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Observations of a Scientist/Diver on Fishing Technology and Fisheries Biology

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Observations of a Scientist/Diver on Fishing Technology and Fisheries Biology

by

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PREFACE

During my 37-year career in science diving, many underwater observations were made from which a number of reports were published. Additional observations incidental to dive objectives were also documentated in diving logs. Some of these previously unpublished underwater glimpses may contribute to the understanding of marine life and fishing gear technology. It is hoped that such notes may be useful to corroborate findings by other underwater investigators.

This report was prepared to preserve the underwater observations of the Bureau of Commercial Fisheries (BCF) and National Marine Fisheries Service (NMFS) biologists, engineers, and technicians who jointly spent thousands of hours underwater at depths up to 1,000 feet and more. I draw upon both my personal and professional recollections, diving logs, informal and formal reports, and, where possible, interviews with former members of the NMFS' self-contained underwater breathing apparatus (SCUBA), undersea habitat and submersible dive teams.

Seattle, WA

Bill High

ACKNOWLEDGMENTS

I greatly appreciate the assistance of my numerous diving partners, who contributed to a better understanding of what takes place underwater. Special thanks to science/divers Gary Loverich, Larry Lusz, and Ian Ellis, for their contribution to this report and for occasionally getting me out of a difficult situation. Without Richard McNeely, Lee Alverson, Al Pruter, and William Aron, who understood diving was a worthwhile tool for gathering science data, this underwater research would not have been possible. Gary Stauffer's encouragement was essential to my preparing this report and he was instrumental to our participation in ghost net recoveries.

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BACKGROUND

Scuba diving within the influence of fishing gear was first performed by British Navy frogmen about 1951. An impressive cine film, produced at about that time for a British fishery agency, illustrated some features of a Danish seine during its retrieval. The first dives made to observe a shrimp trawl in operation took place near the Bahamas about 1956. The dive team included Dick McNeely and Reider Sand, gear specialists with the BCF, Miami, Florida. Those divers used a sea sled pulled by the same vessel that towed the fishing net so they could travel adjacent to and observe the operating net.

Between 1957 and 1960, BCF divers Dick McNeely, Fred Wathne, Mel Greenwood and Pete Larson began occasional trawl diving studies near Seattle, Washington from the NOAA research vessel RV <u>John N. Cobb</u>. Those divers continued to use the sea sled method to approach a working midwater trawl. Their objective was to evaluate configurations of experimental trawls.

In 1958, accompanied by commercial diver Dale Dean, I was arguably the first scientist/diver to descend directly on trawl tow cables and make observations while moving hand-over-hand on the operating net. The dive was conducted from the University of Washington's RV <u>Commando</u> (Captain Tom Oswald). My underwater research career had begun in 1955 during temporary employment with the BCF performing underwater assignments in support of a migrating Pacific salmon diversion project at Leavenworth, Washington. After rejoining the BCF in 1963, I developed techniques for diving directly on trawls that became the standard for making trawl observations until that form of trawl study terminated in 1979 when NMFS missions were redirected.

During the years 1957 to mid-1963, I conducted a number of research dives, primarily to observe the effect of tagging on Pacific halibut (<u>Hippoglossus stenolepis</u>) confined to large undersea enclosures. On several occasions, I was detailed to the BCF, while employed by the International Pacific Halibut Commission (IPHC), to participate in sea sled-supported trawl dives. I later joined the BCF to assist Dick McNeely form a technical dive team as part of that agency's newly established Exploratory Fishing and Gear Research Unit (EF&GRU).

Members of the EF&GRU dive team, during portions of the most active years, included Ian Ellis (biologist), Larry Lusz (electrical engineer), Gary Loverich (ocean engineer), Robert Loghry (technician), Dan Twohig (electronic technician), Laurel Touchette (contract diving specialist), Forrest Carvey (biologist), and Nate Golly (technician). Many visiting scientists and some volunteers participated in the Unit's research diving program primarily to train in the special techniques required for diving directly on bottom and midwater trawls.

Extensive research diving activities of the NMFS' EF&GRU (presently the Resource Assessment and Conservation Engineering (RACE) Division, NMFS, Alaska Fisheries Science Center [AFSC]) included using scuba, submersibles, and undersea laboratories and continued through 1983. Thereafter, diving intensity declined as the agency's focus changed until diving projects drew upon collateral duty divers only once or twice each year. However, AFSC units in Kodiak and southeast Alaska have on-going diver-supported projects. After my retirement from active diving (as a National Oceanic and Atmospheric Administration [NOAA] Master Diver) at the end of 1992, the AFSC at Sand Point maintained only three science divers to respond to unscheduled needs.

METHODS

Three methods were used by NMFS divers to make underwater observations. The majority of descents were made using scuba gear. Saturation diving (ambient pressure habitat open to the sea) and submersible (miniature submarine with viewing ports) operations allowed for extended time underwater. Scuba research operations were generally limited to less than 150 feet in depth. During four undersea habitat programs, Tektite II (sponsored by the BCF parent agency, the U.S. Fish and Wildlife Service), and Hydro Lab, FLARE (Florida Aquanaut Research Expedition), and Helgoland (sponsored by the Manned Undersea Science and Technology office of NOAA), maximum excursion depth was about 140 feet, but the total hours in the water for each mission day was up to 10 hours. Submersibles, including Pisces I, Nekton Gamma and Mermaid, permitted dives as deep as 1,500 feet lasting as long as 8 hours.

Equipment

For the most part, our scientific diving scuba gear was the same as that used by sport divers. Initially, we attempted to use two-hose scuba regulators while riding on trawls but this proved unsuccessful. The soft hose material collapsed at even slow trawl speeds, thereby restricting our air supply. Pull rods which activated the reserve air valve mechanism were altered, then removed altogether because they frequently became snagged in net web. Thereafter, each diver pulled his partner's reserve valve when the low air signal was given. Eventually, submersible pressure gauges replaced the valve reserve feature.

Diving knives were an essential gear component. Most early diving knives had a portion of the cutting blade ground to a serrated edge. Serrations were very poor for cutting web in the event of diver entanglement because the web threads tended to be caught within the serrations and not be cut. It was normal practice to carry a large, straight-blade diver knife on the medial calf surface of the leg. Typically, recreational divers positioned the knife on the lateral surface. When placed there however, the handle inevitably caught in net web and was either pulled from its sheath or contributed to diver entanglement. A second, smaller knife was often carried on the forearm in case entanglement prevented the diver from reaching the primary knife.

Conventional weight belts, with the common quick release safety buckle, were lost in large numbers while trawl diving. It was not safe to disable the release even though it often snagged on webbing and disengaged. Frequently the trawl diving team observed previously lost weight belts lying in the trawl path. Many were recovered by grabbing a belt as the trawl passed, lifting the belt up onto the net and securing it for the fishing crew to later remove on board the trawler.

Dive team members were quickly chilled in the cold Northwest marine waters so they wore full-length, one-quarter-inch thick wet suits, including gloves, boots, and hood. When one-eighth inch foam neoprene material became available, short pants and a hooded vest were added beneath the primary suit. Dry suits were acquired for most team members beginning in 1971.

Judging Underwater Visibility

Visibility, or degree of turbidity in water, can be difficult to define. An assessment made by a surface observer measuring the distance he can see an object below the surface may only describe a fraction of the water column. Even horizontal distance, the degree to which one diver can see one another, varies depending upon the criteria used. Material (sediment, algae, etc.) in water that determines the distance that objects can be seen often varies greatly between the surface and the sea floor.

Silt-laden freshwater runoff initially distributes fine material primarily in marine water surface (mixing) layers. While preparing for a winter dive near Duamish Head (Seattle), I noted the water had the color of a slightly diluted chocolate drink. In the water, we divers could not see beyond 12 inches. Descending by feel to about 10 feet, we suddenly passed below the turbid freshwater layer into exceedingly clear salt water. There was essentially no mixing of the two waters. However, almost no light penetrated to the deeper marine water. We estimated that we could see underwater lamps of other divers at a distance well beyond 50 feet; excellent horizontal visibility for anywhere in Puget Sound.

Similar conditions were found during numerous dives in waters subject to runoff of the Fraser River in British Columbia, Canada. There mixing was far greater with suspended matter reducing visibility to less than 5 feet to as deep as 30 feet. Below that depth, underwater lights showed less turbid conditions.

For the purposes of gear research studies our dive team defined visibility to be the horizontal distance one diver in a black wet suit, holding an 8 by 10 inch white plastic tablet, could see another diver's tablet in natural light. Objects were visible up to twice as far when we looked toward the surface. Therefore, while we might just barely see an opposite trawl wingtip 35 feet away, the entire net mouth, from footrope to headrope (70 feet) was seen at once. Extensive experience at measuring operating trawls gave our dive team the ability to accurately estimate distance underwater. Comparing estimates of visibility during non-working dives, our science divers concluded that most other

Northwest divers significantly underestimated underwater visibility.

Throughout our underwater research travels, we discovered that visibility often varied by depth. I found near-surface waters offshore of the Mississippi delta, in the Gulf of Mexico, usually to be quite clear, with 60 feet or more horizontal visibility. On the other hand, where the bottom depths were 80 to 120 feet, a very turbid layer of water lay from the bottom up 6 to 10 feet. Using a deep-water camera at several locations on the Bering Sea shelf, I concluded a similar condition of more turbid water near the sea floor was common there. Reduced visibility near bottom was also found during some submersible dives in Alaska.

Undoubtedly a number of factors contribute to near-bottom visibility. Certainly, at times, fish disturb sediment. From the submersible Nekton Gamma, we saw both Pacific cod and walleye pollock (Theragra chalcogramma) dart into the substrate causing clouds of mud to drift up into the water column.

Diving on Trawls

A two-person sea sled (Sand 1956) was initially used by NMFS divers to observe trawls because the safety of working directly on the net, cables, and doors of trawls had not been tested. Prior to 1958 no divers had attempted direct contact with midwater and bottom trawls using scuba. The BCF transition from the sea sled to direct diver-to-trawl contact was slow and cautious. It was obvious to divers and administrators alike, that trawl diving was exceedingly dangerous work and a safe diving protocol was needed. Some hazards were obvious, while others would be discovered.

