfish per trap (39.5/trap) and significantly larger hagfish (37.1 cm) than traps with side escapement holes (34.7/trap; 36.4 cm). Considering individual trap designs, traps with two funnels and no side escapement holes caught more and larger hagfish than all other trap designs tested (55.6/trap; 38.6 cm), and traps with one funnel and side escapement holes caught the least and smallest hagfish (17.4/trap; 34.4 cm). These results are consistent with our initial experiment.

It appears that traps with two funnels and without side holes are the best trap design, because they catch more and larger fish. Compared to the single funnel traps with side escapement holes (typically used in the California fishery), double funnel traps without side holes could produce up to two times more fish/trap averaging 15 inches in length, or 1.5 inches larger than those collected with the conventional trap. We speculate that two funnels provide enhanced access to the trap, producing greater catch success and enhanced access for larger animals. Escapement holes restricted to the area around the funnels focus hagfish behavior to the funnel area and reduce futile efforts by larger hagfish to enter the trap through escapement holes. Further, it is likely that smaller hagfish enter the trap through escapement holes; therefore, fewer holes may limit access of smaller fish to the trap.

Comparisons of skin quality among various fishing techniques (trap sizes and soak times) were difficult because few bite marks or dorsal holes were found. The two fishing techniques most likely to show defects, 24-hour soak time (longest soak) and Korean traps (smallest trap), were quantified and compared. Of the 162 hagfish caught in the 24-hour soak, 46% had no dorsal holes or bites, 94% had 2 dorsal holes or less, and 88% had 2 bites or less. In a sub-sample (21) of the hagfish caught using Korean traps, 29% had no holes or bites, 71% had two dorsal holes or less, and 95% had two bites or less. Most hagfish from all the comparisons had one or no bites and one or no dorsal holes. We suspect that dorsal holes are a product of poor temperature control and that hagfish are a highly perishable product requiring careful handling.

Two trials were completed comparing the skin quality of hagfish held on-board in different treatments. The first trial compared the skin quality of hagfish held in six treatments (seawater (SW) and ice, 120 ppm MS_{222}/SW solution, 120 ppm MS_{222}/SW solution and ice, freshwater (FW), 500 ppm bleach, and bubbled CO_2) to a control of SW only. Hagfish held in CO_2, bleach, FW and FW/SW treatments were highly agitated and the mean number of bites for hagfish held in CO_2 and freshwater were more than for all other treatments (6.4 and 3.5, respectively). Hagfish held 48 hours in bleach had few bites (1.4), but skin damage was extensive in all cases. Differences in skin quality among the SW control, the SW/ice, and MS_{222}-SW/ice treatments were few. Mean number of bites varied from 0.3 to 1.7 bites per animal and dorsal holes were equally rare.

In the second trial, which repeated comparisons of the four most promising treatments (SW/ice, 120 ppm MS_{222}/SW, 120 ppm MS_{222}/SW/ice, and 500 ppm bleach for two hours), no differences in skin quality were found among the four treatments or between the treatments and the SW control. The mean number of bites per animal varied from 0.5 to 1.8; the number of dorsal holes smaller than 0.02 in. (0.5 mm) varied from 0.1 to 0.9 per animal; and the number of dorsal holes greater than 0.02 in. varied from 0 to 0.1. The skin quality of bleach-held animals (two hours) was similar to that of the other treatments. We speculate that although the hagfish are highly agitated in bleach, they cannot effectively bite and damage the skins of other animals.

Results suggest that the seawater and ice treatment is probably the most desirable for delivering high quality hagfish for all possible markets for the following reasons: 1) it produces a product of similar quality to other treatments including MS_{222}; 2) it renders hagfish inactive on the vessel; 3) it minimizes enzymatic or bacterial decomposition that might occur; 4) it produces a product suitable for human consumption as well as skins; and 5) ice is inexpensive, generally available, and safe to use.

In none of our work, did we see the extensive dorsal hole skin damage reported by industry buyers. It is possible that by handling relatively small quantities of fish and holding fish on board for less than 2 hours under highly controlled conditions, we precluded the extent of damage experienced under commercial production conditions. Attempts to compare on-board handling techniques under production conditions and to evaluate the quality of the skins with trained tannery technicians were unsuccessful due to the lack of fishing activity in 1991. The density at which hagfish are held at sea and the amount of seawater used are likely factors influencing the extent of bite damage to hagfish skins. In addition, we consistently observed that hagfish are least agitated when submerged in seawater and that quick transfers from the trap to a holding container are very important for minimizing stress to these animals. The seawater/ice and MS_{222}/ice mixtures should be compared at different densities under production conditions before an industry recommendation on handling is developed.

Discussions with Yang Cho, Oh Yang International, Raymond, WA, made it clear that dorsal holes greater than 0.5 mm (tears) and bites limit the value of the skins. Tiny pin holes, mostly smaller than 0.5 mm, are few and generally not limiting. Tears seem to be the result of temperature abuse and are in some cases caused by bites. Based on the results of this research and these discussions, it appears that if the product is kept cold, and densities in 55-gallon barrels are kept at approximately 100 to 150 pounds of hagfish per barrel, skin quality can be improved and anesthetics can be eliminated. Further work at a production level should resolve these issues and open the door to a profitable fishery.

Industry recommendations from this study include the following. Hagfish 12 inches or greater in length should be selectively captured by using 5-gallon bucket traps modified to include two Korean entrance funnels with 0.48-inch escapement holes drilled into the lid and bottom of the trap in the area surrounding the funnels. Traps should be baited with 4 to 5 pounds of bait. Mackerel and rockfish frames are both effective baits; the least expensive is probably the best choice. Traps should be fished for 12 to 24 hours to optimize both numbers and size.

In order to deliver the highest quality hagfish for both the tanning and food markets, holding hagfish in seawater and ice on the vessel is recommended. Hagfish should be transferred immediately after they come on the deck to the seawater and ice mixture to minimize stress from being out of water. The mixture should be kept as close to 32 degrees F as possible to minimize skin damage from biting and from dorsal holes (tears). An optimal holding density is estimated at 100 to 150 pounds of hagfish per 55-gallon barrel containing approximately 25 to 30 gallons of the seawater/ice mixture.

Before a conclusive industry recommendation is made regarding on-board treatment of hagfish exclusively for tannery markets, three treatments (seawater and ice, MS_{222} and seawater and MS_{222}, seawater and ice) should be compared under commercial production conditions with the help of tannery technicians.

II. INTRODUCTION

Skin quality defects, and a lack of information on fishing gear, fishing techniques, and management tools threaten the development of a profitable and sustainable Pacific hagfish fishery on the Pacific Coast of North America. This project was initiated to characterize and develop means to control skin quality problems, to develop gear and techniques that select for more and larger hagfish, and to develop industry recommendations for capturing and handling Pacific hagfish. Funding for this project was provided by the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, through Saltonstall-Kennedy Funds for the period of March 1, 1990 to September 30, 1991.

III. PURPOSE

A. Description of Problem

Decline in the Korean and Japanese hagfish fisheries led to the development of a limited fishery for Pacific hagfish, *Eptatretus stoutii*, on the West Coast of the United States and Canada, beginning in 1988. Hagfish are utilized primarily for the skins, which make a soft but durable leather product that is marketed as eel skin. The total value of hagfish finished leather products imported into the United States is estimated at $70 million U. S. (Y. Cho, pers. comm.) The flesh of the hagfish is a popular food among Koreans and, to a lesser extent, among Japanese people.

Two of the five species of hagfish found in the Pacific waters of North America are of commercial interest, the Pacific hagfish, *Eptatretus stoutii*, and the black hagfish, *E. deani*. Both range from Baja California to Southeast Alaska (Eschmeyer et al., 1983; Wisner and McMillan, 1990). In the first four years of the fishery, effort has focused almost exclusively on the shallower dwelling Pacific hagfish (10 to 516 fathoms) with minor exception. Its light skin color and thickness are most similar to the Asian species (*Paramyxine atami* and *Eptatretus burgeri*) and allow for a greater diversity of leather products. Black hagfish are found deeper (85 to 633 f) and the skins are dark and relatively thick, making them more difficult to dye, tan, and sew. Both Pacific and black hagfish range up to 25 inches in length (Eschmeyer et al., 1983), although reports from the fishery indicate that black hagfish tend to be several inches larger on average.

Development of the West Coast fishery for Pacific hagfish is limited by a number of product quality problems and a lack of information on commercial fishing gear and techniques. Pacific hagfish from the West Coast tend to have small holes (pin holes) in their skins along the dorsal, anterior-posterior axis that are not related to slime glands. Because the skins are used whole for different leather products and the holes are along the center of the skin, removal of the damaged section is impractical. Dorsal hole damage is highly variable and unique to the Pacific hagfish. Speculation on the source of these dorsal holes includes environmental, biological, and handling factors. Bite marks from other hagfish also reduce the quality of Pacific hagfish skins. The anesthetic MS_{222} (Finquel or tricane methanesulfonate) continues to be used in the West Coast fishery to control biting. Unfortunately, MS_{222} is expensive, is of limited effectiveness, and renders the flesh unsuitable for human consumption.

Problems with skin quality (both dorsal holes and bite marks) have led to the rejection of large quantities of Pacific hagfish after shipment to tanneries in Asia, causing great financial difficulty for brokers, processors,and harvesters. A major difficulty in addressing the skin quality problem is the lack of access and communication with tannery personnel. Typically, hagfish are accumulated from a variety of fishermen and shipped whole and frozen by the container load to tanneries in the Republic of Korea or Mainland China through a broker. Negative reports come back to the harvesters and processors through the broker, months after the product was handled and with little knowledge of how skin quality was determined. No record exists of how the fish were handled or by whom. Skin quality defects and poor communication with tanners are the greatest obstacles to developing a successful fishery on the West Coast for Pacific hagfish.

West Coast hagfish production has varied greatly since commercial fishing began in 1988 (Table 1). Coastwide landings peaked at 4.8 million pounds in 1990, with the bulk landed in ports throughout California. Fewer than 200,000 pounds were landed in Oregon ports, fewer than 35,000 pounds in Washington, and more than 300,000 pounds in British Columbia. Landings coastwide dropped to 0.55 million pounds in 1991. Similar quantities were landed in California and Oregon—278,000 and 221,000 pounds, respectively—and fewer than 50,000 pounds in British Columbia and Washington. This decline is the result of greatly reduced fishing effort. Skin quality problems and overproduction in 1990 led to lower ex-vessel price ($0.20 to $0.30/pound from $0.40 to $0.55/pound) and reluctance by harvesters and processors to risk further involvement in the fishery.

Table 1. Estimated Pacific Hagfish Landings. *Pacific hagfish landings (pounds) by state, province, and coastwide totals for 1988 through 1991.*

STATE/PROVINCE	1988	1989	1990	1991	TOTAL
CALIFORNIA	326,000	2,642,540	4,251,217	277,842[b]	**7,497,599**
OREGON	25,782	344,187[a]	167,453	221,470[c]	**758,892**
WASHINGTON	0	0	34,000	4,000[d]	**38,000**
BRITISH COLUMBIA	145,887	1,211,942	320,033	48,418	**1,726,280**
COASTWIDE TOTAL	**497,669**	**4,198,669**	**4,772,703**	**551,730**	**10,020,771**

[a] adjusted weight [b] through October 1991 [c] through October 15, 1991 [d] through May 1991

Sources: Pete Kalvass, California Department of Fish and Game; Bill Barss, Oregon Department of Fish and Wildlife; Brian Culver, Washington Department of Fisheries; C.M. Neville and R.J. Beamish, 1992.

Gear and techniques vary widely in the Pacific hagfish fishery and were described by Kato (1990). Several trap designs are used and they vary in volume, shape, number of entrance funnels, and size and placement of trap escapement holes. Initially the Korean trap, which is available commercially and used extensively in the Asian fisheries, was used. It is a molded plastic cylinder measuring five inches in diameter and 24 inches in length with 0.34-inch diameter escapement holes throughout the trap. A single funnel is fitted in one end and is removable, providing access to the trap contents. These small traps tended to be completely filled with hagfish, leading to experimentation with larger traps. Traps made from 4- to 6-gallon plastic buckets became common. Holes were drilled throughout the trap and a single funnel from the Korean trap was fitted into the lid or bottom. Traps made from 30- to 55-gallon plastic pickle barrels are also used, with varying size and placement of escapement holes and one to several funnels. Traps are weighted and fished at varying distances along a groundline.

The type and concentration of bait, length of time the traps are fished (soak time), and the number of traps used vary greatly among individual fishermen. Depths fished range from 45 to 200 fathoms. Hagfish are usually sorted by size and are held live on the vessel in 55-gallon drums containing 5 to 10 gallons of seawater with 60 to 120 ppm of MS_{222}. Innovative approaches to controlling skin quality damage have included holding hagfish in sawdust, peat moss, mixtures of ice and seawater, ice seawater and MS_{222}, and seawater and chlorine bleach. Once in the plant, the catch is usually re-sorted for size and quality and frozen live in 25-pound boxes. These whole frozen fish are then shipped to tanneries in Korea and Mainland China, where they are skinned and tanned. There is little agreement on the best gear and techniques for catching Pacific hagfish or on methods to hold live hagfish on the vessel.

Elimination of anesthetics is likely to increase the value of West Coast hagfish by creating the opportunity to sell the flesh for food as well as the skins and by eliminating the cost of the anesthetic. Increased price would probably help stabilize the fishery by reducing financial risk to harvesters. Treatments combining temperature, salinity, and mild caustic chemicals may provide methods to immobilize hagfish and control skin quality damage; however, clues on alternatives to anesthetics are few in the scientific literature. Pacific hagfish are extremely active several hours after decapitation, and respond violently but survive exposure to warm water (Worthington, 1905), and they are highly sensitive to changes in salinity (Jensen, 1966). Their highly developed sense of smell (Sutterlin, 1975) suggests that they may be sensitive to mild chemical treatments. Pacific hagfish are reported to have a blood oxygen affinity as high as, or higher than, any other vertebrate (Manwell, 1958) and a very low rate of metabolism, suggesting that suffocation techniques would be difficult.

Reports on substrate preference, depth, seasonal migrations, and fishing techniques are few and vary widely in the scientific literature. Several researchers report catching a variety of hagfish species over soft, mud substrate (Honma, 1960; Adam and Strahan, 1963; Jensen, 1966; and McInerney and Evans, 1970), yet others (Worthington, 1904; and Dean, as reported by Conel, 1931) reported catching Pacific hagfish over hard substrates in Monterey Bay. Optimal fishing depths for *E. stoutii* are virtually unknown, and may vary with season as with other species (Dean, as reported by Conel, 1931; Honma, 1960; Adam and Strahan, 1963; and Tsuneki et al. 1983).

Descriptions of fishing techniques for hagfish in the recent literature are few, and information on fishing techniques for Pacific hagfish is extremely limited. Gorbman et al.,(1990) described the hagfish fishery in three locations in Japan. Traps vary in size and design and are made from a variety of materials (plastic and bamboo). They are fished for a maximum of 4 hours at 50 to 250 f in depth. Hagfish are held in live wells on the vessel without anesthetics and are delivered live for processing. Descriptions of the relatively large Korean fishery are unavailable.

Eptatretus burgeri is nocturnal and is fished exclusively at night (Fernholm, 1974) and *Paramyxine atami* is fished at night in some areas of Japan (Strahan and Honma, 1960; and Gorbman, 1990). Nothing is known about possible nocturnal behavior in Pacific hagfish, and therefore the likelihood of catching more hagfish at night is also unknown.

Researchers have reported a number of baits used to catch various species of Asian hagfish; they include: cod, herring, sardines, mackerels, smelt, squid, and cuttlefish (Adam and Strahan, 1963; Honma, 1960; Tsuneki et al, 1983; and Gorbman et al., 1990). Given the highly developed sense of smell in hagfish, bait selection could be critical to fishing success (Fernholm, 1974; Strahan, 1963). There is considerable speculation as to the best bait for Pacific hagfish. Mackerel and rockfish carcasses are most commonly used, depending on price and availability.

Worthington (1905) reported early commercial fishing in Monterey Bay using large wicker traps or hooks on longlines baited with squid and sardines and fished overnight. She suggested that sardines and hagfish eggs were preferred foods, based on her aquarium observations. She also described swarming feeding behavior in Pacific hagfish, suggesting that large traps might be more efficient at catching commercial quantities of hagfish and might provide an advantage in controlling skin quality by providing more space.

Decline of the Korean and Japanese hagfish resource (primarily *Paramyxine atami* and *Eptatretus burgeri*, limited fecundity, and a general lack of information on hagfish life history, have led to cautious management of the Pacific hagfish resource in Canada and the United States. Regulations by state and provincial governments include limited entry , limits on the number of traps fished per vessel, limited term experimental permits, and requirements for self-destruct mechanisms on traps to minimize suspected ghost fishing by lost traps. Research is in progress on aspects of Pacific and black hagfish life history (Reid, 1990; Cailliet, 1991; Nokamura, 1991; and Ryan and Kato, 1992). These efforts will provide, among other things, estimates of the size at which hagfish become reproductive. In discussions with hagfish resource managers throughout the West Coast, the need for a means to select for large hagfish to protect nonreproductive hagfish was unanimously expressed.