Our first effort to descend directly to a trawl was along a rope tied between a surface float and the trawl headrope (High and Lusz 1965). This method was arduous and divers consumed a significant portion of their air supply just to reach the trawl. Late in 1963, I initiated less-strenuous descents to trawls by entering the water from a small boat traveling adjacent to the tow cables at the point where they entered the water. Success with this method prompted us to begin our trawl dives by entering the water directly from the trawl vessel. Typically, two divers jumped from the port and starboard midships areas, then quickly swam to the passing trawl cables.

By descending slowly down the tow cables the divers consumed very little air and could observe the sea floor well ahead of the otterboards (doors). We had to be careful to not allow the tow cable to slip through our hands. Broken wire strands occasionally caused hand injuries. The leading edge and front surface of a door, although a potentially extremely dangerous location, could be closely examined. Although visibility ranged widely by time of year and location, we often could see 20 to 40 ft horizontally. Mud stirred up by turbulence behind the door concealed all of its rear surface and for varying distances back along the tail chains and bridle. Whenever information was sought about this obscured zone, the diver felt his way along the door tail chains while being buffeted by the turbulent water. Knowledge of how the door was rigged was essential to keep hands and fingers away from potentially snarled chain. As these techniques evolved, teams of two divers could physically contact and observe, on a single dive, an entire trawl system from the vessel to the net codend.

Where divers worked forward of bottom trawl headropes or footropes, extreme caution was warranted. Even on grounds where many trawl sets had previously been made, there was the possibility of striking objects. Sunken logs, boulders, and two sunken ships were all encountered while divers were on trawls. Logs tended to be lifted by groundlines up toward the wing tips or headrope and were potential hazards to the divers making observations.

Large boulders occasionally snagged by a footrope, bridle, or tickler chain momentarily stopped most of the trawl's forward motion at the point of contact. The net pivoted around the snag while tow cables pulled tight. Within a few seconds, the restrained cable or chain broke free and the entire net instantly jerked forward with great force. On most of those occasions, the divers were aware of the imminent forward net surge and were able to stay out of the path of danger as serious injury or death were a possible consequence. At the time the trawl released from the obstruction, divers grasping web usually had the net pulled from their hands and a quick swimming dash was required to return to the trawl.

We often spent many minutes holding onto the headrope, wing tips or footrope to observe net dynamics or fish behavior. At trawl speeds greater than 2.5 knots, it was essential to look forward, otherwise water was forced into the face mask and the drag placed on the air supply mouth piece caused jaw and teeth fatigue. Danger was greatly diminished once divers were aft of the trawl mouth except when they entered the trawl or moved beneath a bottom trawl belly near the sea floor. Water currents decreased toward the codend of large trawls to the point that often the divers, once held within the back eddies formed close to the codend bag, were carried along without holding the net.

Midwater trawls were by far much safer for divers to work on than nets fished near the sea floor. Without the fear of running into obstructions, midwater trawl dives were occasionally made to, and beyond 150 feet to view the largest trawls which had vertical openings of as much as 90 feet.

Diving in Purse Seines

For members of our dive team with trawl diving experience, the purse seine dives were considered easy even though several unique hazards existed. We made numerous dives on both conventional and experimental salmon seines in Puget Sound, Washington, and tuna purse seines offshore from San Diego, California. I dove alone in a tuna seine on the high seas near the Galapagos Islands, as well.

Initially the net formed a curtain of web which hung vertically from the surface down to as deep as 250 feet. As the retrieval process progressed, purse rings and cable rose to safe diver depths at which time the divers had to be alert not to allow their arms or legs to be near those moving components. Overall, the greatest danger was the distressed sharks confined within the tuna seines.

The hazards of diving in a seine containing large yellowfin tuna, dolphins, and sharks were largely unknown when we began our research dives. During the high seas dives, I was unharmed by up to about 1,000 dolphin and 15 tons of tuna concentrated in the backdown area. They avoided striking me whenever space allowed

(High 1991a). I either killed aggressive sharks, mostly oceanic white tip sharks, or left the water.

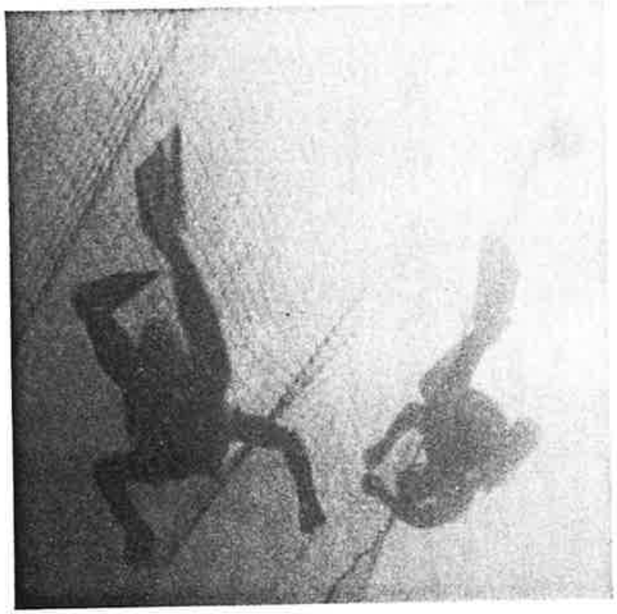
Diving Near Gill Nets

Many dives were conducted near both surface and sunken gill nets. Numerous dives were made to remove ghost web entangled on the sea floor or upon underwater obstructions. Ghost nets are either complete or partial nets lost or abandoned by a fisherman and still capable of entangling aquatic animals. Because gill net web is nearly invisible, hangs in loose folds, and can move with water motion, it is a considerable hazard for divers. Special safety measures were warranted and taken, including having safety divers stand by underwater to assist divers in contact with the web. We expected that some diver entanglement would occur whenever we recovered ghost web. Therefore, only experienced divers were allowed to work around gill nets and all participants received special training how to deal with gill net web underwater. As a result, diving gear was streamlined or reduced to the greatest extent possible.

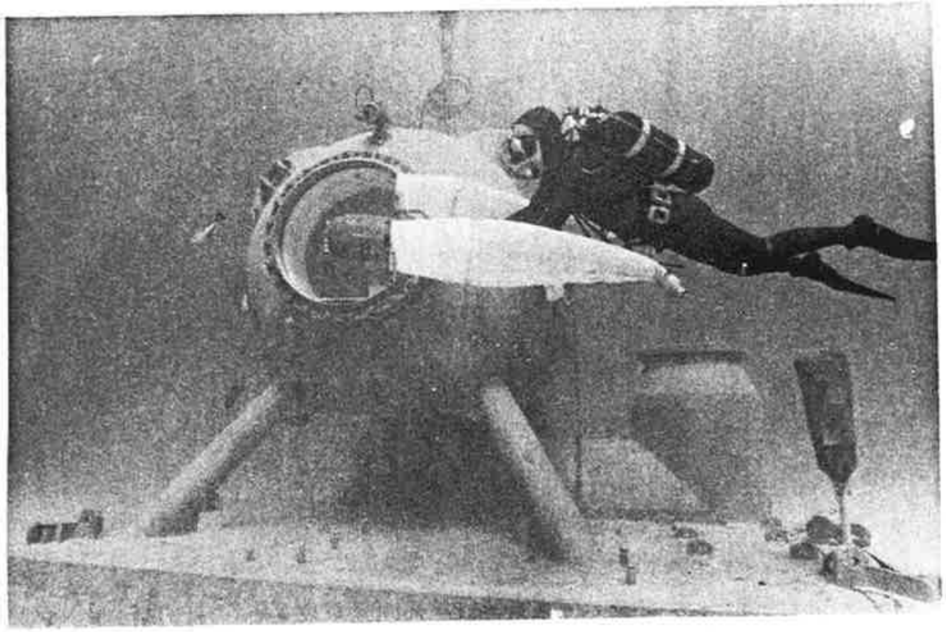
Only once was a member of my dive team in serious trouble from entanglement. The occasion was a non-government-related underwater filming of octopuses for television. My diving partner and I inadvertently became entangled in a ghost salmon gill net lost on the shipwreck Dauntless. Safety divers hired by the film company failed to intervene. I depleted my air supply but managed to escape to the surface while my partner remained entangled. As I returned to her aid with additional air, she freed herself and safely ascended. That close call contributed much to formalize and amplify the safety practices used when diving near gill nets.

Submersible Operations

Our BCF introduction to submersibles for marine research came in 1964 when I participated in dives with the Cousteau saucer Soucoupe off San Diego. By the fall of 1966 the first Pisces-class submersible was launched in Vancouver, Canada. The designer-builder, Mac Thomson, made an offer to the EF&GR Unit that it couldn't refuse (High 1967a). Over 20 scientists made



Divers cling to an operating midwater trawl.



Habitat Hydrolab provides shelter for aquanauts.

Aquanauts working from a habitat relocate an experimental trap.

Submersibles extended science observations deeper than 1,000 feet.

dives in Puget Sound and adjacent waters to learn about the research potential of submersibles. We learned that the submersible was unable to safely follow a trawl because of low visibility near the trawl, difficulty in finding the net when operating, slow speed and limitations in precise maneuvering. I made other dives in the *Pisces* to 1,500 feet to study behavior of juvenile Pacific whiting (*Merluccius productus*) and assessed the capabilities of several other submersibles for making fisheries-related observations (High 1971a).

Between 1978 and 1983, four submersible-supported expeditions were carried out in Alaskan waters. The submersibles *Nekton Gamma* and *Mermaid* were chartered. *Nekton Gamma* was not well suited for our Pacific halibut longline survey. The submersible's speed and endurance were limited and viewing ports were not well located for observing longline. Overall however, adequate data was gathered (High 1980). The *Mermaid*, on the other hand, with its large hemisphere viewing port, provided an extraordinary panorama of the sea floor, halibut longline gear, and marine animals (High 1987). Neither sub could be launched in the moderately rough seas which were likely in the most desirable study areas. A variety of mechanical failures occasionally reduced the data-gathering capability of both submersibles. Submersible operations and safety were the responsibility of the charter company's support personnel and mothership crew.

Currents posed several problems for submersibles operated in Alaska. With limited propulsion power and low water visibility, it was safer to operate the submersible in slow currents or while motoring into a nominal current. Motoring in the direction of water flow was hazardous when visibility was low as it was difficult to stop quickly. Unfortunately it was not possible in Southeast Alaska waters to accurately predict the best operating time or which end of a halibut gear string to begin our observations. More often than not, the current direction on the seabed at depths of 250 to over 600 feet were nearly opposite of that seen at the surface. Occasionally, the bottom current was irregular or stronger. For these reasons and because the halibut longline gear that we attempted to follow often meandered considerably, we reluctantly operated occasionally with the current.

Habitat Support For Diving

Undersea habitats provided a safe living haven for divers using a variety of breathing systems (High et al. 1973a). With the habitat pressurized to that of the surrounding water at depths up to 130 feet, the divers greatly extended their underwater working time. Even when within the habitat, viewing ports allowed personnel unlimited opportunities to view the nearby aquatic surroundings.

The primary research goals during the first science mission dives in Tektite II, Hydrolab, Edalhab and Helgoland were to study the behavior of fish within the influence of several trap and gill net designs (High and Ellis 1973b). An extensive amount of personnel and equipment were required to support habitat operations, although the Hydrolab habitat was an exception during the first NOAA mission. On that mission, Robert Wickland, habitat manager, nearly single-handedly maintained the surface support system for our three-man aquanaut team.

MARINE ANIMAL BEHAVIOR

From the first time that I attempted to share underwater observations, some land-bound colleagues and other authorities disagreed with my methods. A Professor of Fisheries proclaimed around 1957 that the cabezon (Scorpaenichthys marmoratus) spawned during winter months. When I pointed out that I had a photograph of a cabezon guarding a purple/lavender egg mass during July, he assured me (his student) that I was in error. Also, a Professor of Oceanography shared with me in 1960 his obvious conclusion-diving was simply an excuse for fun and all meaningful science could be adequately gathered by devices sent into the sea from ships.

It seemed that most gatherings of marine scientists during the 1950s and 1960s had at least one confrontation between the scientist/divers and those who did not venture into the water. These observations came into question partly because only a few biologists were divers and it was too often accepted as a fact that all fish were influenced by the divers' presence. The conclusion was that the observations by divers were not valid.

Fortunately, biologists of the 1990s routinely accept much of what could not be accepted 30 years earlier.

After years of diving, I admit that some fish species are influenced by diver presence, but most are not if the diver remains some distance away. I also acknowledge that there may be an impact which the diver cannot detect. In any case, we recorded our observations and assumed that the diver had no relevent effect on behavior. The reader may wish to use caution as to how to interpret these observations.

Pelagic Fish

Clearly, my observations indicate pelagic species tend to react to intruders, including divers, at greater distances than do groundfish. Large Pacific salmon (Oncorhynchus spp.) in open marine waters are not often seen. Smaller salmon, up to about 3 or 4 pounds, were commonly observed by divers from the trawl. On at least two occasions, while riding a midwater trawl, I observed individual salmon swimming toward the net body from the limits of my visibility. Each fish took up a swimming position adjacent to the web and remained there several minutes before moving away.

Most salmon were seen silhouetted as the divers looked or ascended toward the surface. So long as the diver was 15 or so feet away, the smaller salmon appeared to take no notice and eventually swam out of visible range.

Adult steelhead (O. mykiss), once in a river system, appeared to lose some of their elusive behavior. During dives into the Green River south of Seattle, Washington, schools of up to 10 or more large individuals were observed within the lee of stumps, rocks, or other objects. With visibility limited to no more than 6 or 7 feet, I could slowly approach within 2 feet before the school edged away. Fish were spooked only by a sudden movement.

Amberjack (Seriola spp.), and less often tarpon (Megalops atlanticus), schools appeared nightly at the Tektite undersea habitat in the U.S. Virgin Islands. These large predators were observed for long periods from within the habitat as they swam leisurely in and out of the lighted zone. Our four-man aquanaut team made numerous excursions to participate in those regular visits. There was no noticeable change in amberjack behavior except when fish occasionally brushed up against a diver. Numerous photographs were taken of the amberjack school near both the divers and the undersea habitat. They were obviously attracted to the habitat or the associated lighted zone but were neither attracted nor repelled by divers swimming among them.

While ascending toward the surface from a deep dive in the submersible Nekton Gamma off Sitka, Alaska, we encountered a dense school of Pacific herring (Clupea pallasi). The yellow, 15-foot long submarine rose through the vast expanse of fish which extended for many feet in all directions. As the submersible passed, the school simply parted to allow a 10 or 15-foot void between the fish and the submarine. The school reformed as though the disturbance had never been. This same behavior of small schooling fish in other waters has been frequently recorded by divers working on TV documentaries and is shown graphically in the 1960s-era 16 mm film Painted Reefs Of Honduras as the divers and feeding predator fish pass through an extensive anchovy (Engraulidae) school.

Demersal Fish

The critical distance at which an intrusion appears to alter the activity of marine animals decreases as the species' habitat preference gets closer to the sea floor. Divers commonly swim within a few feet of rockfishes (Sebastes spp.) and can catch small flatfishes by hand. Active Dungeness crab (Cancer magister) commonly flee when a diver approaches within 5 feet. When buried in sand, either individually or as clasping pairs, Dungeness crab must be literally pried from the substrate. Pacific cod (Gadus macrocephalus) tend to avoid divers (in Puget Sound, Washington) but are dramatically attracted (off Kodiak, Alaska) to a well-illuminated stationary submersible.

Rockfishes exhibit a wide range of behavior. Some species school while others do not; some species are always found within a few feet of the seabed, while others routinely venture well up into the water column. Black rockfish (Sebastes melanops) often form vast schools during hours of low tidal flows, but as the current increases, the school may slowly descend until nearly all individuals are sheltered in caves, depressions, or the lee of rock formations. All of the dozen or more rockfish species that I observed devoted much of their time to hovering or lying upon the seabed. I never saw yelloweye rockfish (Sebastes ruberrimus) in the San Juan Islands, Strait of Juan De Fuca, or Southeast Alaska form schools. Fewer than 15 yelloweye rockfish were seen at any moment, yet occasionally individuals were in view throughout diver or submersible tracklines lasting minutes to an hour or more. I know of no yelloweye observations at depths less than 85 feet, as this species usually inhabits rocky bottoms deeper than 100 feet.

Shrimp

Spot (Pandalus platyceros), pink (P. borealis) and broken-back shrimp (Heptacarpus spp.) were seen by divers and submersible observers. Broken back shrimp are, at times, found in large numbers in Puget Sound on muddy/sandy bottoms. Their near-translucent form and small size makes them less noticeable than the more pigmented larger species. On only two occasions were they in such abundance that the seabed appeared carpeted with this species. Most often they are found in limited numbers lined up in close proximity to seabed debris such as sunken logs, tires, kelp fronds, etc. When disturbed by an object moved within a few inches, the shrimp jump away to a more sheltered location or surprisingly, expose themselves by swimming up into the water column as much as 15-18 inches. Small rockfish taking refuge near the debris were observed to quickly dart out and capture the exposed shrimp.

Pink and spot shrimp were studied from a submersible operating in bays adjacent to Chiniak Bay, Alaska. Turbid water and the soft mud seabed usually limited observations to 10 to 15 feet from the submersible's viewing ports. Pink shrimp were found in large numbers up to about 8 feet off bottom. Sudden illumination did not cause either the shrimp in the water column or on the sea floor to move. Only when the submersible came within 3 feet did they begin to jump or swim away. Occasionally, spot shrimp were seen in nearby offshore areas. Nearly all spot shrimp were located on hard bottom, well protected within crevasses.

In Hood Canal, Washington, both pink and spot shrimp were found by scuba divers at night perched on the seabed in depths as shallow as 85 feet. Much greater numbers were seen well beyond 100 feet (High 1971b). Neither species moved when caught in the beam of the divers' flashlights. Individuals were readily captured in a small, hand-held dip net. Both species of shrimp jumped in what appeared to be a single motion horizontally or upward vertically about 18 inches maximum, and unless disturbed none swam up in the water column as was seen near Kodiak, Alaska.

Octopuses

Octopuses (Octopus dofleini) have been the subject of special diver interest since modern diving equipment allowed descents into North Pacific waters where the largest specimens reside. I first wrote about the animal in a 1960 Southern Outdoors Magazine article (High 1960) following 3 years of independent research. My studies have continued intermittently for more than 20 years with some information published in sport diving and adventure magazines, as well as one general interest article in Marine Fisheries Review (High 1976a). National Geographic magazine reported upon my studies in its December 1971 issue (Voss and Sisson 1971). In 1977 the IMAX film production company documented my work in a segment of the film OCEANS. The next year, I assisted a film producer for the Penzoil Corporation film a television octopus documentary.

Octopuses were not a subject relevant to the purposes of my first employer, the IPHC, although the animal was used extensively as a durable halibut bait. Because octopuses typically inhabited shallow, near-shore waters (a region regulated by state resource agencies), the resource also was not subject to investigation by the BCF or NMFS. Nonetheless, fishermen frequently approached the latter agency seeking information on octopuses and their potential for commercial harvest. Those inquiries were directed to me after I joined that agency.

In 1957 the Puget Sound Mudshark diving club initiated an octopus abundance and migration study. As host of the then popular World Octopus Wrestling Championship (High 1963), the club sought to assess the impact of that activity. Tagging was authorized by the Washington Department of Fisheries (WDF). Our initial effort produced no tag returns, most likely because the modified salmon tag provided by the WDF was not suitable for a bottom-dwelling animal. A labeled plastic loop was threaded through a portion of one arm. Undoubtedly, the loop snagged on sea floor objects and pulled free.

In 1958, while I worked with the Floy Tag and Manufacturing Company to develop a more visible halibut tag, the company donated a supply of the experimental dart tags for my independent octopus migration study. Initial tag retention tests were conducted on aquarium-held animals at the University of Washington. The dart tag remained in place and was conspicuous for periods up to 93 days until the animals were sacrificed for other research.

Several volunteer divers participated in the tagging project. In 3 years, about 50 animals were tagged between Tacoma's Titlow Beach, Washington, area and north to Whidbey Island. The only source for recovery information was from underwater hunters and our own searches.