Skin tanners also require larger hagfish, creating the need to sort hagfish by size on the vessel or in the plant. Reports of the minimum size required vary from 12 to 14 inches, but 12 inches or larger in length is most commonly accepted. Size sorting is difficult and time-consuming and may be a factor contributing to skin quality defects, as well as to future resource depletion. The degree to which larger hagfish can be selected by fishing gear and/or techniques is unknown, but development of size selective techniques has emerged as a high priority among the industry and resource managers.

The extent to which lost hagfish traps continue to fish is also a major concern of resource managers, but the degree to which ghost fishing occurs in unknown.

B. Project Objective

The objective of this project was to provide the seafood harvesting industry with the tools to fully develop a profitable and sustainable fishery for the Pacific hagfish on the West Coast of North America, and to provide an alternative or supplemental fishery for small coastal vessels, especially displaced gillnet vessels. Specific objectives were to: 1) develop gear and techniques that would select for more and larger hagfish; 2) characterize hagfish behavior around baited traps and improve trap designs based on these observations; 3) characterize and develop means to control skin quality problems; and 4) develop industry recommendations for capturing and handling Pacific hagfish.

IV. APPROACH

A. Description

Three general categories of testing were completed: fishing efficiency, trap design, and skin quality. Fishing efficiency tests consisted of comparing trap sizes, gear soak times, concentrations and types of baits, fishing depths, and escapement hole sizes that would select for large fish (>= 12 inches) without compromising overall production, and tests on the extent of ghost fishing by lost traps. Trap design tests compared design features that would select for more and possibly larger fish based on ROV (Remotely Operated Vehicle) observations of hagfish behavior in the presence of baited traps. Skin quality tests compared a suite of on-board handling techniques that might minimize or eliminate skin quality defects. A series of experiments were completed under each category and are described individually. The basic fishing gear and techniques, experimental design, and statistical analyses are also described.

1. Gear

Experimental fishing was done from Moss Landing Marine Laboratories' 35-foot R/V *Ed Ricketts*. Hagfish were fished with trapline gear at two locations in Monterey Bay (Figure 1). Station one is located on the north rim, and station two is on the south rim of the Monterey Bay Submarine Canyon. Both stations are characterized by green mud substrate at 50 fathoms.

The basic fishing gear consisted of baited 5-gallon plastic bucket traps fixed at 10-meter intervals to a groundline (5/16-inch leaded polypropylene) with a single vertical line (5/16-inch, polypropylene, Dungeness crab line) running to a buoy, flag, and radar reflector array at the surface (Figure 2). The free end of the groundline was held on the bottom with a danforth anchor and a 25-pound salmon ball; a 25-pound salmon ball was positioned at the vertical/groundline junction. A 5-pound lead was fixed to the vertical line 10 meters below the surface to submerge slack in the line.

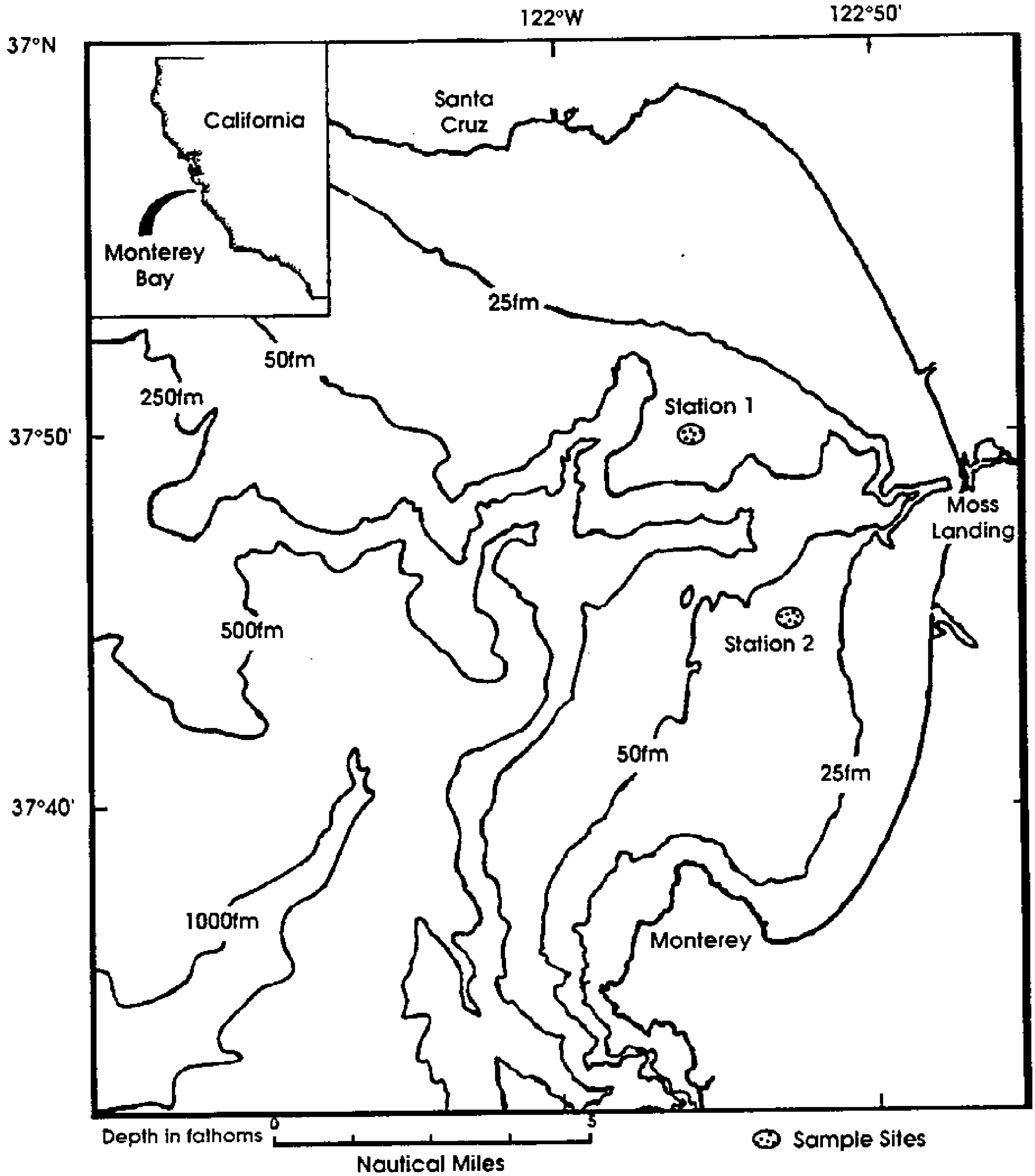

Figure 1. Hagfish collection stations in Monterey Bay, California. Both Station 1 and 2 are characterized by mud substrate at 50 fathoms.

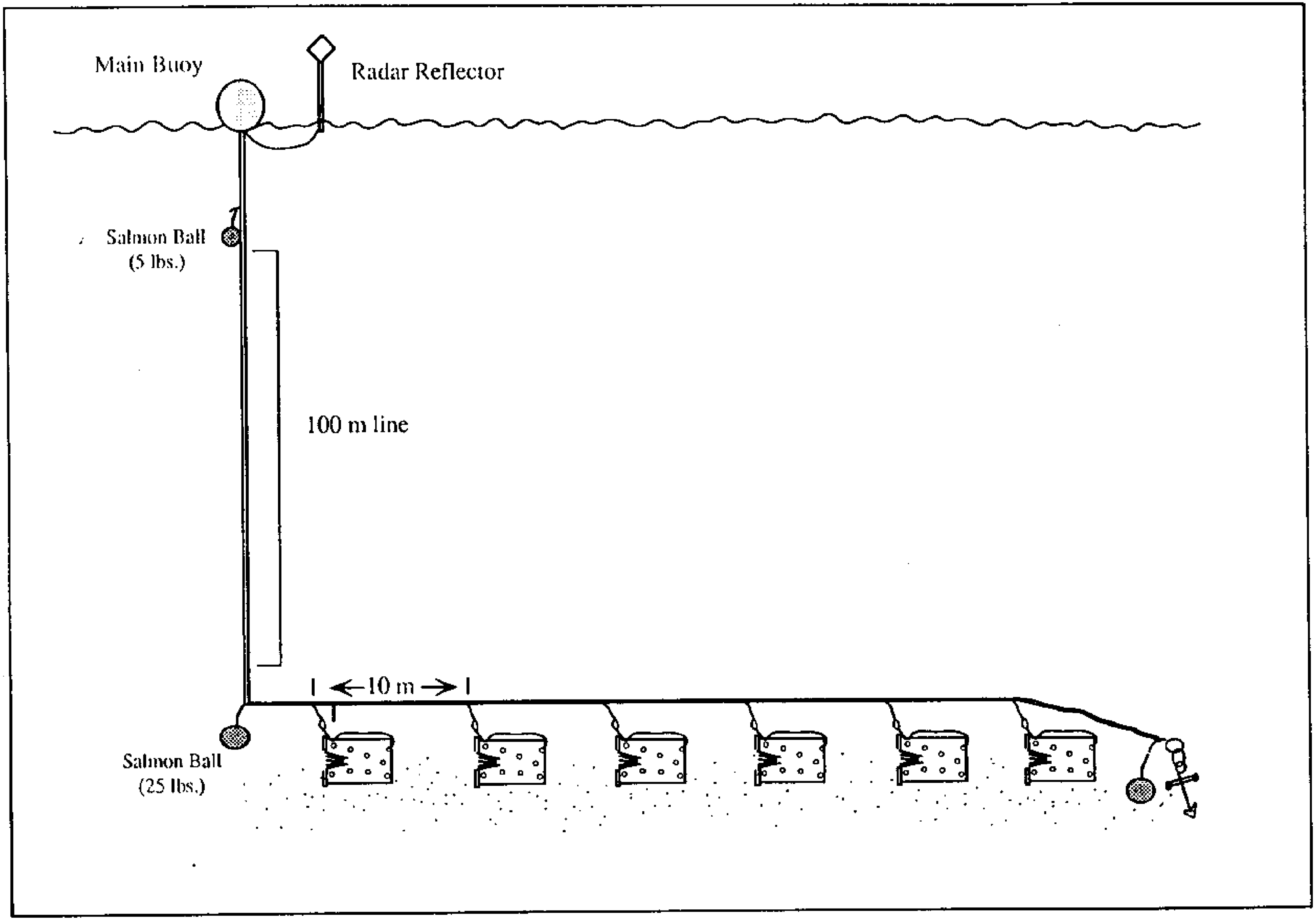

Figure 2. *Schematic of hagfish trapline fishing gear.*

Based on the results of initial experiments comparing traps of different sizes, bucket traps served as the basic gear unit for comparisons. Bucket traps are 5-gallon plastic buckets (14 inches tall and 10 to 12 inches in diameter) with a conical entrance funnel fitted into the lid and escapement holes drilled at approximately every 2.5 to 3 inches throughout the trap (lid, bottom, and sides). Trap escapement holes allow detection of the bait and possibly escapement of smaller hagfish. The entrance funnels used were from commercially available Korean hagfish traps. They are conical in shape, 5 inches in diameter and 9 inches long. The upper third of the funnel is perforated plastic, and the latter two-thirds consists of plastic fingers tapering to a point allowing entrance to the trap but no exit. Initially, escapement holes were 0.34 inches in diameter to match the diameter of escapement holes in Korean traps, but later they were varied in an attempt to select for larger hagfish. Trap lids were held closed with 2-inch strips of tire tube material. Trap ganions were 18 inches in length and made of 0.25-inch hollow crab line. Eight ounces of gillnet lead were threaded onto each ganion to ensure that traps stayed on the bottom. Traps were attached to the groundline with 5/16-inch halibut snaps fixed to each ganion. Gear was deployed and retrieved with a hydraulic crab block hung from an "A" frame at the stern of the vessel.

2. Experimental Design and Statistics

All gear comparisons were made using a sequentially randomized design, where equal numbers of treatments were randomly sequenced along a single or multiple groundline(s). SYSTAT 5.0 statistical software for Macintosh computers was used for all statistical analyses. One-way and two-way Analysis of Variance (ANOVA) techniques were used to test for significant differences ($p < 0.05$) between and/or among treatments. Tukey's multiple range comparison test was used for post-hoc comparison of means. Where possible, two-way ANOVA experimental designs were used to economize ship time and to explore the interplay between experimental factors. The number of hagfish per trap was determined in all fishing efficiency and trap design experiments. Length measurements were of hagfish total length to the nearest millimeter. Although the minimum size demanded by buyers has varied from 12 to 14 inches, 12 inches (30.38 cm) is most common and was selected as the evaluation criterion for size. The amount and condition of the bait in each trap were recorded in all comparisons.

3. Fishing Efficiency Comparisons

Trap Size Comparisons: Five each of three different size traps (Korean, 5- gallon bucket, and 30-gallon trash can) were fished along a common groundline for 5.5 hours at station 1. Korean traps are plastic cylindrical traps, 5 inches in diameter and 24 inches long, with 0.34-inch escapement holes throughout and a single entrance funnel. These traps are commercially available and were used extensively in the early West Coast fishery. Five-gallon bucket traps were the basic gear unit described above. Thirty-gallon trash cans had a single entrance funnel fitted into the lid, and 0.34-inch escapement holes were drilled throughout the trap. The lid was held shut with plastic wire ties. Each trap was baited with one pound of whole mackerel. Hagfish caught were placed into a solution of 300 ppm MS_{222}, seawater and ice and later frozen on shore (see skin quality determinations). All fish were counted, skinned, sexed, and measured. Total weight for the contents of each trap was determined. Skins were dried, labeled and stored. The objective was to determine if the mean number of hagfish per trap, mean length, and skin quality varied significantly with trap size. Hagfish were sexed to determine if skin quality varied with sex.

Soak Time: Five each of the 5-gallon bucket traps with 0.34-inch escapement holes were fished for 4, 8, and 24 hours at station 1. Traps were baited with one pound of whole mackerel. Hagfish were placed into a solution of 300 ppm MS_{222} (anesthetic), seawater and ice and later frozen on shore. All fish were counted, measured, sexed, and skinned and total number and total weight were determined for each trap. The objective was to determine if mean number per trap, mean length, and skin quality varied significantly with the length of time that traps were fished (soak time). Hagfish were sexed to determine if skin quality varied with sex.

Trap Hole Size and Soak Time Comparisons: To address the question of whether trap design and fishing techniques can be modified to select for larger fish and therefore eliminate discards, time sorting on deck, and probable quality loss from the sorting procedure, two experiments were completed. In the first experiment, four bucket traps for each of three different escapement hole sizes (0.34, 0.45, and 0.56 inches) and four traps with no holes (control) were fished at each of three soak times (4, 8, and 24 hours). Two groundlines with 2 traps of each hole size and 2 controls were fished for each soak time (16 traps). Traps were baited with 2 pounds of chopped mackerel. Hagfish caught were held live in a mixture of 120 ppm MS_{222}, seawater, and ice. The number per trap and fish length were determined for the entire catch. The objectives were to determine if escapement occurs through trap holes, and if so, determine if mean number per trap and mean length vary significantly with escapement hole size and soak time (two-way ANOVA).

In the second experiment, traps with five different escapement hole sizes, selected based on the results of the first experiment, were fished at the same three soak times. Four bucket traps for each of five different escapement hole sizes (0.38, 0.42, 0.45, 0.48 and 0.52 in.) were fished at each of three soak times (4, 8, and 24 hours) using the same experimental design and methods described above. The objective was to identify a trap hole size that best selects hagfish greater than or equal to 12 inches in total length and to confirm our findings on the effects of soak time.

Trap Hole Size and Bait Concentration Comparisons: In the course of collecting hagfish for on-board treatment trials, trap hole size comparisons were repeated using hole sizes from earlier experiments that showed the greatest likelihood of optimizing catch in terms of numbers caught and size (0.42, 0.45, and 0.48). In the first experiment, eight bucket traps of each of two trap hole sizes (0.42 and 0.45 inch) were baited with two pounds of mackerel and fished for 24 hours at station 2. Six traps of each hole size were fished on one groundline and two each of each hole size were fished on a second groundline. Because fishing at the northern rim location (station 1) produced fewer and fewer hagfish, this new location was selected with the hope of increasing the catch. The number of hagfish per trap and total length were determined for the entire catch. The objective was to determine which of the two hole sizes tested best selected for larger hagfish (one-way ANOVA).

In the second experiment, four bucket traps with 0.45-inch holes and four bucket traps with 0.48-inch holes were fished with each of three bait concentrations (chopped mackerel; 1, 2, and 4 pounds) in a 24-hour soak at station 2. Four traps of each hole size and bait concentration were fished in a random sequence along two groundlines. The number of hagfish per trap and total length of each hagfish were determined for the entire catch. Our objective was to determine if the mean number of hagfish per trap and total length varied significantly with the two trap hole sizes and the three bait concentrations (two-way ANOVA), and if so, which trap hole sizes and bait concentrations catch more and larger fish.