Usually tagged animals were found subsequently in or near the same cave for periods up to a month or more. Beyond that time, it appeared most tags were lost. Animals taken from caves previously occupied by a tagged animal often had a conspicuous scar at the precise tagging site. There is little doubt that they were once tagged animals. One recreational diver reported having pulled a dart tag from an animal not realizing its purpose.

These results prompted us to apply two dart tags and eventually a loop tag on the animal's body. Tagged and scarred animals were re-located for up to 3 months. No marked animals were seen the following year in caves once inhabited by tagged octopuses although several were active dens.

Octopuses are among the most fascinating creatures in the sea. They demonstrate considerable intelligence and often interact with divers. Perhaps my most intriguing encounter occurred while studying Dungeness crab escapes from pots (High 1976b). Upon arriving at the underwater study pots, we discovered a 35-pound octopus sitting on one pot while using several arms to probe inside for crab. The animal was forceably removed and was deposited on the sand about 15 feet from the crab-laden pot. I then returned to record data at the pot. From the corner of my eye I watched the animal walk back toward the pot. The creature slipped between my kneeling position and the pot, then thrust upward between my arms to sit on top of my writing slate. While looking me straight in the eye and displaying its most vivid red color and projecting its fleshy horns, it proceeded to reach into the pot for crab. Once again I carried the octopus away. It rapidly and repeatedly altered its color between bright brick red and a pale white. When I returned to my work, the octopus proceeded back toward the pot. Being low on breathing air, I reluctantly ended the encounter. I removed an un-needed crab from the pot, slowly swam to the creature, and held out the offering. It stopped, reached out with one arm, assessed my hand and the offered food, then neatly picked up the crab, tucked it beneath its web canopy, and walked out of sight.

On at least two occasions large octopuses deployed multiple arms out of their caves to investigate my presence. Once at an occupied cave beneath the wreck Dauntless, I slowly wiggled my gloved fingers. One suction disc-laden arm came out to inspect my fingers and wrist, then continued on toward my face. A second arm grasped my wrist and slowly began to pull. While the first arm delicately probed the exposed flesh on my face, a second, third, and then fourth arm participated in what became a minor tug-of-war. Lying on the sand with nothing to hold onto, I was drawn to the cave entrance. As I pulled each arm free it was withdrawn into the cave.

I have observed two separate unprovoked attacks by octopuses on divers. Both animals were perched on ledges above the passing diver. I believe the encounters were simply cases of mistaken identity. The animal considered the diver to be a source of food until it discovered its error. While the suprise attacks momentarily startled the experienced octopus wrestlers, no harm was done. A novice diver might well have panicked with such an encounter. A 1978 Associated Press article from Tokyo reported the death of a diver found next to a stabbed large octopus. Snow (1970) describes two incidents where divers handling octopuses were bitten. My notes include four additional bite reports. Profuse bleeding and some prolonged healing were reported by the injured divers but no bite proved serious.

Artificial Reef

The wreck of the wooden steam vessel Dauntless provided a valuable arena in which to study the attractive influence of objects placed on an otherwise featureless seabed. Our discovery and first dives on this (then) 42-year-old shipwreck took place in July 1968. There was, at that time, some interest by both scientists and sportsmen in the potential for placing man-made objects into the water as an attractant or habitat for marine life. However, it was difficult to assess the maximum capacity of such material because once placed into the sea, fishermen and divers immediately began to harvest the newly arrived inhabitants.

Almost certainly the Dauntless was a virgin "reef" and allowed us an undisturbed series of first looks. The sport diving community was not aware of its existence and no recreational fishermen were observed fishing over the wreck during my many trips to the area. What we saw during several years of diving on the wreck was its stable marine life population. The later impact of spearfishermen was also noted.

The Dauntless was built in the 1890s for passenger trade along the shoreside towns of Puget Sound, but burned and sank around 1926. The remains lie in 55-60 feet of water north of Meadow Point, Washington, where the seabed is unremarkable, being nearly flat and composed of sandy silt. Beyond the influence of the wreck, marine species are limited to an occasional small flatfish, small individual quillback rockfish (Sebastes maliger) and copper rockfish (Sebastes caurinus), sea pens, geoducks, sea cucumbers, nudibranches, blood and sun stars and, at times, a few Dungeness crab. The wreck and adjacent substrate, however, supported a considerable concentration of fish and invertebrates.

All that remained of the wooden ship was the iron propeller, drive shaft, engine, boiler, and condensing coils. Metal deck machinery, fittings, wooden beams, and scattered fire brick revealed the outline of a ship that was once about 97 feet long and 16 feet wide. At the time of its discovery, the boiler and coils stood 9 feet above the sea floor.

Most surfaces were densely covered with marine growth which consisted mostly of white sea anemones. Copper and quillback rockfish, ranging in size from juvenile to adult, were abundant within and immediately adjacent to all sheltered areas. A large school of yellowtail rockfish (Sebastes flavidus) and a few black rockfish (estimated to include more than 500 fish) hovered above the wreck to within 20 feet of the surface. Up to 5 adult cabezon (to 15 pounds) and 8 lingcod (Ophiodon elongatus) (between 10 and 20 pounds) were regularly seen for several years until speared by the first group of outside divers to locate the wreck. Other frequently observed species included shiner perch (Cymatogaster aggregata), striped sea perch (Embiotoca lateralis), painted greenling (Oxylebius pictus), gobi (Gobidae) and up to three 30- to 50-pound octopuses. Estimates for the total number of fish ranged from 1,000 to 2,000.

Lingcod, when frightened from the wreck by diver presence, typically were relocated on the sea floor lying no more than 70 feet from their departure point on the wreck. When divers approached within 3 to 5 feet, cabezon usually sought more secluded regions of the boiler. All other species did little more than to temporarily move from a diver's path and re-established its location after the diver passed. Since divers could usually see for distances exceeding 25 feet horizontally, we believe our observations were not biased.

On several occasions, at various times of the year, the dive team swam tracklines from the wreck directly away out onto the sand to note the changing abundance and variety of marine life. Because there was almost no overlap of species found at the wreck and elsewhere on the nearby relatively uninhabited seabed, we concluded that we could judge the zone of influence offered by the wreck. Numerous times our dive team members took a fire brick from the wreckage, swam outward from the wreck and deposited the brick at the point where the last fish associated with the wreck was observed (essentially any individual other than a flatfish). The resulting perimeter marks suggested that fish inhabiting the wreck ventured no more than 70 feet away in any direction.

After a few spearfishermen discovered the site, the large lingcod were removed. No others moved in to replace them. At times, cabezon were absent, but subsequently, one or two appeared to replace those harvested. Several times, after gill nets were snagged on the wreck, we released live entangled cabezon.

Influenced Behavior

All fish and invertebrates react to stimuli, but obviously in many varying ways. Researchers can alter the natural behavior of the organisms by their presence and the use of lights, harvest gear and components, camera systems and submersibles. At times the behavior change voided our research objective, and of course often the effect of the influence was our objective.

Early underwater television required bright light to produce usable images on tape. Small blackcod (Anoplopoma fimbria) were attracted to the camera system, negating its use to estimate that species' natural density. Still cameras with extremely fast electronic strobe lights, when placed above an experimental blackcod trap, did produce representative pictures.

Dungeness Crab

Scuba was a valuable aid in a study conducted to determine crab escapement from pots. The objective was to assess the damage from ghost pots to crab resources since each year many crab pots were lost. By diving to the simulated ghost pots, we identified tagged crab that remained and those which managed to escape (High 1976b). Also, we eliminated any bias created by the otherwise repeated lifting process needed to count escapes. Diving also avoided using buoylines and floats for locating and lifting the pots. In Puget Sound, where the Dungeness crab study was conducted, unauthorized lifting of pots is common; crab theft would have voided our results. By diving to the pots, we enjoyed the previously described encounter with an octopus attempting to remove crab. We also surveyed nearby octopus caves to learn whether tagged crab, either before or following escape, were preyed upon.

King Crab

Studies of king crab (Paralithodes spp.) pots were made at diver depth incidental to crab escape studies (High and Worlund 1979) and from a deep submersible which sat on the sea floor near a pot. King crab appeared to pay little attention to the extraordinary illumination provided by the sub 600 ft below the surface. Pacific cod, on the other hand, were quickly and strongly attracted. Within 5 to 10 minutes of illuminating a pot, cod gathered around the sub in large numbers. In that time, often the number of cod were sufficient to obscure the nearby crab pot. Submersible lights were shut off until the fish dispersed. Then another short lighted study period was attempted.

More often than can be explained by random movement, we observed king crabs walking toward a pot and arriving at the side having the trap opening rather than either non-tunnel side. Usually the crab moved very quickly through the tunnel. On one occasion a single crab was noted beyond the submersible away from the trap. With seeming purpose, it climbed over the submersible to continue its near-straight route to the crab pot. It went directly to the tunnel and, without hesitation, passed through the gate.

A similar event was observed during the U.S. Virgin Islands Tektite dive. There, fish behavior in relation to traps was studied. I observed a small grouper perched on a coral outcrop about 10 feet from the trap tunnel. After several minutes, the fish left its perch and swam in a straight line, and without hesitation, directly through the 8-inch square gate. It appeared that the grouper selected its precise route and destination before departing.

Escape by king crab through the pot tunnel was a matter of random chance. Although the crab were usually roaming the pot interior, the tunnel design tended to direct them away from the route out. Whenever a crab did pass into the gate, it usually quickly walked down the tunnel and away from the pot beyond our visible range. None of the numerous escapees immediately re-entered the pot. Over a period of a few days, up to 100% of the king crab escaped.

King crab walk across the sea floor at a speed much less than that of a Dungeness crab. Our divers' maximum short distance speed with fins was only slightly more than 2 knots. We could easily chase down a king crab but often it took a maximum effort to out-swim a running Dungeness crab. King crab invariably continued walking without diversion even when aware of the pursuit. Dungeness crab usually made a sudden direction change as the diver neared. Some years ago an argument was raised in the marine science community as to whether king, snow (Chionoecetes spp.), or Dungeness crabs remain exclusively in contact with the sea floor. Our dive team and submersible investigators spent many hours viewing and chasing all three species. Not one of the Pacific coastal crab species was ever observed to swim off the bottom. Turbulence from otter boards, tickler chains and net bridles occasionally forced crab short distances into the water column. However, the crab immediately returned to the seabed.

Reactions To Trawls

Many dives were made to gather information on the behavior of marine animals which came in contact with a variety of midwater and bottom trawls, otter boards (doors), bridles (sweep lines) footropes, rollers, bobbins, and tickler chains. From any location on the net system, we could observe bottom, off-bottom, and midwater species either outside the net or within. Near-bottom species including cod, dogfish (*Squalus acanthias*), sea perch and rockfishes generally began evasive action when doors approached within 5 to 15 feet. Bridles, some over 60 fathoms in length, were less imposing and were often ignored until they were within 1 foot or even touched the fish. Many fish escaped over the bridle but most darted forward and away from the on-coming cable, thereby carrying the animal further into the path of the net.

Once near the mouth of the net, near-bottom species, like pelagic species, attempted to maintain a position ahead of the net mouth (tickler chains, footrope, belly). When there was some distance between the footrope and sea floor, as the fish fell back to very near the footrope, some dove down and to the side in an attempt to escape (High et al. 1969). Many did slip beneath the footrope or between rollers. Once over the footrope, some fish which had until then been swimming forward into the current, turned quickly and drifted back into the confines of the net. Others continued to attempt to maintain their position relative to various parts of the net. If the intermediate and codend were of sufficient volume and crowding low, the fish then swam facing into the much reduced terminal end current.

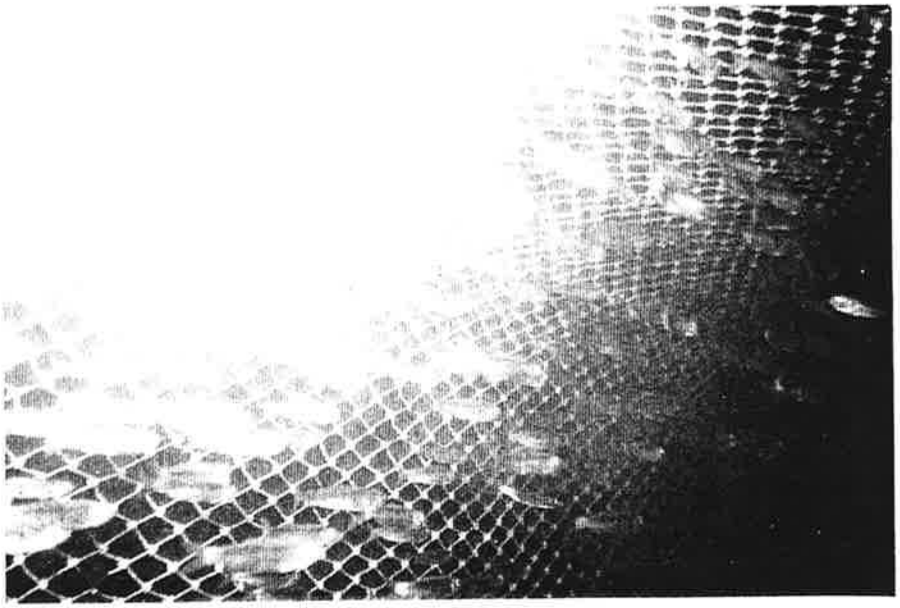
Flatfish stay in close contact with the sea floor. They tend to be easily herded by bridles or sweeplines that are in close contact with the bottom. Usually flounders do not move until the cable comes close or often touches them. They swim short distances (5 to 15 feet) at no more than 2 or 3 feet off bottom, settle, and repeat the procedure when the cable again reaches them. Commonly when touched by the cable, flatfish dart upward into the water column just far enough for the cable to pass beneath them, thereby placing them beyond the trawl path. Repeated avoidance maneuvers forward and away from the cable lead flatfish to the moving trawl. (Note from diving log- Dive observation 9/4/73, modified eastern bottom trawl. Lower bridle 4-5 inches off bottom does not disturb sediment. Buried flounder allow cable to pass over them. Flounder on the bottom swam over the bridle cable and out of trawl path). Swimming into the current, flounders may remain ahead of the footrope or tickler chain for several minutes. Typically they surge ahead to lie on the bottom until the cable or chain again reached them. Many attempted to escape downward beneath the footrope or rollers whether or not conspicuous routes were open. Eventually, many rose above the footrope to let it pass below, some escaped beneath the net, while others turned and swam into the net. Halibut have only been observed on a few occasions. For the most part they behaved similar to smaller flatfish by swimming just ahead of the footrope until tired. They then rose up enough to allow the footrope to pass beneath them. One halibut of about 50 pounds, seen well back into the trawl was able to swim forward out of the net and escape.

Our diver observations on herring were limited to small schools of 6- to 8-inch fish. Herring simply swam away from an on-coming tow cable or door except when a school or component chose to take a position near the object and swim to maintain the school's relative position to it. Thus, fish encountered between those gear components were directed further into the path of the oncoming net. These occasional opportunities to watch herring swim at speeds and for durations greater than the literature suggested, based upon laboratory experiments, prompted us to measure herring swimming speed and endurance (High and Lusz 1966). Fish often swam for relatively long periods (up to 20 minutes or more at 1.13 m/sec) just ahead of the net mouth or within the net. Over time the herring gradually moved back into the cavernous midwater trawl and generally distributed themselves over the entire body interior. They did not appear to distinguish the divers hanging onto the headrope or other parts of the net from the net itself. Herring swam equally close to both net and divers. However, at times, when the divers released bursts of bubbles the nearby herring scattered in all directions.

Herring were small enough to swim through the 3 or 4 inch meshes of most nets we studied. Nearly all made escape attempts upward

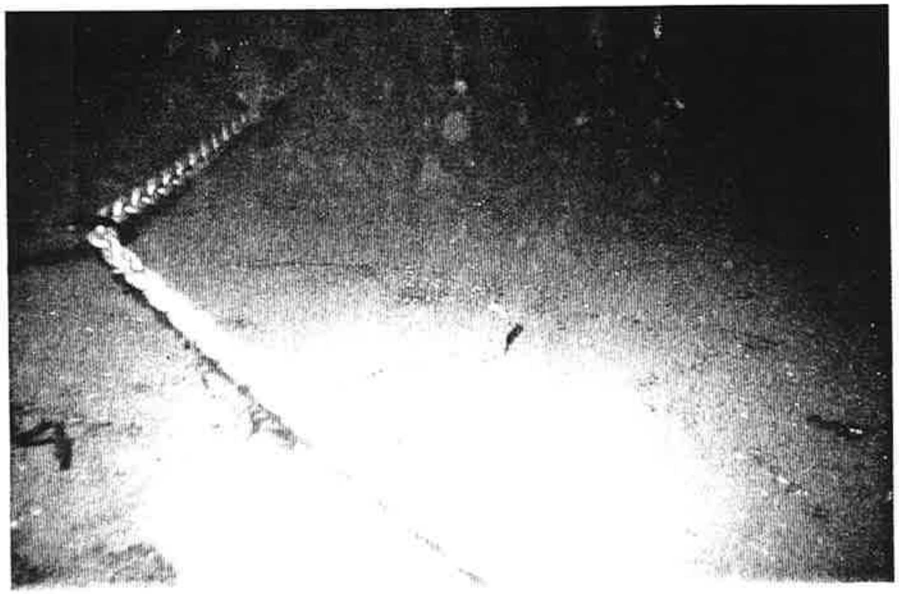
Spot shrimp take little notice of our anchor chain.

Trapped king crab occasionally encounter the tunnel gate at just the correct angle to escape.



Herring swam for long period within the trawl.

Herring swim through trawl codend meshes when startled.

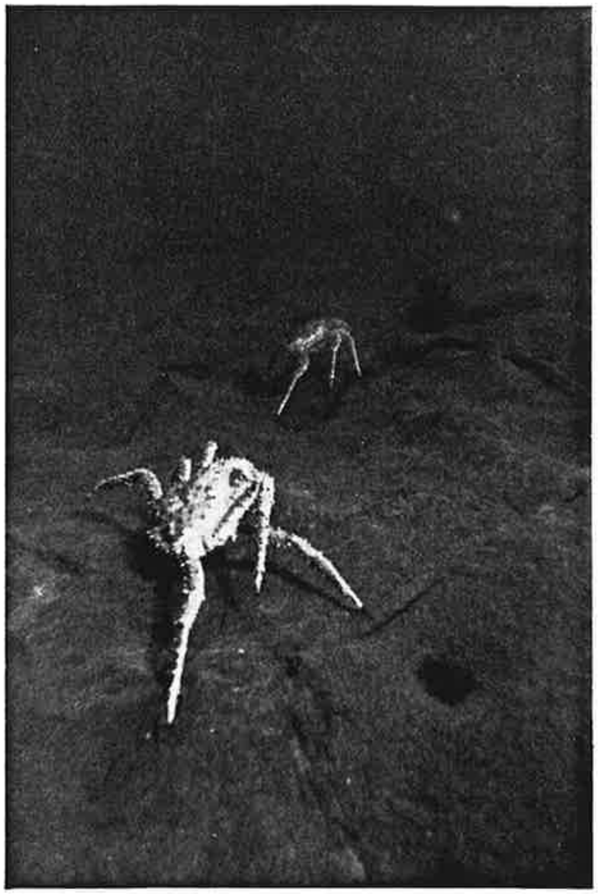


Ineffectively rigged tickler chain approaches flounder.

Flounder at top left swims from under chain as did flounder in center moments before.

One flounder swims forward to avoid tickler while second swims up and back toward trawl.

While flounder swim ahead, a bottle and Dungeness crab are about to be carried over a mud obscured footrope.



King crab walk across the seabed after escaping from a pot.

A halibut hooked on longline gear.

through the top web. Herring turned onto their side to pass through the top meshes. It was most interesting on one occasion to observe a small herring school outside the net swim up to a net side panel and dart through the web into the net.

Swimming within the net intermediate and codend, herring did not make aggressive attempts to escape unless frightened by a diver's sudden motion. Divers striking the adjacent web instantly prompted dozens of herring to escape through meshes. Only low numbers of these small-sized herring were captured upon net recovery. Although not observed, apparently most escaped when the net size diminished during the retrieval process.