Nocturnal Activity and Bait Comparisons: To test the possibilities that Pacific hagfish might exhibit increased nocturnal behavior and that hagfish might prefer a specific bait, we completed the following experiment. Bucket traps, with 0.48-inch escapement holes limited to the trap lid and bottom, were fished at station 2 using the following experimental design: 1) 20 traps were fished for a 12-hour period during the day (8 a.m. to 8 p.m.); 2) 20 traps were fished for a 12-hour period at night (8 p.m. to 8 a.m.); and 3) 20 traps were fished for 24 hours (8 a.m. to 8 a.m.). Twelve-hour soaks were used to economize vessel time. Half of the traps (10) for each time period were baited with 4 pounds of chopped mackerel and ten traps were baited with 4 pounds of rockfish carcasses, and were fished in a randomized sequence along a common groundline. The 12-hour daytime and 24-hour soaks were both set at 8 a.m. The 12-hour nighttime soak was set at 8 p.m. before the daytime soak was retrieved, and later retrieved with the 24-hour soak the following morning. The number of hagfish in each trap and total length of approximately 200 randomly selected hagfish from each soak period were determined. The objectives were to determine if the number of hagfish per trap varied significantly with fishing period and bait type (two-way ANOVA), and if hagfish total length varied significantly with fishing period (one-way ANOVA).

Ghost Fishing: Two experiments were completed to determine if lost hagfish traps continue to catch hagfish and pose a threat to the hagfish resource. In the first experiment two bucket traps were baited with 1, 2, and 4 pounds of chopped hagfish (six traps total) and fished for 24 hours at station 2. In the second experiment, four bucket traps, with two entrance funnels and 0.48-inch escapement holes in the lid and bottom only, were baited with 4 pounds of chopped hagfish and fished for 24 hours at station 2.

Depth Comparisons: Five bucket traps with 0.48-inch holes and baited with 2 pounds of chopped mackerel were fished at each of five depths (50, 112, 175, 238, 300 fathoms) for 24 hours. Number per trap and total length were determined for the entire catch. The objective was to determine if mean number per trap and total length varied significantly with depth (two-way ANOVA).

4. Trap Design Comparisons

ROV Observations: A unique opportunity arose to observe hagfish behavior in the presence of baited traps using the Monterey Bay Aquarium Research Institute's (MBARI) Remotely Operated Vehicle (ROV) *Ventana*. The ROV is equipped with a Sony Betacam video system that transmits signals through a fiber optic cable from the submersible up to the R/V *Point Lobos* where it is displayed and recorded on 20-minute Beta video tapes. Two clear cylindrical traps, 12 inches in diameter and 24 inches long, were fabricated from optical quality acrylic. A single funnel was fitted to one end and 0.25-inch holes were drilled into the sides and ends of the trap. The two clear traps and two 5-gallon bucket traps were baited with 5 pounds of chopped mackerel and deployed by the ROV on the northwest wall of Soquel Canyon at 180 fathoms. Traps were deployed along a 30-foot section of groundline with clear traps at each end and bucket traps approximately 10 feet apart in the middle. Hagfish were observed for approximately 4 hours aboard MBARI's R/V *Point Lobos*. A 23-minute video summary was made of various hagfish behaviors and is available from the authors. The objective was to use these observations to improve the design of hagfish traps so that they are more efficient at capturing hagfish and to determine if behavior within the trap is linked to skin quality defects.

Trap Design Comparisons: Three experiments were completed comparing modifications of 5-gallon plastic bucket trap based on the results of ROV observations. The 0.48-inch hole size was used in all trap designs tested.

Two trap design features were tested (traps with one versus two funnels, and traps with or without side escapement holes) in the first experiment. Four trap variations were built: 1) the standard bucket trap (holes in the sides, bottom and lid) with a single entrance funnel fitted into the lid; 2) the standard trap with holes throughout and a second funnel fitted into the bottom of the bucket; 3) a trap with a single funnel but with holes drilled in the bottom and lid only (without side holes); 4) a trap with two entrance funnels as described above, but without side holes. Four traps of each of the four trap designs were fished (16 traps total) for 24 hours at station 2. One of each of the four configurations were fished in a random sequence along each of four groundlines. Groundlines were fished along a one nautical mile transect. The number of hagfish per trap and total length of approximately 200 hagfish from each of the four trap designs were determined. The objective was to determine if mean number per trap and mean length varied significantly with the number of funnels and/or the presence or absence of holes in the side of the trap (side holes: two-way ANOVA).

The first experiment was repeated but with double the number of traps fished for each trap design feature. Eight traps for each of the four configurations described above were baited with 4 pounds of mackerel and fished for 24 hours at station 2. Two traps of each configuration were deployed in a random sequence on each of four separate groundlines along a transect of approximately one nautical mile. The number of hagfish per trap was determined for each of the 32 traps. Length measurements in the first experiment yielded small standard errors adequate for robust statistical comparisons and so were not repeated. The objective was to confirm results found in the first experiment using larger sample sizes.

In the third experiment, the second experiment was repeated using larger sample sizes and new entrance funnels because comparisons of one versus two funnels in the first and second experiment produced conflicting results. We speculated that damage to the entrance funnels allowed enhanced escapement from traps with two funnels in the second experiment. Twelve each of the same four trap designs (1. one funnel with side holes; 2. one funnel without side holes; 3. two funnels with side holes; and 4. two funnels without side holes) were baited with 4 pounds of mackerel and fished for 24 hours at station 2. Three traps of each design were fished in a random sequence along each of four groundlines. The number of hagfish per trap and total length of approximately 200 hagfish from each trap design were determined. The objective was to determine if number per trap and total length varied significantly with funnel number and presence or absence of side holes in the traps (two-way ANOVA).

5. Skin Quality

Hagfish were skinned by placing the fish dorsal side down and fixing the head to a cutting board with an ice pick through the mouth. A cut was made with a knife immediately posterior of the mouth, perpendicular to the notochord. A second cut was made from the first cut to the vent along the ventral surface, exposing the viscera. The notochord was severed immediately below the mouth and pulled posteriorly—thus moving the viscera, muscle, and notochord. The slime glands were removed from the skin by scraping with a knife. The quality of the skins was determined by observing the presence or absence of dorsal holes, and the number of bite marks on the skins.

Fishing Related Skin Quality: Hagfish caught in trap size and soak time comparisons (described under Fishing Efficiency methods) were placed into a mixture of 300 ppm MS_{222}, seawater and ice and later frozen on shore. All fish were skinned, sexed, and measured. The skins were laid out on a sheet of Plexiglass or wax paper and allowed to dry for 24 hours. The objectives were to determine if skin quality can be determined from untanned skins and, if so, if skin quality varies with trap size or soak time.

On-board Treatments: Two trials were conducted comparing the quality of hagfish skins held in different treatments on the vessel after capture. Hagfish were captured in the course of trap hole size and bait concentration comparisons (see Fishing Efficiency methods). The first trial compared six treatments (seawater (SW) and ice, 120 ppm MS_{222}/SW solution, 120 ppm MS_{222}/SW solution and ice, freshwater (FW), 500 ppm bleach, and bubbled CO2) to a control of SW only. The contents of individual 5-gallon bucket traps were emptied into individual 5-gallon buckets containing approximately 2 gallons of each treatment. Hagfish behavior in each treatment was observed for up to two hours. Separate buckets were used for the contents of each trap to allow for counts and length measurements for hole size comparisons. All treatments were transferred to a cold room on shore and held for up to 48 hours. Ten hagfish per treatment were examined for bites prior to skinning and for pin holes after skinning. Skins were placed on

Plexiglass sheets for inspection and to facilitate photographs. The skins from each treatment were photographed to create a permanent record. Our objectives were to characterize skin quality defects and develop test criteria, and to determine if skin quality varies with the six holding treatments on the vessel. In addition, hagfish were placed in three treatments (200 ppm bleach, 1,000 ppm bleach, and a solution of equal parts of SW and FW) for observation only. The objective was to characterize hagfish behavior in these treatments for possible further study.

To address the difficult and subjective nature of skin quality determinations, a method was devised in which two evaluators examined the carcasses and skins independently and estimated the number of bites, the number of dorsal holes less than or equal to 0.5 mm and the number greater than 0.5 mm. In cases where the two evaluators disagreed, the samples were reexamined by both evaluators, discussed, and a final number was agreed upon and recorded. Based on feedback from tannery technicians, dorsal hole damage was determined after scraping away the fat layer from the dorsal area of each skin. Attempts to eliminate the fat layer by soaking skins in a saturated lime solution, as is done in the tannery process, were not successful.

In the second trial, four treatments (SW/ice, 120 ppm MS_{222}/SW, 120 ppm MS_{222}/SW/ice, and 500 ppm bleach) were compared with a seawater control. In addition, hagfish were held in 240 and 360 ppm MS_{222}/SW solution for observation only. All fish were frozen immediately after returning to shore and were thawed for skin quality evaluation the following day. The objective was to confirm results from the first trial.

B. Project Management

Ed Melvin, North Sound Field Agent for the Washington Sea Grant Program and former Area Marine Advisor for California Sea Grant/U.C. Cooperative Extension, was responsible for project management. He designed, supervised, and participated in all aspects of the project and is responsible for technical reports. Steven Osborn, post graduate researcher, assisted with collections, experimental design, data collection, analysis and interpretation, and gear acquisition and maintenance.

V. FINDINGS

A. Accomplishments

1. Fishing Efficiency Comparisons

Trap Comparisons: In comparisons of Korean, bucket, and 30-gallon traps, mean number per trap (Figure 3), and mean length (Figure 4), did not vary significantly with trap size. The smaller Korean traps caught the fewest hagfish (19.8 /trap) and unlike the other traps, Korean traps contained considerable amounts of slime, indicating increased stress. Bucket traps caught more hagfish (29.6/trap) than the 30-gallon trap (24.8/trap), but results were not statistically significant. Given that there was great variation in the numbers caught per trap, especially in the Korean and trash can traps, greater numbers of replicates are required to detect significant differences. Also, it is likely that one pound of bait was not adequate to attract hagfish in a 5.5-hour soak. The mean length per trap type was greatest for trash can traps (34.1 cm) and least in bucket traps (33.1 cm).

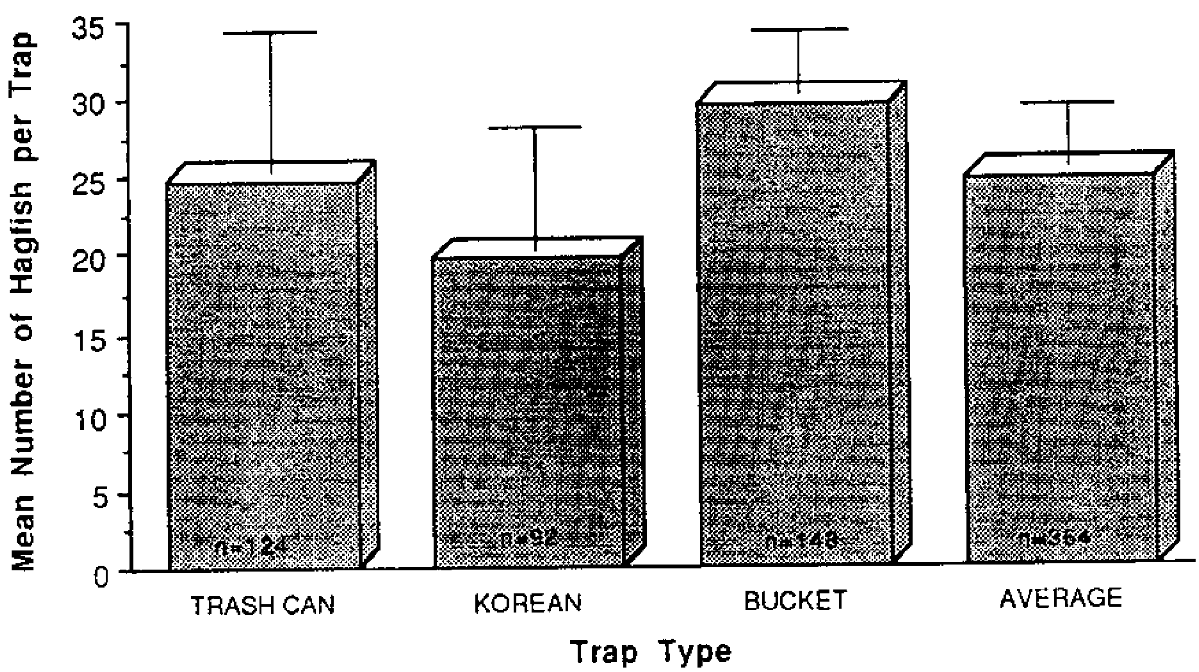

Figure 3. *Mean number per trap of hagfish for each of three trap types (30-gallon trash can, Korean, and 5-gallon bucket trap) and average for all traps combined. Error bars are standard errors. Five (n=5) of each trap type with 0.34-in. escapement holes were baited with 1 pound of whole mackerel and fished for 5.5 hours at Station 1. Mean number per trap did not vary significantly with trap type (F=0.469; p=0.636).*

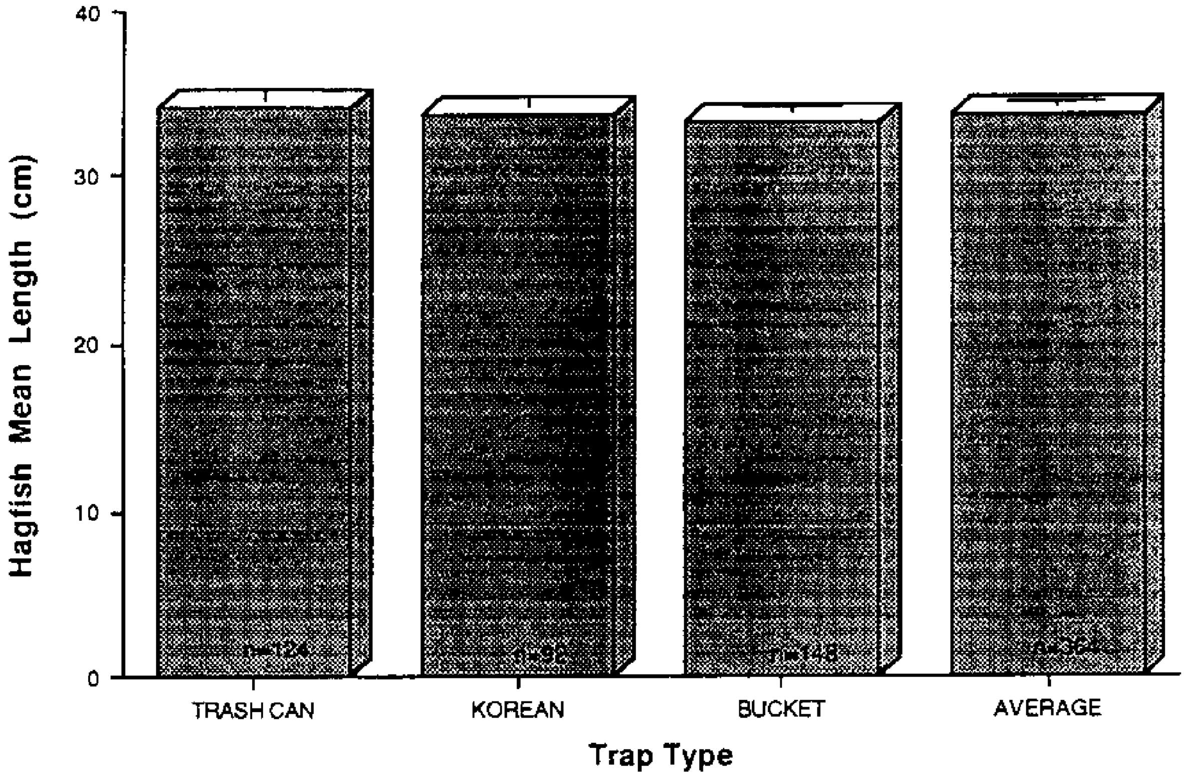

Figure 4. *Mean length per trap (cm) of hagfish for each of three trap types (30-gallon trash can. Korean, and 5-gallon bucket trap) and average of all traps combined. Error bars are standard errors. Five (n=5) of each trap type with 0.34-in. escapement holes were baited with 1 pound of whole mackerel and fished for 5.5 hours at Station 1. Mean length per trap did not vary with trap type (F=0.95; p=0.387).*

Using pooled data, the mean length of males (35.1 cm) was greater than that of females (34.1 cm), but this difference was not significant (p=0.095). Hagfish with undeveloped gonads were labeled immature and made up 13.7 % of the catch. Because the relatively few hagfish caught with Korean traps appeared stressed, and the 30-gallon traps were difficult to handle and possibly less efficient, 5-gallon bucket traps were selected for future comparisons.

Soak Time: Comparing three soak times (4, 8, and 24 hours), mean number per trap increased slightly with increasing soak time (29.6, 32.0 and 32.6/trap, respectively); but results were not statistically significant (p=0.974; Figure 5). The mean length of hagfish caught in the 24-hour soak was significantly greater (34.8 cm; p=0.000) than those caught in either the 4-hour (33.2 cm) or the 8-hour soaks (32.4 cm; Figure 6). The difference in mean length between the 4- and 8-hour soaks was not statistically significant. The percent of hagfish >= 12 inches followed the same trend as mean length (79.1, 64.8, and 72.9 % in the 24-, 8-, and 4-hour soaks, respectively). This result suggests that smaller hagfish have the opportunity to escape in longer soaks, and that soak time may be a vehicle to select for larger hagfish.