Diving scientists rode midwater trawls through vast schools of threespine sticklebacks (Gasterosteus aculeatus). Those 2 to 3 inch long fish could not swim at 2 knot trawl speeds so they were quickly swept into the net. Uncountable numbers were carried against and pinned to mesh threads. Many suffered severe injury due to the extreme arc to which the body was subjected while held by the force of the water momentarily or for some seconds against the thread. As water current eventually carried pinned sticklebacks off the threads and beyond the net, most were motionless or swimming erratically.

FISHING SYSTEMS

The EF&GRU diving scientists and engineers examined in close detail a wide variety of fishing systems including trawls, seines, gill nets, traps (pots), and hook-and-line. The primary limitation for scuba divers was depth and, to a lesser extent, time. Our deepest trawl scuba dive was over 150 feet. Submersibles greatly extended our depth range and duration, but its use was restricted to sedentary gear such as longline and traps. Several attempts to follow trawls with submersibles failed. Even with diver depth and submersible maneuvering limits, we saw and usually touched the operating gear without disturbing its function.

Trawls

By far, the majority of our gear-assessing dives were made to evaluate bottom, off-bottom, or midwater trawls. These trawls varied in size from small shrimp try nets to nets with mouth openings of 80 feet or more both vertically and horizontally. An exceptionally long winged bottom net (lampara trawl) had a 600-foot-long headrope.

Impact of Divers

The forces acting on a full-size trawl, with few minor exceptions, are far too great to permit one or even several divers to alter the configuration. Occasionally, divers holding onto the headrope of a small shrimp trawl or 57 foot eastern bottom trawl with few floats could force the headrope down and temporarily decrease the mouth opening. When those deliberate efforts ceased, the net returned to its normal configuration.

The net, on the other hand, had the potential to harm the diver if he were caught between the net and a solid object. Therefore, whenever divers were ahead of any leading edge, whether it be the door, bridles, breastlines, tickler, footrope or the headrope, they were at greater risk. Once aft of these components, divers usually had ample opportunity, should the need arise, to release their hold on the web and immediately be free of the trawl as it passed by.

Otterboards (doors)

Fishermen often estimated the efficiency of a bottom trawl door by assessing the area of its steel surface shined during contact with the seabed. Occasionally, portions of the door were painted to later see where the paint was scoured away. Divers added more detail by measuring angle of attack, toe and heel contact, and degree of lay over.

We were once asked to assess the effect of a trawl door on the seabed and its impact upon clams or other sedentary animals. Our divers spent some hours riding doors of several designs as they were pulled across a rather firm, sand/silt bottom. After having made hundreds of trawl sets over the same grounds, we formed some opinions on both the short- and long-term effects of those trawl sets.

Trawl doors left a furrow varying in depth and width according to the shoe size, door weight, and seabed composition. Several swims by divers along furrows failed to reveal evidence of crushed animals although the area was moderately populated with geoducks, Dungeness crab, and sea pens. Following a series of intermediate steps (our finned feet had several times been run over by door shoes), I concluded that I could best judge the force of a 5 by 7 foot steel door (weighing less than 800 pounds) in contact with the sea floor by placing my gloved hand beneath it. As anticipated, on the sand/silt bottom, my hand was pushed into the substrate beneath the door shoe without harm. Obviously, this is not a test that should often be repeated. It is rather pointed evidence that some otterboard types move relatively lightly across the ocean floor.

Occasionally divers arrived at the door to find it sliding across the bottom lying on its bail side. Only once were we able to stand on the sea floor and lift the passing door top far enough for water pressure to raise it to an upright position.

Water is dramatically disrupted by a moving otterboard. A pressure wave builds along the front or leading face of the door and spills rapidly around it. Doors in contact with a sand or mud sea floor usually have their aft surface completely obscured with sediment lifted from the bottom by turbulence. After the door passes, the zone of disturbed, silted water expands. Fine sand and silt particles, sufficient to appreciably reduce visibility for divers, were observed to extend up to about 15 feet off bottom and horizontally for 20 or more feet after a 6 foot by 8 foot bottom contact door passed. Luketa 3 foot by 5 foot "V" doors disturbed only a fraction of the sediment as did the larger doors. Sediment, depending upon its size and weight, slowly return to the sea floor, spread somewhat by near-bottom currents.

Door-generated turbulence can lift large sea cucumbers, starfish, and other small marine animals as much as 8 feet off the bottom. Being nearly neutrally buoyant, they were seen carried into a net whose footrope was not in contact with the sea floor. This phenomenon may cause fishermen, who use the presence of bottom dwelling creatures in their net as a measure of its closeness to the bottom, to misjudge its position.

Tickler Chain

One or more tickler chains may be secured at the bottom trawl wing tips to disturb shrimp, flounders, and other desirable on-bottom creatures. The chain length is several feet or more shorter than the net footrope to force animals up into the water just before the footrope passes beneath them. When the chain is too short, the animals have time to return to the seabed before the net arrives. If too long the tickler chain lies behind the footrope and serves no purpose.

A correctly functioning tickler chain attached only at each wing tip loses its effectiveness when the vessel pulls the net in a turn. A nominal vessel turn to the starboard causes portions of the chain to lie beneath the port footrope, and the remainder is often too far away from the starboard half of the footrope to be effective.

In my opinion a tickler chain is more likely to disrupt benthic invertebrates and objects than do most footrope types. The chain is designed to be in full contact with the sea floor. Since the chain is not fitted with bobbins, rollers, various wraps, or rubber discs as are used with the footrope, the tickler snags more small objects, displaces rocks, and injures some sedentary animals. When a snagged object withstands the vessel pulling force, the relatively low-strength chain parts.

Footrope

There are many choices for footrope configurations. Our underwater observations included only a few footrope types found on beam trawls, pelagic trawls, off-bottom trawls, shrimp trawls, flatfish (bottom contact) trawls, high riser nets, a lampara trawl, un-named experimental trawls, and try nets. The load bearing portion of the footrope was rope, chain, or cable, along with various combinations of hose wrap, 4 or 8 inch rubber discs, 18 inch rubber or steel bobbins, 9 to 18 inch rubber rollers and several experimental rollers. Some other devices were tested to achieve selected characteristics.

When a trawl footrope hangs up on an immovable object, such as a solid rock outcrop, the trawl is momentarily stopped and the footrope at the point of contact becomes a pivot point. Net wings are drawn together around the pivot point. As pull on the footrope continues, it either jumps over the object, which often happens when the snag is a relatively low profile rounded rock, or something breaks. Usually the footrope parts along with portions of the net belly.

Trawl footropes typically form a deep "U" shape when towed. Obviously the depth of the "U" is dependent upon several factors, including tow speed, door efficiency, net design, and amount of net drag. As a result of this shape, most bobbins, rollers, etc. along the footrope are pulled sideways. Rollers, either built into the footrope or attached to a parallel cable, are intended to allow the footrope to roll, slide, or jump over objects in lieu of snagging. Only those designed-to-roll devices near the footrope center in fact routinely do roll. However, all serve their purpose rather well when a hang-up occurs. As the pivot point forms around the sea floor object, the impacted rollers are turned so as to roll over the object. The greater surface area of bobbins distributes net pressure more broadly on bottom objects and may reduce damage.

Large-sized roller gear allow a variety of fish escape routes between the rollers and net web. Our observations indicate that flatfish species were the most successful at darting through the spaces and beneath the net. No shrimp escaped by that route since they, and most round fish species, do not dive to the seabed during escape efforts.

Similar escapes by flatfish occurred whenever the footrope lifted off the bottom. We made dives on a 57 foot eastern bottom trawl from the fishing vessel Tordenskjold. The captain considered the net to be the most successful of several of that design he used. We observed the footrope, along most of its length, to be as much as 10 inches above the sea floor. We estimated 25 to 50% of the potential flatfish catch escaped beneath the footrope. The net would have been better if rigged for closer contact with the sea floor.

Headrope

Fishermen and our own gear specialists often attempted to increase the vertical opening of a trawl by adding buoyancy in the form of conventional trawl floats. Usually the gain was small and the net simply rose off the bottom. While riding on the trawl, we saw that web under great strain prevented further opening.

Body

Perhaps the greatest value of our diving observations on trawls was to report the manner in which web hung to strength members (e.g. footrope, headrope, breastline, and riblines). Immediately upon arriving at a location on the net under tow, we could determine whether the meshes were open, closed, skewed, taking strain meant for a ribline, or just hanging slack. Many descriptive photographs were taken and, when viewed by the net makers, those specialists better understood how modifications and adjustments would allow proper distribution of forces.

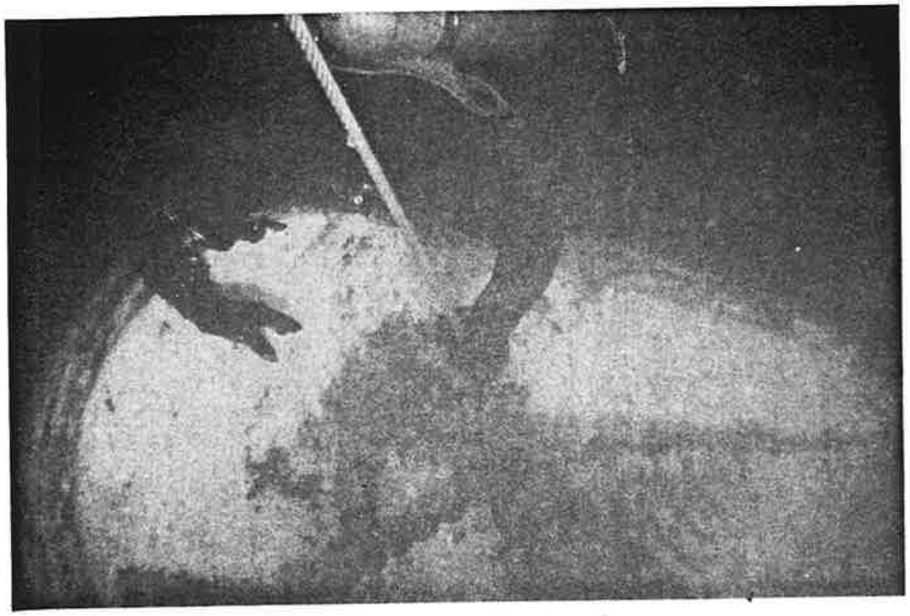
The 400-mesh (57 foot) eastern bottom trawl was a popular 1950s-1960s resource sampling trawl. Its web corner wedges were poorly configured so great strain was placed upon only a few web threads. The area was prone to tear. Once evaluated by the divers, some quick improvements in strain distribution were made by changing the web taper. Also, diver reports allowed ribline hang-in adjustments on Cobb pelagic trawls to produce uniform web shapes and improved strain distribution. The overall result was nets that required less repair and often opened more fully.

Water Flow

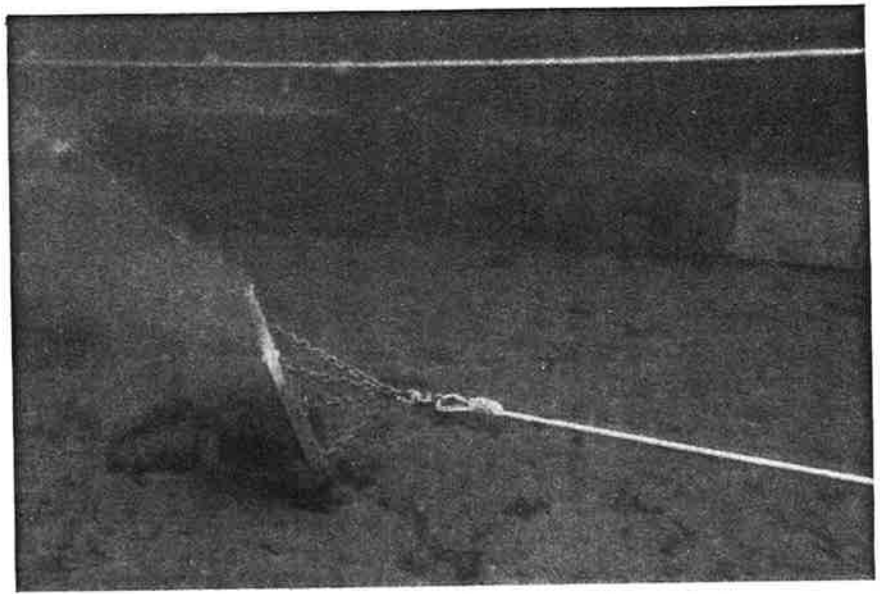
Water flow near and within moving trawls has been the topic of study by a number of investigators, primarily using model nets in test tanks of various designs. Knowledge of the flow patterns may contribute to net design, catch success, and help explain some aspects of fish behavior within the influence of a trawl.

Our interest in water flow in and adjacent to a large midwater trawl was prompted by our observations of herring behavior. Individual herring and small schools were seen swimming for longer periods within and ahead of the trawl mouth than was reported in the literature. We measured the associated flow rates using current meters. Details of both the method and our findings are published in two papers (High and Lusz 1966, High 1967b).

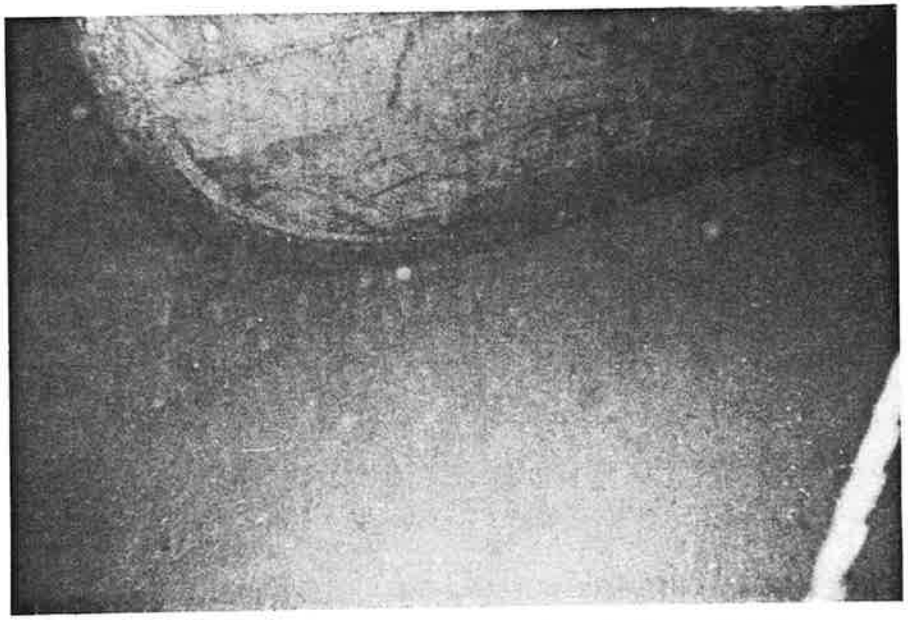
In general, we found that the water immediately in front of and within several models of the Cobb pelagic trawl moved more rapidly than did the entire trawl system. A decline in water speed was gradual toward the codend, but more pronounced along the trawl exterior. Within the codend the flow was nil. Fish arriving at the net terminal end could swim leisurely.



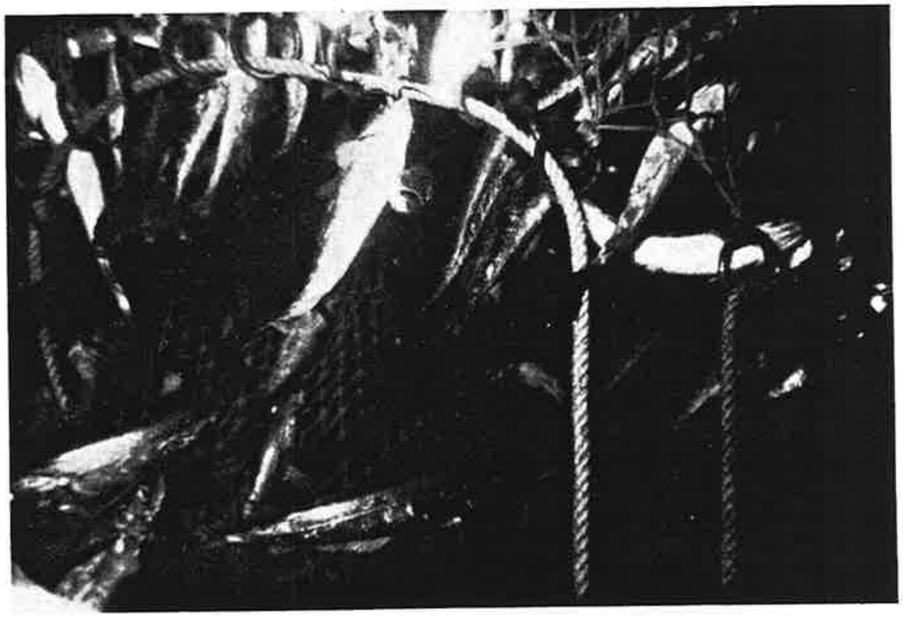
Diver observes trawl door contact with sea floor.



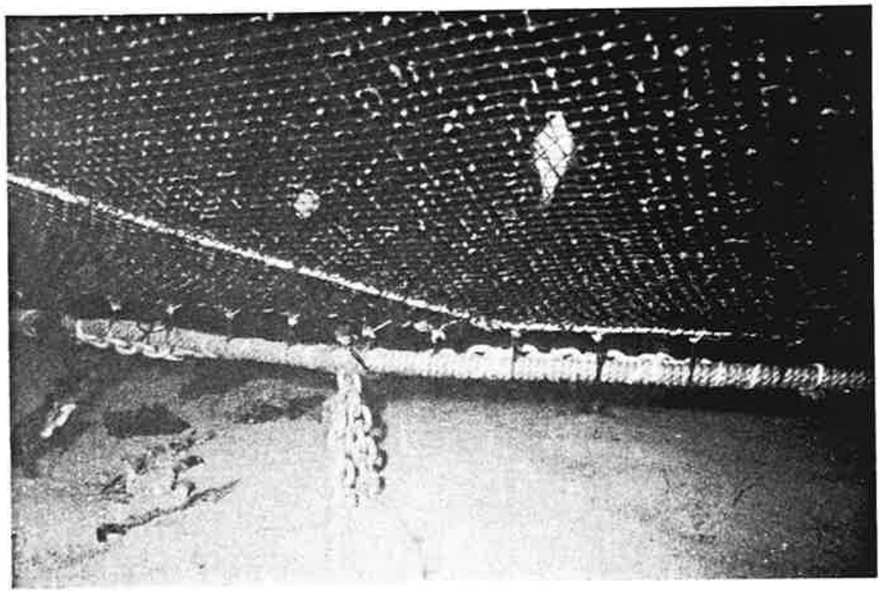
Sediment raised by passing door obsures its trailing surface and portions of the trawl wing.



Trawl door shoe in contact with seabed.

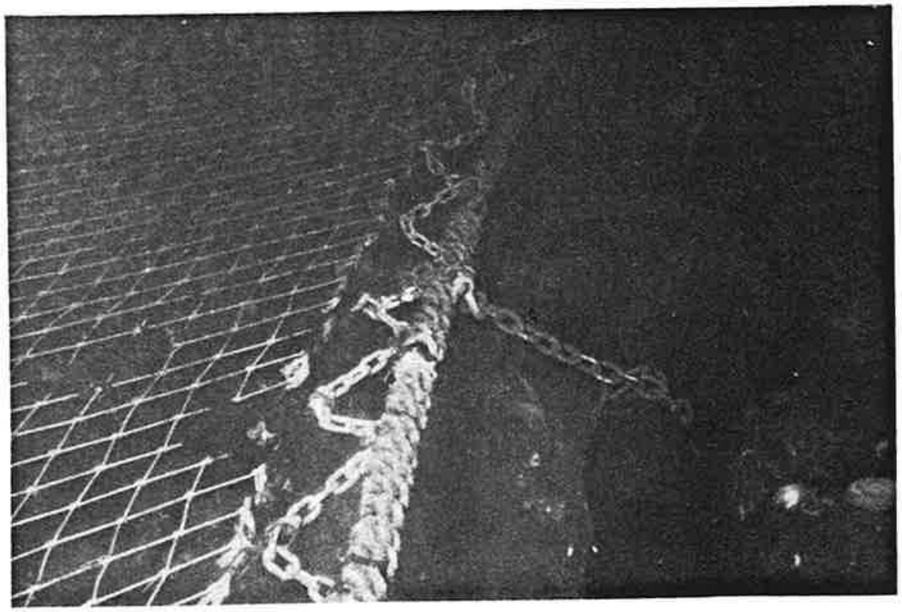


Although codend was opened by divers lack of water flow prevents flushing fish out.