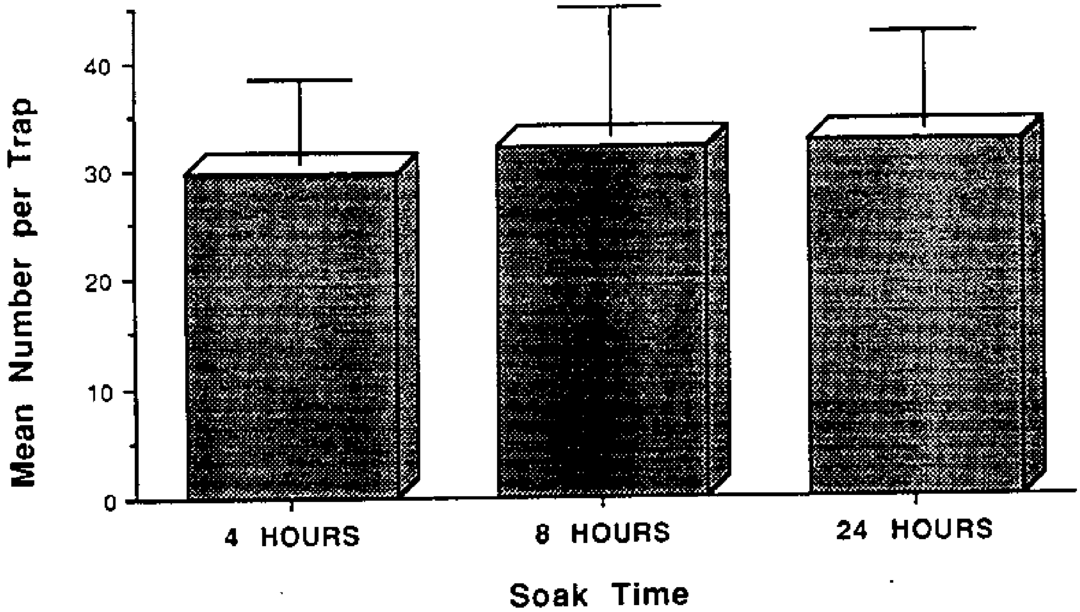

Figure 5. Mean number of hagfish per trap for each of three soak times (4, 8, and 24 hours). Error bars are standard errors. Five bucket traps (n=5) with 0.34-in. escapement holes were baited with 1 pound of whole mackerel and fished at Station 1 for each soak time. Mean number per trap did not vary significantly with soak time (F=0.026; p=0.974).

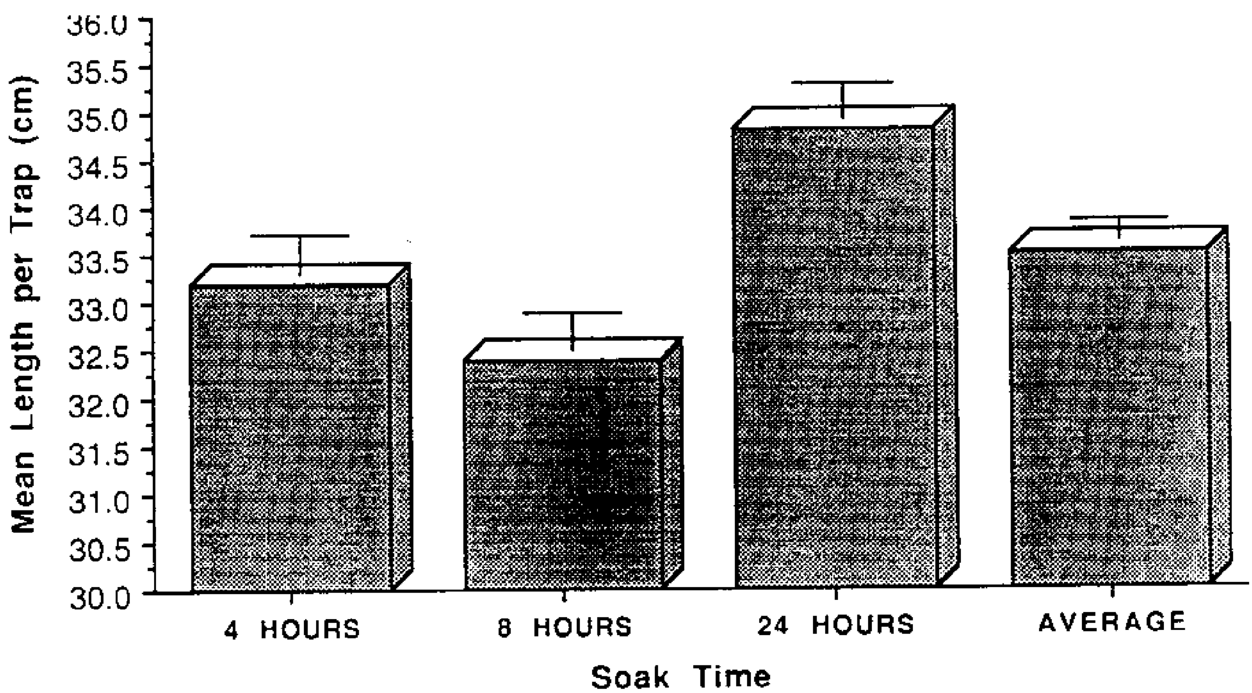

Figure 6. Hagfish mean length per trap (cm) for each of three soak times (4, 8, and 24 hours). *Error bars are standard errors. Five bucket traps (n=5) with 0.34-in. escapement holes were baited with 1 pound of whole mackerel and fished at Station 1 for each soak time. Mean length per trap varied significantly with soak time (F=11.413; p=0.000).*

Using pooled data from all soak times, males were significantly larger (35.2 cm) than females (33.5 cm; p=0.000); 13.5 % had undeveloped gonads and were labeled as immature.

Trap Hole Size and Soak Time Comparisons: Mean number per trap and mean length per trap varied significantly with trap escapement hole size (0.34, 0.45, and 0.56 inches) and the control (no holes), soak time (4, 8, and 24 hours), and interaction between factors. The number of hagfish increased with increasing soak time and decreased with increasing trap hole size (Figure 7). Traps with no holes caught significantly more hagfish on average (127.8/trap) and traps with the largest holes (0.56 inch) caught significantly fewer (1.58/trap). Traps with 0.34-inch and 0.45-inch holes caught similar numbers (26.8 and 24.4 hagfish per trap, respectively) and were not significantly different in post hoc comparisons. Significantly more hagfish (mean number per trap) were captured in 24 hours (77.9/trap) than in 4 or 8 hours (20.9 and 32.8/trap, respectively). Only heads remained of the 2 pounds of whole mackerel used for bait for all soak times and escapement hole sizes.

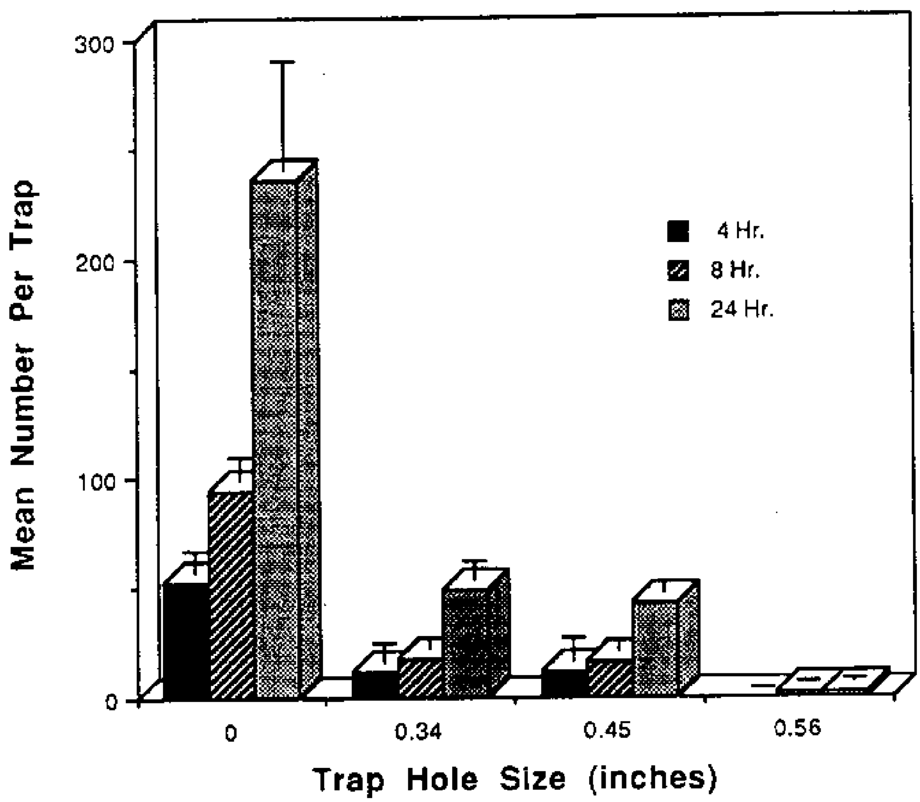

Figure 7. *Mean number of hagfish per trap for each of three trap escapement hole sizes (0.34, 0.45, and 0.56 in.) and for traps with no holes (0) at each of three soak times (4, 8, and 24 hours). Error bars are standard errors. Four bucket traps (n=4) baited with 2 pounds of chopped mackerel were fished for each hole size and soak time at Station 1. Mean number per trap varied significantly with soak time (F=16.473; p=0.000), hole size (F=38.576; p=0.000) and interaction between factors (F=7.625; p=0.000).*

Hagfish size increased as trap hole size and soak time increased (Figure 8). Hagfish caught in traps with 0.56-inch holes were not included in statistical analyses of mean length, because so few fish were caught. Mean lengths for the control (no holes) and each hole size (0.34 and 0.45) were all significantly different (22.1, 26.7, and 31.4 cm, respectively) in post hoc comparisons. Hagfish caught in the 24-hour soak were significantly larger (24.7 cm) than those caught in the 4- and 8-hour soaks (22.7 and 23.0, cm respectively). These results suggest that: 1) escapement does occur in hagfish traps, 2) trap escapement hole size and soak time are potential tools to select for larger fish, and 3) a 24-hour soak and a trap escapement hole size near 0.45 inches are most likely to best select for the greatest number of hagfish 12 inches or larger.

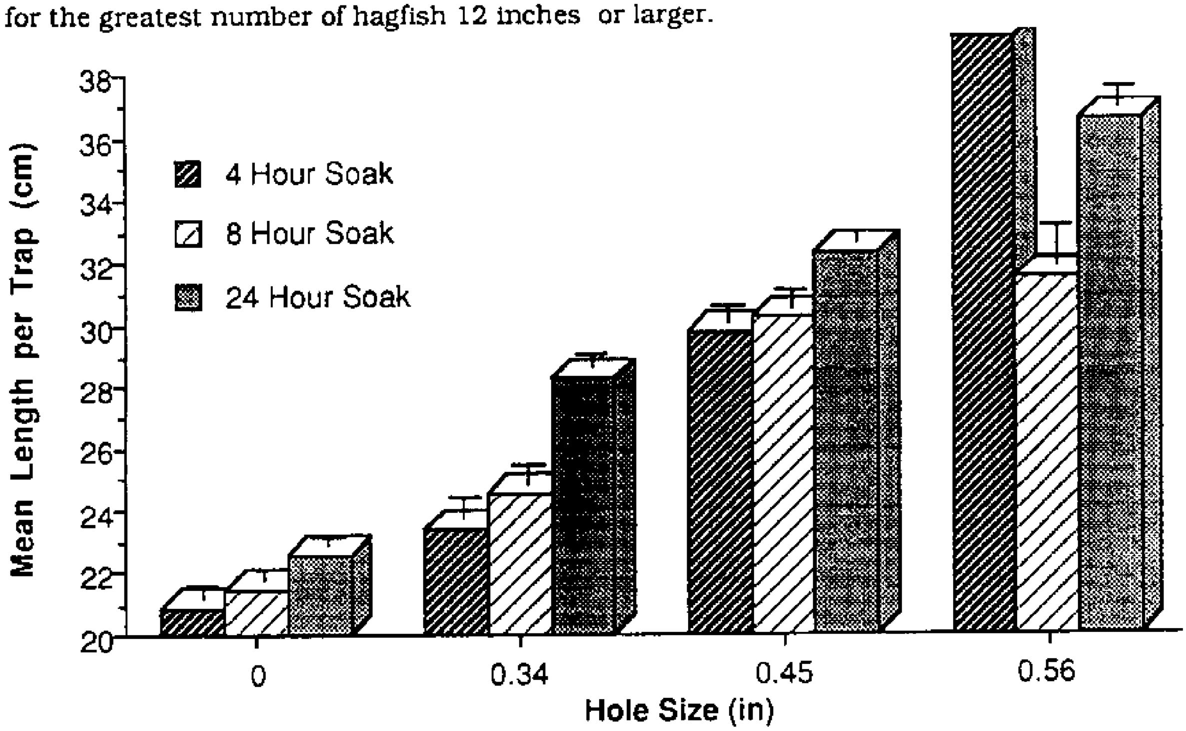

Figure 8. *Hagfish mean length per trap (cm) for each of three trap escapement hole sizes (0.34, 0.45, and 0.56 in.) and for traps with no holes (0) at each of three soak times (4, 8, and 24 hours). Error bars are standard errors. Four bucket traps (n=4) baited with 2 pounds of chopped mackerel were fished for each hole size and soak time at Station 1. Mean length per trap varied significantly with soak time (F=30.185; p=0.000), hole size (F=38.576; p=0.000 (0.56-in. hole size not included)) and interaction between factors (F=3.711; p=0.005).*

In the second experiment, comparing five hole sizes (0.38, 0.42, 0.45, 0.48, and 0.52 inches) at three soak times (4, 8, and 24 hours), the patterns found in the first escapement experiment repeated with minor exceptions. Again mean number per trap and mean length varied significantly with trap escapement hole size, soak time, and the interaction between factors was significant for mean length only (Figures 9 and 10). The mean number of hagfish per trap decreased with increasing trap hole size, and means were all significantly different with the exception of the 0.42- and 0.45- hole sizes. The number of hagfish increased with increasing soak time with one exception; 4-hour soaks caught more hagfish on average (28.8/trap) than the 8-hour soaks (26.5/trap), but this difference was not statistically significant. Twenty-four-hour soaks caught significantly more hagfish on average (57.0/trap) than the shorter soaks. Mean number per trap generally increased with increasing soak time within each hole size, with two exceptions. Traps with 0.38- and 0.48-inch hole sizes caught fewer fish in 8 hours than in 24, and 0.45 hole size traps caught fewer fish in 24 hours than in 8 hours. Only heads remained of the 2 pounds of whole mackerel used for bait for all soak times and escapement hole sizes.

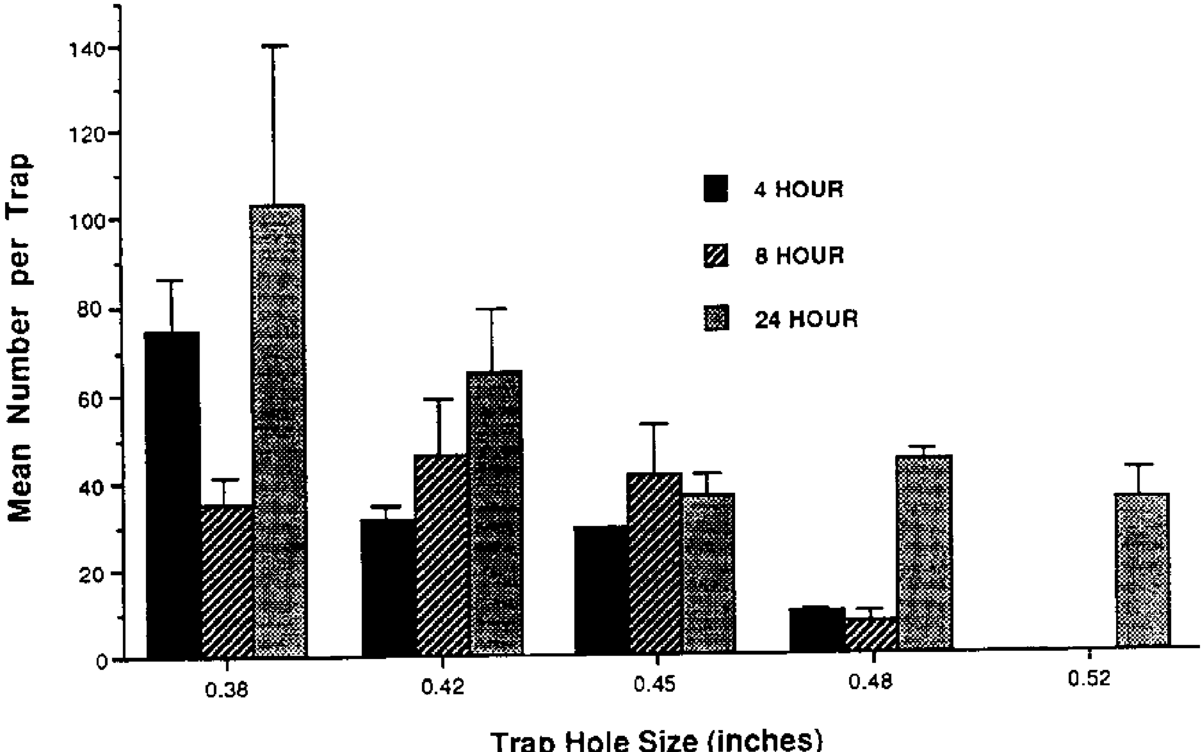

Figure 9. *Mean number of hagfish per trap for each of five trap escapement hole sizes (0.38, 0.42, 0.45, 0.48 and 0.52 in.) at each of three soak times (4, 8, and 24 hours). Error bars are standard errors. Four bucket traps (n=4) baited with 2 pounds of chopped mackerel were fished for each hole size and soak time at Station 1. Mean number per trap varied significantly with soak time (F=10.264; p=0.000), hole size (F=11.705; p=0.000) and interaction between factors (F=1.612; p=0.015).*

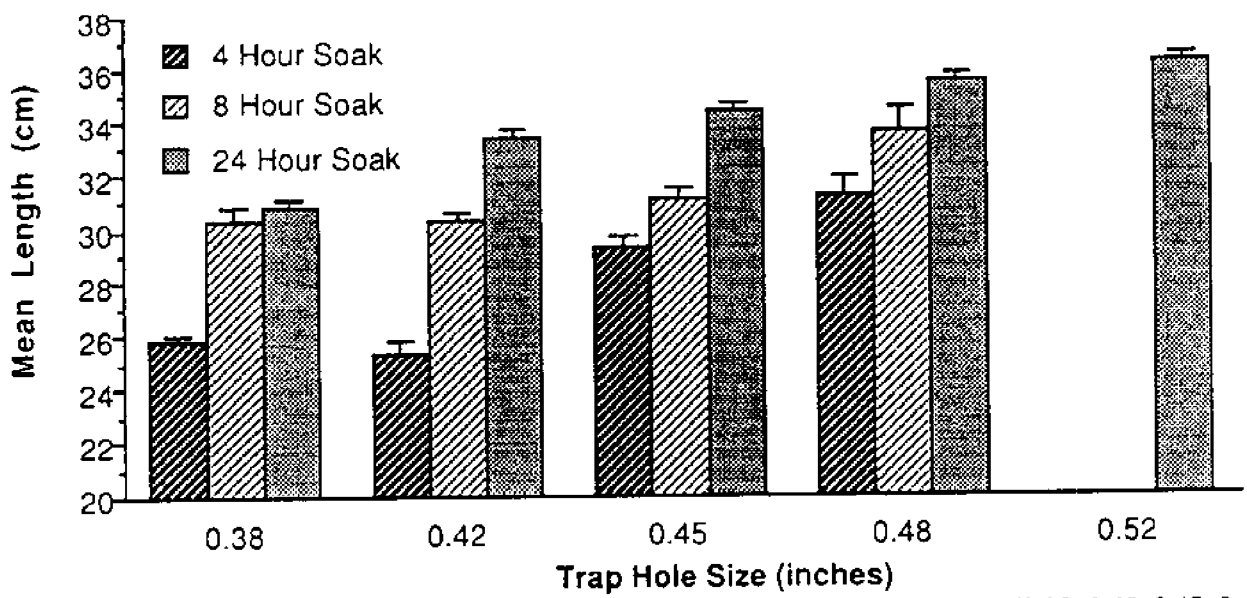

Figure 10. *Hagfish mean length per trap (cm) for each of five trap escapement hole sizes (0.38, 0.42, 0.45, 0.48 and 0.52 in.) at each of three soak times (4, 8, and 24 hours). Error bars are standard errors. Four bucket traps (n=4) baited with 2 pounds of chopped mackerel were fished for each hole size and soak time at Station 1. Mean length per trap varied significantly with soak time (F=167.186; p=0.000), hole size (F=48.010 p=0.000 (0.52-in. hole size not included)) and interaction between factors (F=7.320; p=0.000).*

The pattern of variation in mean length with trap hole size and soak time observed in the first experiment was repeated without exception (Figure 10): hagfish size increased as trap hole size and soak time increased. Hagfish caught in traps with 0.52-inch holes were not included in statistical analyses of mean length, because none were caught in the shorter soaks. Mean lengths for each holes size (0.38, 0.42, 0.45, and 0.48,) were all significantly different (29.0, 30.6, 31.7, and 34.6 cm, respectively) in post-hoc comparisons. Hagfish caught in the 24-hour soak were significantly larger (32.8 cm) than those caught in the 4- and 8- hour soaks (26.8 and 30.7 cm, respectively).

Percent >=12 in. (30.48 cm) follows the same pattern as mean length (Figures 11 and 12). In all cases, traps with the largest trap hole size and fished longest caught the greatest percentage of large hagfish (Figure 11). The percent hagfish >= 12 inches ranged from 11.5% for traps without holes to 81.2% for traps with 0.48-inch holes (Figure 11) and from 14.3% in 4-hour soaks to 71.7% in 24-hour soaks (Figure 12). Based on these results, traps with 0.48-inch holes fished for 24 hours show the greatest potential for selecting hagfish 12 inches in length or over. However, because the 0.42- and 0.45- hole sizes caught significantly more fish, the 0.42-, 0.45-, and 0.48- hole sizes were tested further.

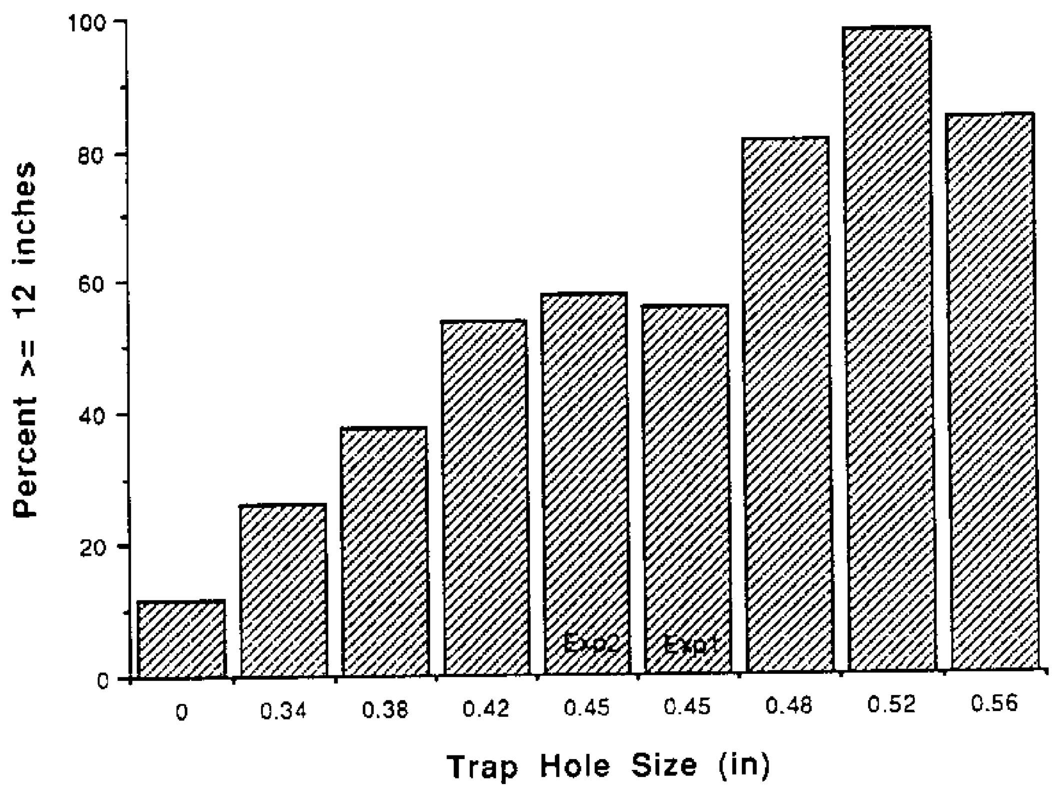

Figure 11. Percent hagfish >= 12 in. (30.48 cm) for all trap escapement hole sizes (in.) tested and for traps with no holes (0) from two experiments comparing length with trap hole size and soak time. Soak time data are pooled for each hole size. Four bucket traps (n=4) baited with 2 pounds of chopped mackerel were fished for each hole size and soak time at Station 1. (See Figures 7 through 10).

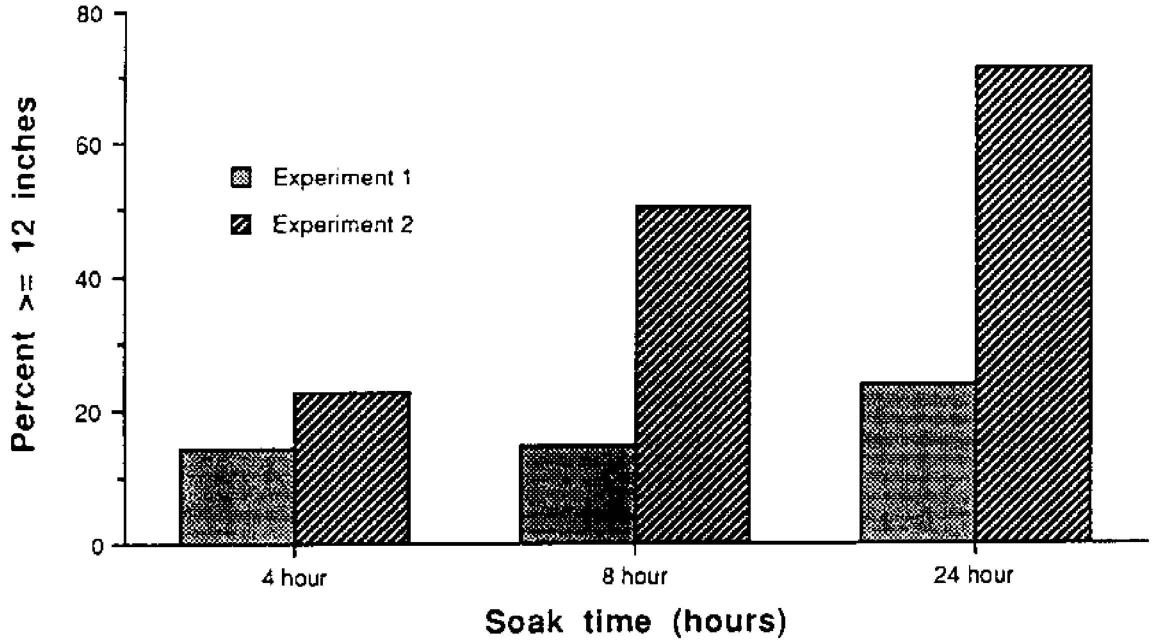

Figure 12. *Percent hagfish >= 12 in. (30.48 cm) for three soak times (hrs) from two experiments comparing trap hole size and soak time. Hole size data are pooled for each soak time for two experiments. Four bucket traps (n=4) baited with 2 pounds of chopped mackerel were fished for each hole size and soak time at Station 1. (See Figures 7 through 10).*

Trap Hole Size and Bait Concentration Comparisons: In a comparison of traps with 0.42-inch and 0.45-inch hole sizes fished for 24 hours, traps with 0.45-inch holes caught more fish per trap (72.0; p=0.387) and significantly larger hagfish (37.1; p=0.001) than traps with 0.42-inch holes (60.4/trap and 35.9 cm; Figures 13 and 14).

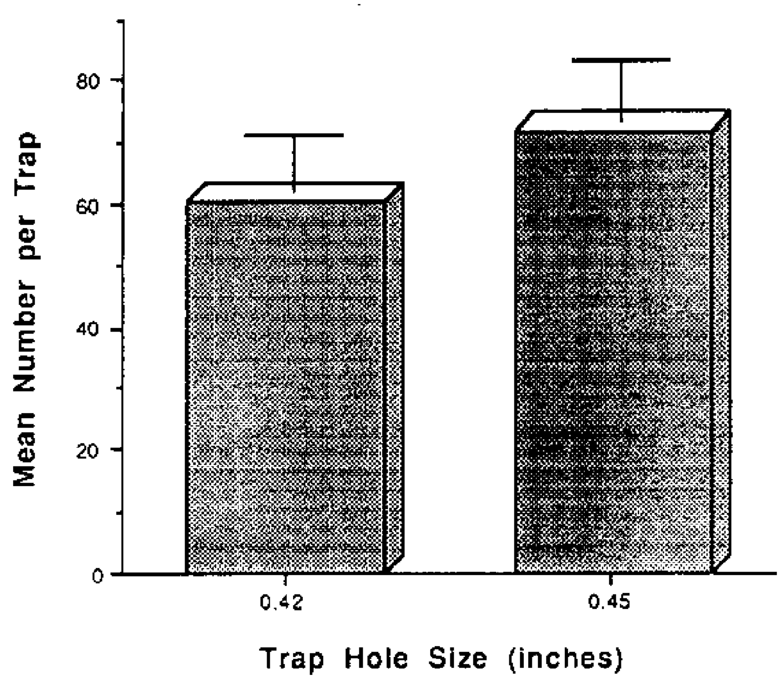

Figure 13. *Mean number of hagfish per trap for traps with two escapement hole sizes (0.42 and 0.45 in.). Error bars are standard errors. Eight bucket traps (n=8) were baited with 2 pounds of chopped mackerel and fished for 24 hours at Station 2. Mean number per trap did not vary significantly with trap escapement hole size (T=0.893; p=0.387).*

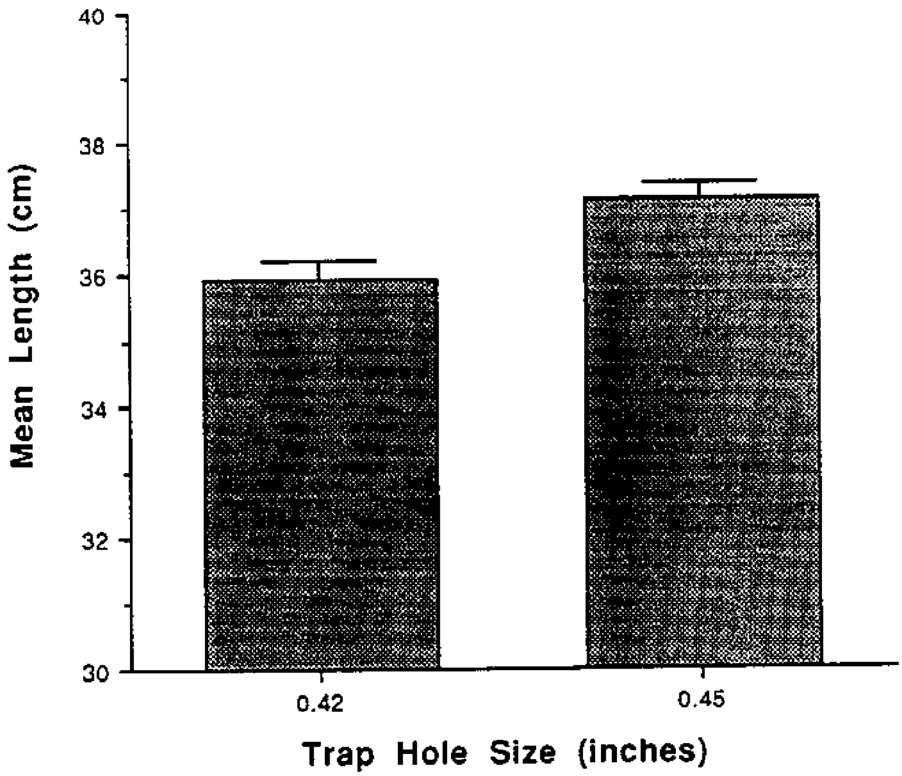

Figure 14. *Mean length of hagfish per trap (cm) for traps with two escapement hole sizes (0.42 and 0.45 in.). Error bars are standard errors. Eight bucket traps (n=8) were baited with 2 pounds of chopped mackerel and fished for 24 hours at Station 2. Hagfish mean length per trap varied significantly with trap escapement hole size (T=3.254; p=0.001).*

In a comparison of traps with 0.45- and 0.48-inch escapement holes and three bait concentrations (1, 2, and 4 pounds of chopped mackerel per trap), mean number per trap varied significantly with bait concentration only (Figure 15). Numbers per trap for the two hole sizes were nearly identical, 72.6 and 72.9 per trap for the 0.45- and 0.48-inch hole sizes, respectively. 4 pounds of mackerel caught significantly more hagfish (110.8/trap) than 1 (65.4/trap) or 2 pounds of mackerel (42.3/trap), and the 1- and 2-pound bait concentrations were not significantly different from each other.

Hagfish mean length varied significantly with trap holes size (p=0.000) only (Figure 16): 38.2 cm versus 36.6 for 0.45- and 0.48-inch holes, respectively. Mean length varied only 0.24 in. (0.6 cm) for the three bait concentrations tested, suggesting that larger concentrations of bait do not retard the escapement of smaller hagfish. The percent of the catch greater than or equal to 12 inches showed the same trend as mean length (Figure 17); they were 88.1 % and 96.5 % for 0.45- and 0.48-inch holes; and 80.6% and 87.7% for the 0.42- and 0.45-inch holes, respectively.

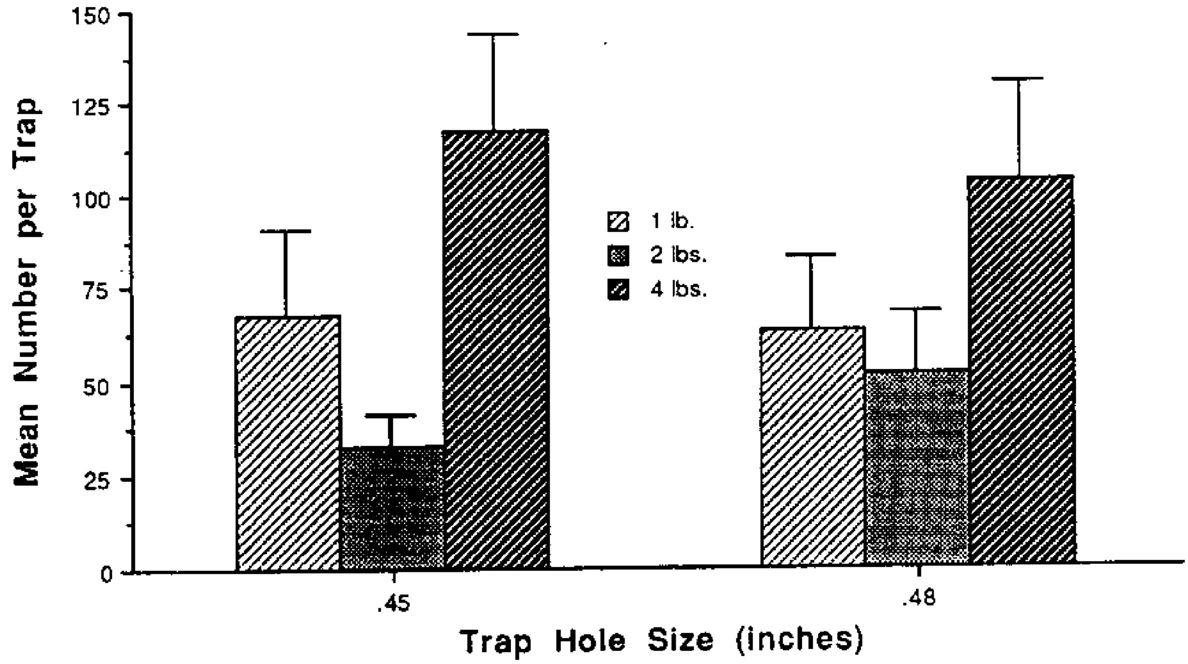

Figure 15. *Mean number of hagfish per trap for each of two trap escapement hole sizes (0.45 and 0.48 in.) at three bait concentrations (1, 2, and 4 pounds of chopped mackerel). Error bars are standard errors. Four bucket traps (n=4) were fished for each trap escapement hole size and each bait concentration for 24 hours at Station 2. Mean number per trap varied significantly with bait concentration only (F=6.37; p=0.008). Hole size (F=0.0002; p=0.988) and factor interaction (F=0.371; p=0.695) were not significant.*

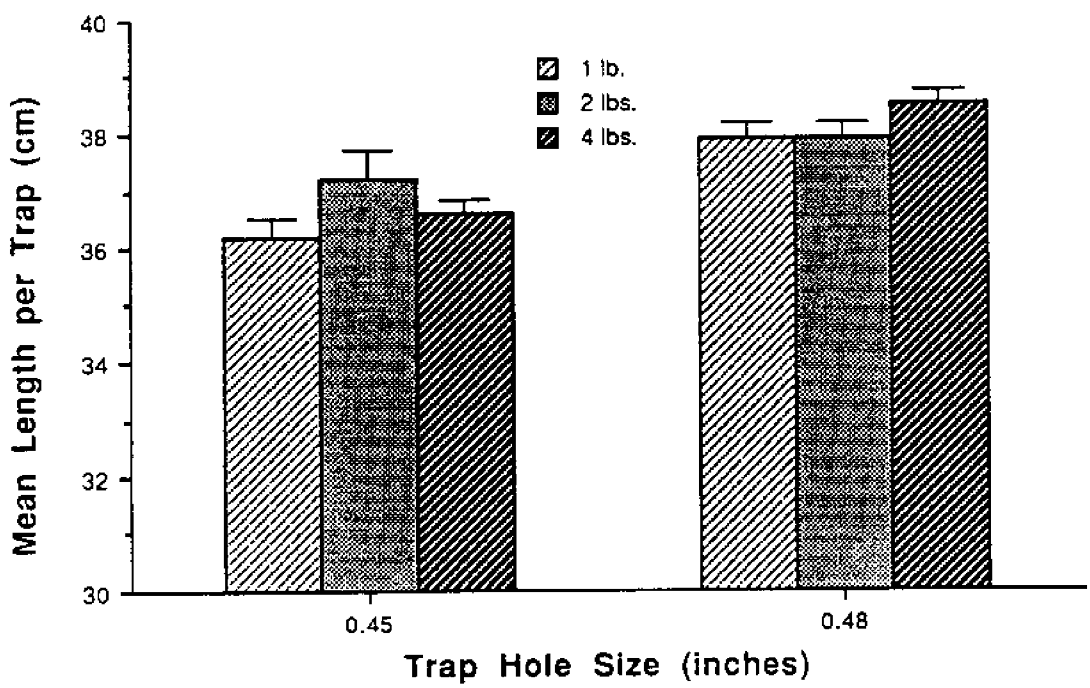

Figure 16. *Mean length of hagfish per trap (cm) for each of two trap escapement hole sizes (0.45 and 0.48 in.) at three bait concentrations (1, 2, and 4 pounds of chopped mackerel). Error bars are standard errors. Four bucket traps (n=4) were fished for each trap escapement hole size and each bait concentration for 24 hours at Station 2. Hagfish mean length per trap varied significantly with trap escapement hole size only(F=33.28; p=0.000). Bait concentration (F=1.95; p=0.143) and factor interaction (F=1.716; p=0.180) were not significant.*

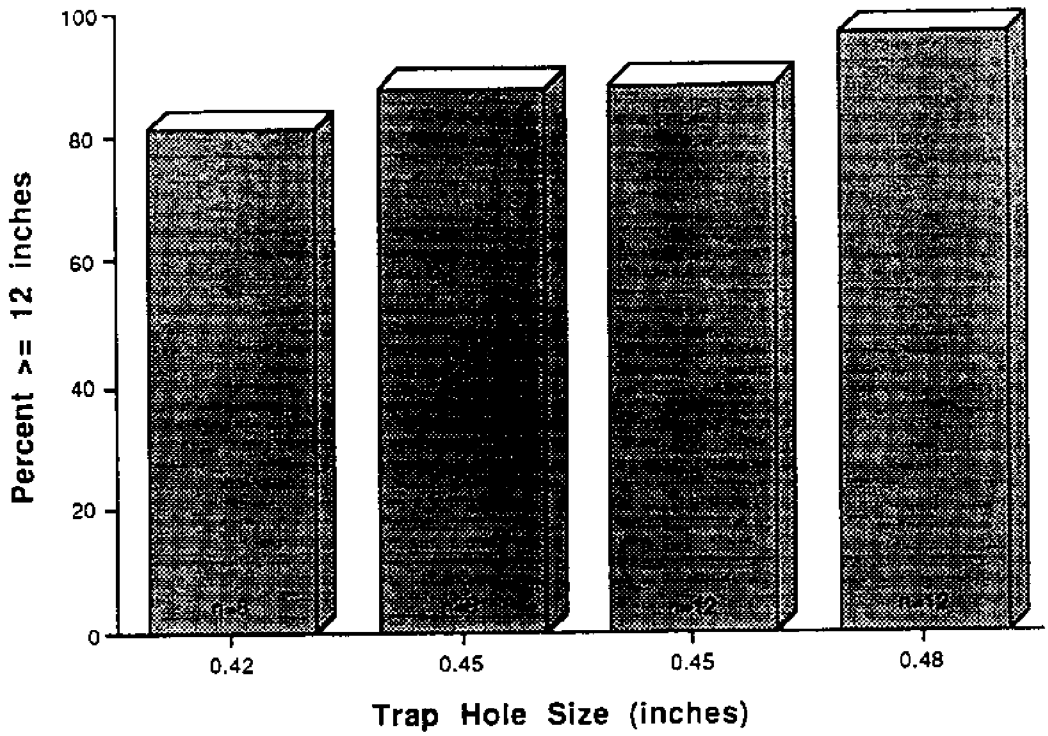

Figure 17. *Percent hagfish >= 12 in. (30.48 cm) for traps with three escapement hole sizes from two experiments. In the first experiment eight bucket traps (n=8) with 0.42-and 0.45-in. escapement holes were baited with 2 pounds of chopped mackerel and fished for 24 hours at Station 2. In the second experiment four bucket traps (n=4) were fished for each of two escapement hole sizes (0.45 and 0.48 in.) and each of three bait concentrations (1, 2, and 4 pounds) for 24 hours at Station 2. Bait concentration data were pooled for each hole size yielding n=12 in the second experiment.*

Given the lack of statistically significant difference in the number and the significant difference in length of hagfish caught using the three hole sizes, we conclude that traps with 0.48-inch escapement holes fished for 24 hours best select for hagfish >= 12 inches in length. Further, we conclude that the optimal bait concentration for 5-gallon traps is near one pound of bait per gallon of trap volume, and that increasing bait concentration does not retard the escapement of smaller hagfish.

Nocturnal Activity and Bait Comparisons: Comparisons designed to test the possibility that more and larger hagfish caught in 24-hour soaks are not an artifact of increased nocturnal behavior in Pacific hagfish, and that hagfish might prefer a specific bait produced the following results. Mean number per trap and mean length did not vary significantly with fishing period (12-hour daytime, 12-hour nighttime, and 24 hours) or bait type (chopped mackerel and rockfish carcasses); and mean length did not vary significantly with fishing period (Figures 18 and 19). Mean length was not tested for bait type. The 12-hour nighttime soak caught the greatest number per trap (66.2/trap), followed by the daytime soak (50.2/trap), and the 24-hour soak (39.8/trap). The 24-hour soak caught the largest fish on average (38.1 cm), and the nighttime soak the smallest (37.7 cm). Traps baited with rockfish carcasses caught on average more hagfish per trap (59.5/trap) than traps baited with mackerel (44.8/trap).

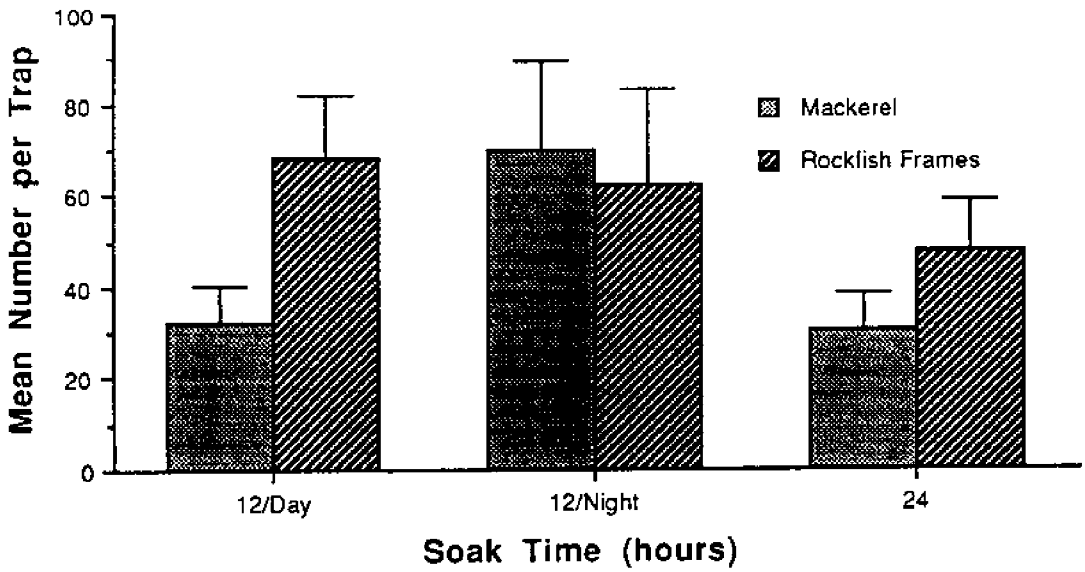

Figure 18. Mean number of hagfish per trap for three fishing periods (daytime/12 hours, nighttime/12 hours, and day and nighttime/24 hours) for each of two bait types (rockfish carcasses and chopped mackerel). Error bars are standard errors. Ten bucket traps (n=10) with a single standard funnel, and 0.48-in. escapement holes on trap ends only (without side holes) were fished with 4 pounds of each bait type for each of the three fishing periods at station 2. Mean number per trap did not vary significantly with fishing period (F=1.670; p=0.198) or bait type (F=1.586; p=0.213).

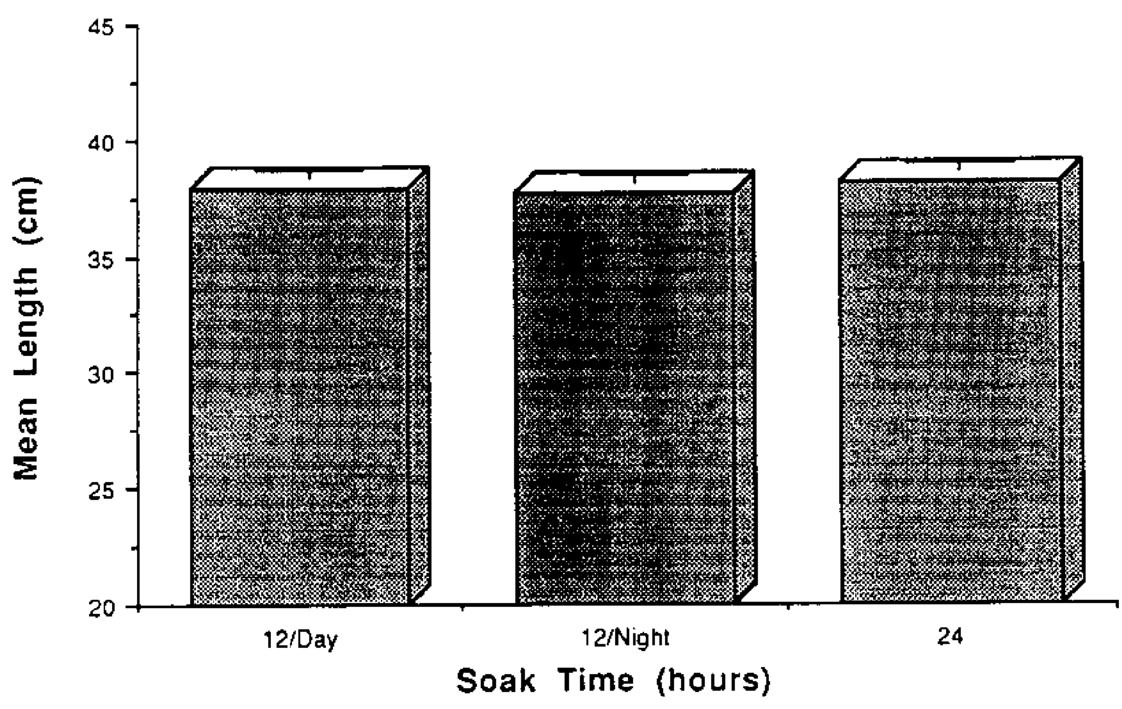

Figure 19. Hagfish mean length (cm) for each of three fishing periods (daytime/12 hours, nighttime/12 hours, and day and nighttime/24 hours). Error bars are standard errors. Twenty bucket traps (n=20) with a single standard funnel, and 0.48-in. escapement holes on trap ends only (without side holes), were fished with 4 pounds of rockfish carcasses or chopped mackerel for each of three fishing periods at station 2. Hagfish mean length per trap did not vary significantly with fishing period (F=1.525; p=0.592).

Although the nighttime soak caught more hagfish on average, we can not conclude that Pacific hagfish demonstrate increased nocturnal activity or catchability from this experiment. The tremendous variation observed in catch both within a specific fishing period and among the three soak intervals, and the resulting lack of statistical significance, preclude confirmation of the trends observed. For example, mean number per trap ranged from 4 to 165, 5 to 228, and 9 to 126 hagfish for the 12-hour daytime, 12-hour nighttime and 24-hour soaks, respectively. We had hoped to avoid this degree of variation by using a 20 trap sample size, more than double the sample size used in our earlier experiments. Unfortunately, a sample size of this magnitude did not compensate for the wide variation encountered.

Although hagfish caught in the 24-hour soak were slightly larger, there is no evidence to suggest that increased size specific escapement occurred in the longer soak given that mean length varied only 0.47 cm (0.2 inches) among the three soak intervals and the lack of statistically significant differences. Earlier experiments comparing 4- and 8-hour soaks with 24-hour soaks repeatedly demonstrated that hagfish caught in the longer soak were significantly larger. We speculated that longer soaks yielded larger fish because smaller fish have more time to escape through trap escapement holes. Apparently a 12-hour soak allows for escapement of smaller individuals with a similar efficiency as 24 hours.

The motive for comparing daytime and nighttime catch rates was to determine whether the increased catch rates repeatedly observed in 24-hour soaks relative to 4- and 8-hour daytime soaks were a function of the longer fishing interval or of increased nocturnal activity. This could not be determined, given that both daytime and nighttime 12-hour soaks produced more hagfish on average than the 24-hour soak, the lack of statistically significant differences, and the tremendous variation in catch among traps within the same soak interval. Further, it appears that 12-hour soaks produce at least as many hagfish of a similar size as 24-hour soaks. Production fishing might produce more definitive answers regarding possible advantages of nighttime fishing verses daytime fishing.

Definite conclusions on bait type are difficult for similar reasons. Once again, the use of a large sample size (30 traps) did not compensate for wide variation in catch among traps. Although rockfish carcasses caught more fish on average, this result was not significant, and was reversed in the nighttime soak. At best, rockfish carcasses might catch more hagfish than mackerel, and at worst, mackerel and rockfish catch similar amounts. Given this ambiguity, the best bait is probably the one that is least expensive and most available in a given port.

Ghost Fishing: In the first of two experiments where two bucket traps were baited with each of three concentrations (1, 2, and 4 pounds) of chopped hagfish, no live hagfish, but approximately 30 red octopus, *Octopus rubescens*, and two eel pouts were captured. In the second experiment, four modified bucket traps (two entrance funnels and 0.48-inch escapement holes in the lid and bottom only) caught a single live hagfish and four red octopus. We speculate from these two experiments that lost hagfish traps do not appear to continually catch more hagfish; however, to conclusively address the ghost fishing question, extended experiments should be conducted in which traps are fished and monitored for weeks as opposed to 24 hours. A degradable escapement mechanism is advisable on hagfish traps to protect other species (red octopus and possibly eel pouts).

Depth Comparisons: Mean number per trap and mean length varied significantly among traps fished at five depths, 50, 112, 175, 238, 300 fathoms (100, 225, 350, 475, 600 meters), but showed no consistent trends in either variable (Table 2). Significantly more hagfish were captured at the 475-meter depth (43/trap), and hagfish caught at the 100-meter (37.1 cm) and the 475-meter (36.5 cm) depths were significantly larger than hagfish captured at other depths. No meaningful conclusion can be drawn from this experiment. The 100-meter depth location (station one) yielded comparatively few hagfish (9.0/trap) in this experiment compared to experiments one month earlier (44/trap), suggesting a local depletion of hagfish. The lack of patterns in the catch suggests that some areas were depleted of hagfish, or considerably greater sample sizes are needed for meaningful comparisons with depth.

Table 2. *Total number caught, mean number per trap, and mean length per trap of hagfish caught using bucket traps (n=5) with 2 pounds of bait fished for 24 hours at five depths (m)*

DEPTH (m)	NUMBER	MEAN NUMBER PER TRAP	S.E.	MEAN LENGTH (cm)	S.E.
100	45	9.0[a]	1.703	37.06[a]	0.742
225	22	4.2[a]	1.655	32.76[b]	1.779
350	130	25.8[a]	7.426	34.47[b]	0.474
475	215	43.0[b]	10.104	36.52[a]	0.266
600	27	5.4[a]	3.906	33.48[b]	0.784
TOTAL	439	17.48	3.902	35.59	0.236

'a' and 'b' indicate significant differences in post hoc comparisons.

One way ANOVA comparing the number of hagfish caught per trap over five depths was significant ($F=7.822$; $p=0.001$). One way ANOVA comparing length over five depths was significant ($F=8.025$; $p=0.000$).

2. Trap Design Comparisons

ROV Observations: ROV observations of hagfish in the presence of transparent baited traps provided a variety of insights on hagfish trap design. Hagfish tended to demonstrate great difficulty in finding the single entrance funnel and attempted without success to enter the trap through the escapement holes, especially those close to the bait. Also, once they found the funnel, they had difficulty entering the trap through it, and would either partially enter and begin to feed on the bait, or become confused and linger in the funnel sensing the bait through the perforations in the funnel. Both of these behaviors blocked the funnel entrance and precluded the capture of other hagfish. Observations on the interactions of hagfish within the trap were limited because few fish were in the area and the two clear traps were damaged by the ROV in the course of our observations. Most hagfish that did enter the trap ceased feeding within one to two minutes and began a search pattern to escape the trap.

We extracted highlights from the several hours of tape and made a brief video that can be shared with interested parties. It appears likely that a more efficient trap could be designed by increasing the number of entrance funnels, restricting escapement holes to the area surrounding the entrance funnels, shortening the entrance funnels, and constructing the funnels from a solid rather than a perforated material.

Trap Design Comparisons: In initial comparisons of two modifications to the 5-gallon bucket trap (one versus two funnels and with and without side escapement holes), mean number per trap did not vary significantly with the number of entrance funnels or for traps with and without side holes. Mean length varied significantly with the presence or absence of side holes only (p=0.002; Table 3). Traps without side holes caught more hagfish (104.63/trap) and significantly larger hagfish (38.8 cm) than traps with escapement holes throughout (74.9/trap; 37.9 cm). Traps with two funnels caught more (92.5/trap) and larger hagfish (38.6 cm) than traps with a single funnel (88.7/ trap; 38.2 cm). Comparing individual trap designs, traps with two funnels and no side holes caught the most hagfish per trap (106.8/trap) and the largest hagfish (39.0 cm), and traps with one funnel and with holes throughout the trap caught the fewest (70.3/trap) and the smallest hagfish (37.7 cm). Although the mean number caught per trap was not significant for either trap design feature, it appears from this experiment that traps with two funnels and no side holes catch more and larger fish than the other designs tested.

Table 3. *Mean number per trap and standard error (S.E.), mean length per trap and S.E., and total number caught for each of four trap designs.*

FUNNEL NUMBER	SIDE HOLES	MEAN NUMBER PER TRAP	S.E.	MEAN LENGTH (cm)	S.E. (cm)	TOTAL NUMBER
1	YES	70.3	10.525	37.7	0.324	200
1	NO	102.5	10.251	38.7	0.292	199
2	YES	78.3	26.449	38.1	0.282	197
2	NO	106.8	37.442	39.0	0.298	202
ONE FUNNEL		88.7	9.341	38.2	0.219	
TWO FUNNELS		92.5	21.886	38.6	0.206	
W/SIDE HOLES		74.9	14.774	37.9[a]	0.215	
W/OUT SIDE HOLES		104.6	17.979	38.8[b]	0.209	
TOTAL		**90.7**	**12.067**	**38.4**	**0.151**	**798**

Trap design features include 1 or 2 entrance funnels, and the presence (yes) or absence (no) of side holes.

"a" iand "b" indicate statistically significant difference in post hoc comparisons of means.

Two way ANOVA comparing the mean number of hagfish caught in traps with one or two funnels and with or without side holes was not significant for any variable. Two way ANOVA comparing mean length of hagfish caught in traps with one or two funnels and with or without side holes was significant for side holes only (F=9.387; p=0.002).

In a second comparison of traps with one versus two funnels and with and without side holes, but using double the sample size, traps without side holes again caught more hagfish per trap (117.5/trap) than traps with holes throughout (96.3/trap; Table 4); however, this result was not statistically significant. In contrast to the first experiment, traps with one funnel caught significantly more hagfish per trap (143.7/trap) than traps with two funnels (71.8/trap). Traps with one funnel and no side holes caught the most hagfish (155.3/trap), and traps with two funnels and holes throughout caught the least (59.1/ trap).

Table 4. *Mean number per trap and standard error (S.E.) of hagfish caught in each of four trap designs.*

FUNNEL NUMBER	SIDE HOLES	MEAN NUMBER PER TRAP	S.E.
1	YES	133.5	12.904
1	NO	155.3	17.264
2	YES	59.1	15.028
2	NO	84.4	21.661
ONE FUNNEL		143.7[a]	10.604
TWO FUNNELS		71.8[b]	13.145
W/SIDE HOLES		96.3	13.555
W/OUT SIDE HOLES		117.5	16.557
TOTAL		**106.6**	**16.557**

Trap design features include 1 or 2 entrance funnels and the presence (yes) or absence (no) of side holes. Eight bucket traps (n=8) with four pounds of bait were fished for 24 hours at station 2 for each trap design.

"a" and "b" indicate significantly different means in post-hoc comparisons.

Two-way ANOVA comparing mean number caught per trap in traps with one or two funnels and with or without side holes was significant for funnels number only (F=18.1114; P=0.0002).

Several additional statistical tests were completed in an attempt to explain why two funnel traps caught more hagfish than the single funnel traps in the first experiment and fewer in the second. Tests of variation in catch per trap among the four groundlines used in the second experiment were not statistically significant, suggesting that variable catch among groundlines was an unlikely explanation for observed differences. In the second experiment, we were forced to work approximately one nautical mile from the station used in the first experiment. A comparison of the mean number caught per trap between the first experiment (90.7) and the second experiment (106.5) was also not significant (T=0.905; p=0.370), suggesting that variation between grounds is an unlikely explanation for observed differences. However, inspection of several entrance funnels revealed that when traps were stacked or nested after completion of the first experiment, funnels in the bottom of the two funnel traps were damaged in such a way that the tapered plastic fingers of the funnel were bent, allowing hagfish to escape through the entrance funnels. It is very likely, therefore, that the observed differences in catch from traps with one and two funnels in the first and second experiment were due to funnel damage to the double funnel traps used in the second experiment.

In a repetition of the second experiment using new entrance funnels and an increased sample size, the mean number per trap varied significantly with funnel number (p=0.008), but not with the presence or absence of side holes in the trap (Table 5 and Figure 20). Mean length varied significantly with funnel number (p=0.0000) and the presence or absence of side holes (p=0.0197; Figure 21). Traps with two funnels caught significantly more hagfish per trap (53.9/trap) and significantly larger hagfish (38.4 cm) than traps with single funnels (20.52/trap; 35.1 cm). Traps without side escapement holes caught more hagfish per trap (39.5/trap) and significantly larger hagfish (37.1 cm) than traps with side escapement holes (34.7/trap; 36.4 cm). Considering individual trap designs, traps with two funnels and no side escapement holes caught more and larger hagfish than all other trap designs tested (55.6/trap; 38.6 cm); percent >=12 inches and >=14 inches was 69.3% and 38.6%, respectively (Figure 22). Traps with one funnel and side escapement holes caught the least and smallest hagfish (17.4/trap; 34.4 cm) percent>=12 inches and >=14 inches was 91.3% and 74.9% respectively (Figure 22). These results are consistent with our initial experiment.

Table 5. *Mean number per trap and standard error (S.E.), total number caught, and mean length per trap (cm) and S.E. for hagfish caught in four trap designs.*

FUNNEL NUMBER	SIDE HOLES	n	MEAN NUMBER PER TRAP	S.E.	TOTAL NUMBER	MEAN LENGTH (cm)	S.E.(cm)
1	YES	11	17.36	4.39	189	34.35	0.41
1	NO	12	23.42	5.39	221	35.80	0.39
2	YES	11	52.00	9.69	213	38.24	0.35
2	NO	12	55.58	13.80	207	38.56	0.37
ONE FUNNEL		23	20.52[a]	3.49		35.13[a]	0.28
TWO FUNNELS		23	53.87[b]	8.38		38.40[b]	0.25
W/ SIDE HOLES		22	34.68	6.42		36.41[c]	0.28
WO/ SIDE HOLES		24	39.50	7.98		37.14[d]	0.28
TOTAL		46	37.20	5.13	830	36.79	0.20

Trap design features include 1 or 2 entrance funnels and the presence (yes) or absence (no) of side holes in the trap. Bucket trap (n) with standard funnels, 4 pounds of bait, and 0.48 in escapement holes were fished for 24 hours at station 2 for each trap design.

a b c d indicate significant differences among means in post hoc comparisons.

Two way ANOVA on the mean number of hagfish in traps with one or two funnels and with or without side holes was significant for funnel number only (F=12.981; p=0.0008). Two way ANOVA on mean length of hagfish caught in traps with one or two funnels and with or without side holes was significant for funnel number (F=76.473; p=0.0000) and for side holes (F=5.456; p=0.0197).

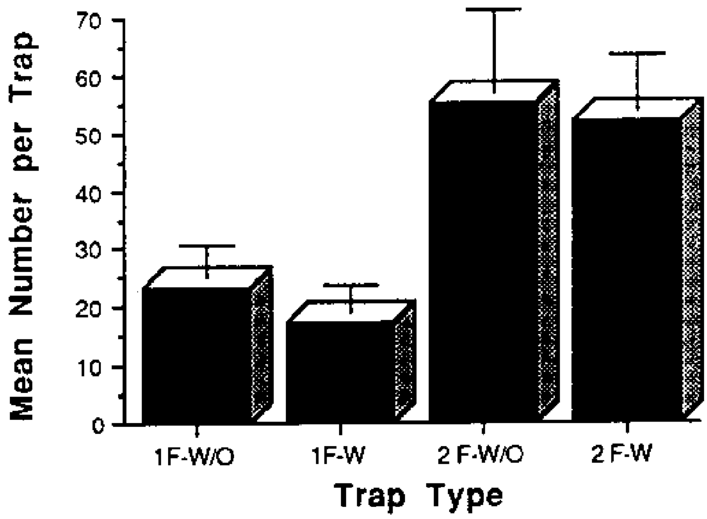

Figure 20. *Mean number of hagfish per trap for each of four trap designs (one funnel/no side holes, one funnel/with side holes, two funnels/no side holes, and two funnels/with side holes). Error bars are standard errors. Twelve bucket traps (n=12) with standard funnels, 0.48-in. escapement holes, and 4 pounds of chopped mackerel were fished for each trap design for 24 hours at Station 2. Mean number per trap varied significantly with funnel number only (F=12.981; p=0.001).*

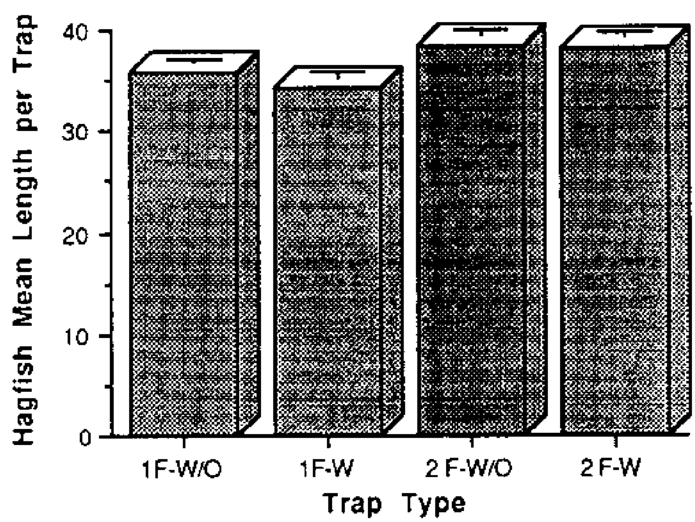

Figure 21. *Mean length (cm) of hagfish for each of four trap designs (one funnel/no side holes, one funnel/with side holes, two funnels/no side holes, and two funnels/with side holes). Error bars are standard errors. Twelve bucket traps (n=12) with standard funnels, 0.48-in. escapement holes, and 4 pounds of chopped mackerel were fished for each trap design for 24 hours at Station 2. Hagfish mean length varied significantly with funnel number (F=76.473; p=0.000) and presence or absence of side holes (F=5.456; p=0.020).*

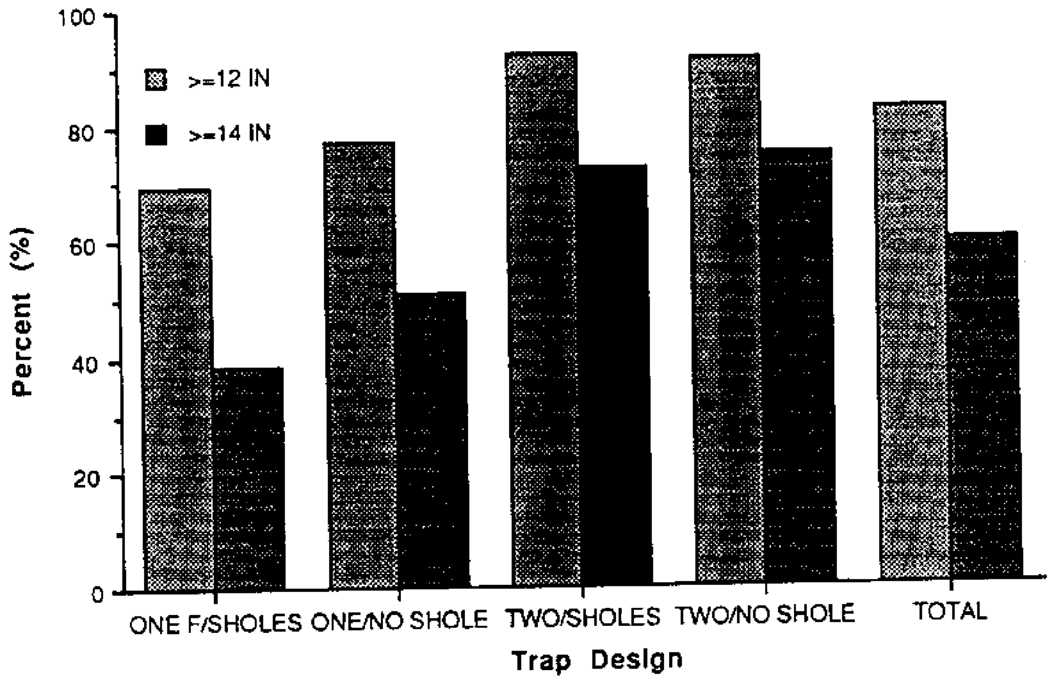

Figure 22. *Percent hagfish >=12 inches and >=14 inches for four trap designs (one funnel/no side holes, one funnel/with side holes, two funnels/no side holes, and two funnels/with side holes) and for totals (all data pooled). Twelve bucket traps (n=12) with standard funnels, 0.48 inch escapement holes, and four pounds of chopped mackerel were fished for each trap design for 24 hours at Station 2.*

We conclude from these three experiments that traps with double funnels and without side holes are the best trap design, because they catch more and larger fish. Compared to the single funnel traps with side escapement holes (typically used in the California fishery), double funnel traps without side holes could produce up to two times more fish/trap averaging 15 inches in length with over 90% >=12 inches, or 1.5 inches larger than those collected with the conventional trap (69.3% >=12 inches). We speculate that two funnels provide enhanced access to the trap producing greater catch success and enhanced access for larger animals. Escapement holes restricted to the area around the funnels focus hagfish behavior to the funnel area and reduce futile efforts by larger hagfish to enter the trap through escapement holes. Further, it is likely that smaller hagfish enter the trap through escapement holes; therefore, fewer holes may limit access of smaller fish to the trap.

Emerging information on the biology of Pacific hagfish has direct application to the findings of this study. Cailliet (1991) and Johnson (1992) working in Monterey Bay, California, report that the size at which 50% of Pacific hagfish become mature is 14.6 inches (+/- 1.2) for females and 14.4 inches (+/- 1.5) for males. Also, they found that the average number of eggs produced per female is 14.5 eggs (+/- 5.4) and that the ratio of females to males is 1.75:1 on average with the ratio nearing parity as fish become larger. These observations confirm that the continued capture of small non-reproductive hagfish could seriously threaten the long term sustainability of the West Coast hagfish fishery.

In this study we demonstrated that the size and placement of trap escapement holes, the number of entrance funnels, and longer soak times, can be manipulated to selectively capture hagfish 12 inches or larger with an efficiency of over 90% and 14 inches or larger with an efficiency of approximately 75% (Figure 22). Given that the size at which Pacific become sexually mature is greater than the minimum required by the industry (14.5 versus 12 inches), it may be necessary to increase the minimum size targeted by the commercial fishery to ensure the long term sustainability of the hagfish resource. Based on the results of this study, trap escapement hole size could be increased to select for animals of a specific minimum size to protect non-reproductive hagfish. This gear modification in conjunction with longer soak times, placement of escapement holes, and more entrance funnels, provide the seafood industry and resource managers with tools to manage the hagfish resource for long term sustainability.

3. SKIN QUALITY

Fishing-Related Skin Quality: Few bite marks or dorsal holes were found in hagfish from any of the treatments, making comparisons of skin quality among various trap sizes and soak times difficult. The two treatments most likely to show defects, 24-hour soak time and Korean traps, were quantified (Table 6). Of the 162 hagfish caught in the 24-hour soak, 46% had no dorsal holes or bites, 94% had 2 dorsal holes or less, and 88% had 2 bites or less. In a sub-sample (21) of the hagfish caught using Korean traps, 29% had no holes or bites, 71% had two dorsal holes or less, and 95% had two bites or less. Most hagfish from all the comparisons had one or no bites and one or no dorsal holes. Given the lack of skin damage, we questioned our ability to evaluate skin quality without technical input from tannery technicians, and the remainder of the skins were dried and labeled for possible later evaluation. The dried skins were shown to the plant manger from Oh Yang International, South Bend, Washington. We were informed that they could not evaluate the dried skins and that skin quality evaluations can be done only on fresh skins.

Table 6. Skin quality of Pacific hagfish captured in 5-gallon bucket traps fished for 24 hours and Korean traps fished for 5.5 hours.

TRAP/ SOAK TIME	PERCENT		
	No Bites or Holes	<= 2 Dorsal Holes	<= 2 Bites
BUCKET TRAP/ 24 HOURS	46	94	88
KOREAN TRAPS/ 5.5 HOURS	29	71	95

Comparing pre- and post-skinning observations, we determined that it is not necessary to skin the fish to fully estimate the extent of bite mark damage. In the course of working up all 830 samples over a 3-day period, we found that hagfish begin to deteriorate rapidly at room temperature. Fish left unrefrigerated for several hours were more difficult to skin, and dorsal holes 0.02 to 0.16 in (0.5 to 4 mm) in size became more common. To what extent this phenomenon was related to the freezing and thawing of samples could not be determined. We suspect that dorsal holes are a product of poor temperature control and that hagfish are a highly perishable product requiring careful handling.

On-board Treatments: The first trial compared the skin quality of hagfish held in six treatments (seawater (SW) and ice, 120 ppm MS_{222}/SW solution , 120 ppm MS_{222}/SW solution and ice, freshwater (FW), 500 ppm bleach, and bubbled CO2) to a control of SW only (Table 7). Differences in skin quality could not be detected between the SW control, the SW/ice, and MS_{222}-SW/ice treatments. In this first trial, skin quality was not evaluated for hagfish held in the MS_{222}/SW solution (without ice). Mean number of bites varied from 0.3 to 1.7 bites per animal (Table 7); the larger mean is a result of eight bites on a single animal. Dorsal holes were equally rare, and in almost all cases were less than 0.02 inch(0.5 mm) in diameter. Hagfish held in these three treatments were inactive or moving very slowly within five minutes of being introduced to the solution. Hagfish held in the seawater control remained active throughout the period of observation. To our surprise hagfish held in MS_{222} without ice resumed movement within 20 minutes while remaining in the treatment, whereas hagfish held in the MS_{222}/SW/ice, and SW/ice treatments, remained inactive throughout the 2-hour period of observation.

Hagfish held in CO2, bleach, FW and FW/SW treatments were highly agitated. The mean number of bites for hagfish held in CO2 and freshwater were more than all other treatments (6.4 and 3.5, respectively; Table 7). Hagfish held in bleach had few bites (1.4), but skin damage was extensive in all cases. This was probably the result of prolonged exposure to the bleach solution (48 hours). Based on observations of hagfish behavior and skin quality data, FW, FW/SW, and CO2 were eliminated as possible treatments.

TABLE 7. *Skin quality of Pacific hagfish held live in six on-board handling treatments (n=10).*

January 11, 1991	SKIN QUALITY VARIABLES		
TREATMENT	Mean No. of Bites	Mean No. of Holes <= 0.5 mm	Mean No. of Holes >= 0.5 mm
Seawater	0.3	4.9	0.3
Freshwater	3.5	1.6	0.6
Seawater/ice	0.3	1.2	0.3
MS$_{222}$/ice	1.7	2.7	2.7
Bleach (500 ppm)	1.4	Extensive	Extensive
CO_2	6.4	3.8	2.2

In the second trial comparing four treatments (SW/ice, 120 ppm MS$_{222}$/SW, 120 ppm MS$_{222}$/SW/ice, and 500 ppm bleach for two hours) again no differences in skin quality were found among the four treatments or between the treatments and the SW control. The mean number of bites per animal varied from 0.5 to 1.8 (Table 8); higher means were due to more bites on one or two animals in a sample. The number of dorsal holes smaller than 0.02 inch (0.5 mm) varied from 0.1 to 0.9 per animal and the number of dorsal holes greater than 0.02 in. varied from 0 to 0.1. The 500 ppm bleach treatment was repeated, but in this trial the bleach solution was replaced with seawater after 2 hours and all the fish were completely rinsed with seawater. The skin quality of bleach held animals was similar to that of the other treatments. We speculate that although the hagfish are highly agitated in bleach, they cannot effectively bite and damage the skins of other animals.

Table 8. *Skin quality of Pacific hagfish held live in five on-board handling treatments (n=10).*

January 16, 1991	SKIN QUALITY VARIABLES		
TREATMENT	Mean No. of Bites	Mean No. of Holes <= 0.5 mm	Mean No. of Holes >= 0.5 mm
Seawater	1.5	0.3	0
Seawater/ice	1.6	0.2	0
MS$_{222}$	0.8	0.4	0
MS$_{222}$/ice	1.8	0.5	0
Bleach (500 ppm)	0.5	0.9	0.1

Hagfish held in all three concentrations of MS$_{222}$ (120, 240 and 360 ppm) were rendered inactive within 3 to 5 minutes; however, hagfish in the 120 and 240 ppm concentrations became active again within 30 minutes of exposure. Hagfish in the 360 ppm concentration showed limited movement within 45 minutes of exposure. In these observations, opaque plastic garbage bags covered the treatments to eliminate light to address the possibility that sunlight might be breaking down the MS_{222}, rendering it ineffective. We cannot explain why hagfish become active after initially being immobilized by the anesthetic.

These results lead us to conclude that the seawater and ice treatment is probably the most desirable for delivering high quality hagfish for all possible markets for the following reasons: 1) It produces a product of similar quality to other treatments including MS_{222}. 2) It renders hagfish inactive on the vessel. 3) It minimizes enzymatic or bacterial decomposition that might occur. 4) It produces a product suitable for human consumption as well as skins. 5) Ice is inexpensive, generally available, and safe to use.

From these results it appears that MS_{222} offers little or no advantage for producing high quality hagfish relative to a seawater and ice mixture. MS_{222} is expensive, possibly dangerous to use, immobilizes hagfish only briefly, and renders the product unsuitable for human consumption. Holding hagfish briefly in seawater alone at low densities may be an acceptable method for delivering high quality skins where the fishing grounds are close to shore. In our experiments, hagfish were held on board the vessel for no more than 2 hours before they were refrigerated or frozen. It is highly unlikely that product for human consumption could be handled without ice for any length of time, since this commodity is highly perishable.

In all our work, we did not see the extensive dorsal hole skin damage reported by industry buyers. It is possible that by handling relatively small quantities of fish and holding fish on board for less than 2 hours under highly controlled conditions, we precluded the extent of damage experienced under commercial production conditions. Recognizing this possible shortcoming, we made several attempts to compare on-board handling techniques under production conditions and to evaluate the quality of the skins with trained tannery technicians. Arrangements were made with Oh Yang International to tan large lots of hagfish skins that were produced under commercial conditions and held in various experimental treatments, but cooperating hagfish harvesters were unavailable within the time frame of the grant. The seawater/ice mixture should be compared to MS_{222} and ice under production conditions before it is recommended to the industry.

The density at which hagfish are held at sea and the amount of seawater used are likely factors influencing the extent of bite damage to hagfish skins. These factors should also be tested under production conditions. The quantities necessary to test density factors were beyond the capability of the R/V *Ed Ricketts*, and would produce unacceptable levels of waste in a research setting. In addition, we consistently observed that hagfish are least agitated when submerged in seawater, and that quick transfers from the trap to a holding container are very important for minimizing stress to these animals.

4. Industry Liaison

Several meetings were held with representatives of Oh Yang International, Raymond, Washington, to discuss aspects of the hagfish fishery including skin quality. Oh Yang is reported to be the largest single hagfish tanning firm in Asia, and began tanning hagfish at their facility in Raymond, Washington, in June of 1991. From discussions with Yang Cho, president of Oh Yang, and a visit to the tannery, we determined that two factors appear responsible for poor skin quality: temperature control or freshness, and storage densities on the vessel. These discussions made it clear that dorsal holes greater than 0.5 mm (tears) and bites limit the value of the skins. Tiny pin holes, mostly smaller than 0.5 mm, are few and generally not limiting. Tears seem to be the result of temperature abuse and are in some cases caused by bites. Based on the results of this research and these discussions, it appears that if the product is kept cold and densities in 55-gallon barrels are kept at approximately 100-150 pounds per barrel, skin quality can be improved and anesthetics can be eliminated. Further work at a production level should resolve these issues and open the door to a profitable fishery.

The extent of demand by tanners for Pacific hagfish is an important consideration for the future development of this fishery. Tanners in Korea anticipate obtaining approximately 10 million skins or 2 to 3 million pounds of Pacific hagfish per year to satisfy production goals (Cho, pers. comm.). This quantity represents about 2/3 of the raw product requirement of the eel skin tanning industry worldwide. It is clear, therefore, that the tanning industry has a long-term interest in Pacific hagfish, and that the need is one to 2 million pounds less than the total West Coast landings in 1989 and 1990, respectively. Given these considerations, the Pacific hagfish fishery is unlikely to exceed 20 vessels coastwide and to reach a magnitude that seriously threatens the resource.

5. General Observations

In the course of experimental fishing few fish were caught on two occasions at station 1 and work was rescheduled. Five 30-gallon trash can traps and 5 bucket traps baited with 1 pound of whole mackerel were fished for 5 hours at station 1 in June of 1990. Eight traps came up empty and two bucket traps held one fish each. In August of 1991 during an attempt to complete the final experiment comparing trap designs, 48 traps caught a total of less than ten hagfish. Large quantities of hagfish were captured at the same depth and substrate at station 2 within days of poor catches at station 1. These observations suggest that hagfish populations in specific areas can be depleted rapidly and recover very slowly.

6. Industry Handling and Capture Recommendations

Based on the results of this study, the following practices and gear are recommended for the capture and handling of Pacific hagfish 12 inches or larger:

Traps: Five-gallon bucket traps with entrance funnels from Korean traps fitted into the lid and bottom with 0.48-inch escapement holes drilled into the lid and bottom around the funnel are recommended. Commercially available Korean traps were too small and are not easily modified to select for larger hagfish. Thirty-gallon traps were difficult to handle when full; the weight of the trap taxed the hydraulics and made quick transfer of hagfish to a holding container difficult. Trap hole size could be increased to select for larger hagfish if necessary. A self-destruct mechanism should be included in trap design to ensure that lost hagfish traps do not continue to capture hagfish or other animals.

Soak Time: Twelve- to 24-hour soak times are recommended because more and larger hagfish were caught in these soaks compared to 4- and 8-hour soaks.

Bait: Four to five pounds of bait are recommended for each 5-gallon trap. Mackerel and rockfish frames are both effective baits; the least expensive is probably the best choice.

Depth and Substrate: No recommendation on depth is possible from this study, and substrate preferences were not tested. From other studies completed in California (Reid, 1990; Nokamura, 1991; and Johnson, 1992) fishing depths of 100 fathoms or less are likely to produce more and larger Pacific hagfish and most hagfish were found on mud and sand bottoms (Cailliet, 1991).

On-board Handling: In order to deliver the highest quality hagfish for both the tanning and food markets, holding hagfish in seawater and ice on the vessel is recommended. Hagfish should be transferred immediately after they come on the deck to the seawater and ice mixture to minimize stress from being out of the water. The mixture should be kept as close to 32 degrees F as possible to minimize skin damage from biting and from bacterial and enzymatic degradation, which can increase the number of dorsal holes (tears). An optimal holding density is estimated at 100 to 150 pounds of hagfish per 55-gallon barrel containing approximately 25 to 30 gallons of the seawater/ice mixture. Specific densities need to be tested under commercial production conditions. Use of 0.48-inch escapement holes eliminate the need to sort the catch by size on the vessel; thus, saving time and effort and improving product quality.

Before a conclusive industry recommendation is made regarding on-board treatment of hagfish exclusively for tannery markets, three treatments (seawater and ice, MS_{222} and seawater, and MS_{222}, seawater and ice) should be compared under commercial production conditions with the help of tannery technicians.

B. Problems

Some difficulty was encountered characterizing skin quality defects, but this was later resolved through contacts with Oh Yang International, Auburn, Washington. Opportunities to test handling procedures under production conditions using the experience of tannery technicians became available after the grant period ended.

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Personal Communications:

Mr. Yang Cho, Oh Yang International, LTD. 1420 20th St. N.W., Suite D, Auburn, WA, 98001.

Mr. Bill Barss, Oregon Department of Fish and Wildlife, Marine Science Drive, Bldg. 3, Newport, OR. 97365.

Mr. Brian Culver, Washington Department of Fisheries, Coastal Lab, 331 State Hwy. 12, Monteseno, WA, 98563.

Mr. Pete Kalvass, California Department of Fish and Game, 19160 S. Harbor Dr., Fort Bragg, CA, 95473.

Mr. Ed Zyblut, Canada Department of Fisheries and Oceans, 555 W Hastings St. Vancouver, B.C., V6B5G3, Canada.