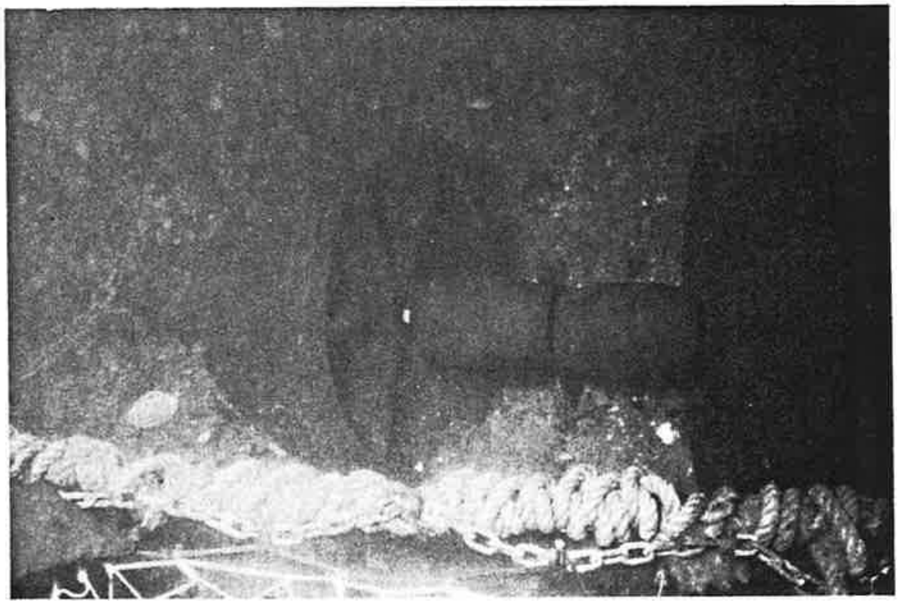


Rope wrapped footrope configured to remain just off bottom.

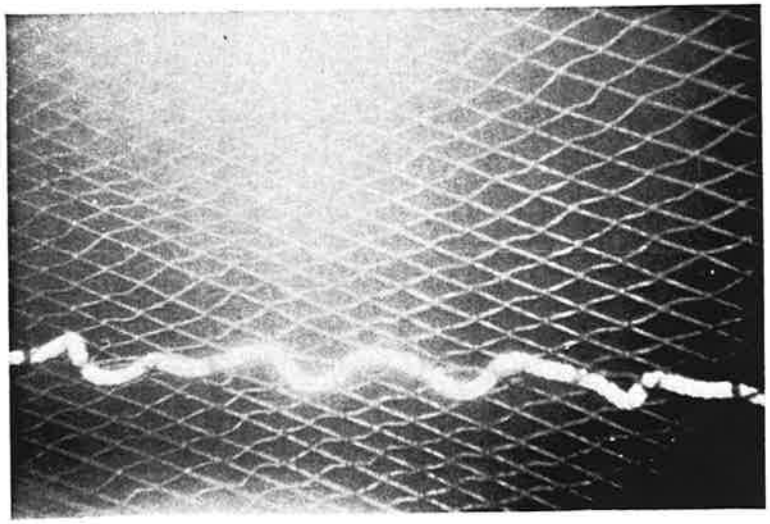
Wing footrope of <u>Tordenskjod's</u> "best" net about 10 inches off bottom.



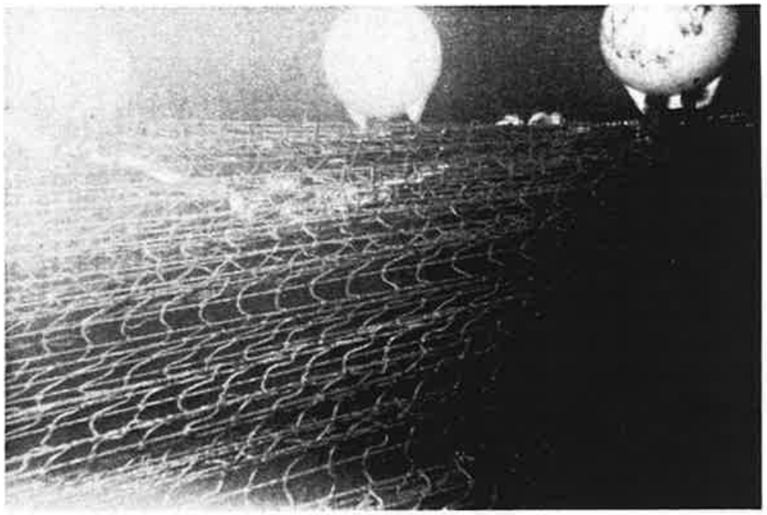
Roller gear rigging along wing allows footrope to rise a short distance.



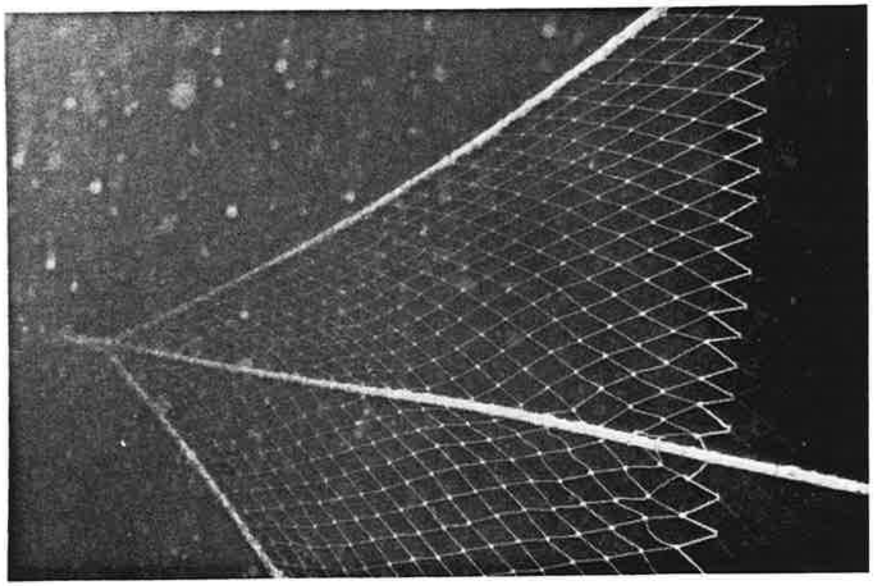
Only a few rollers at footrope center actually roll throughout tow.



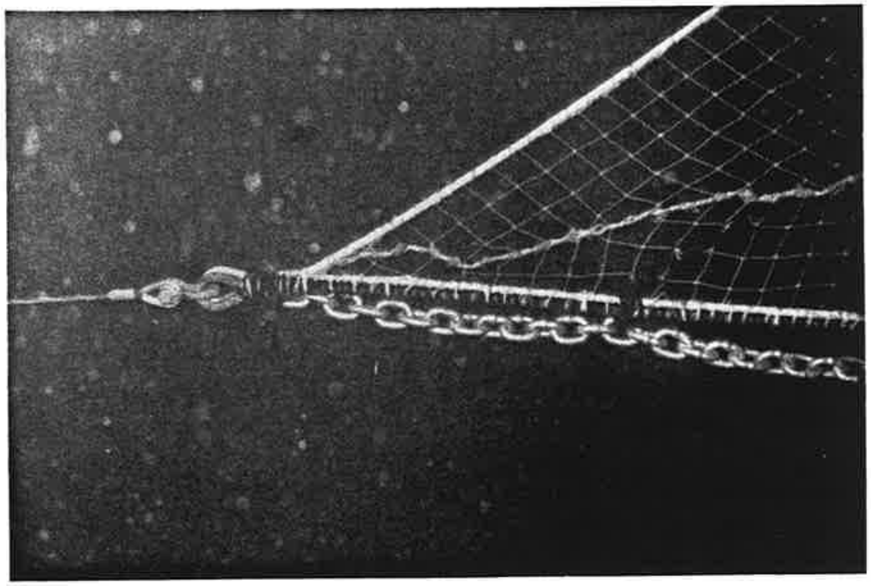
Improperly hung ribline takes no strain.



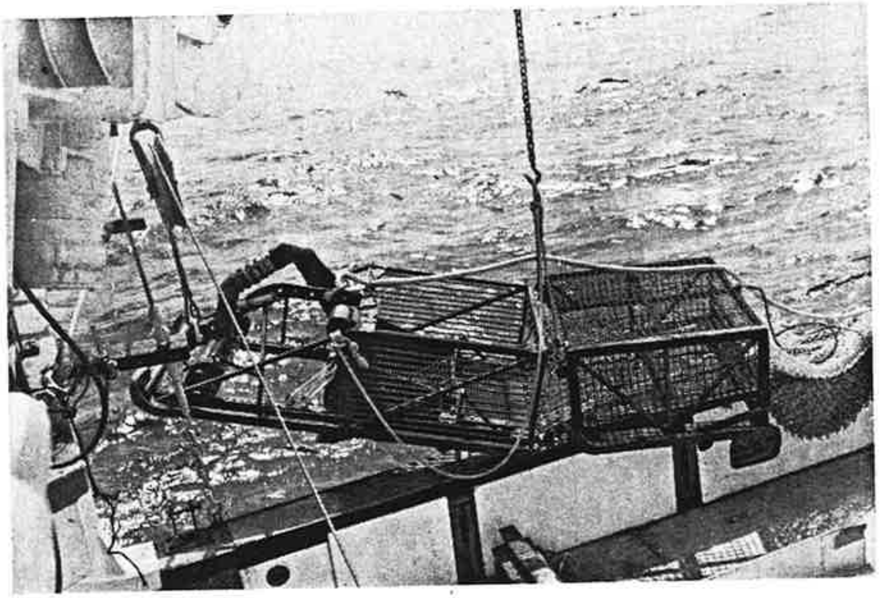
Headrope corner wedge poorly cut and hung.



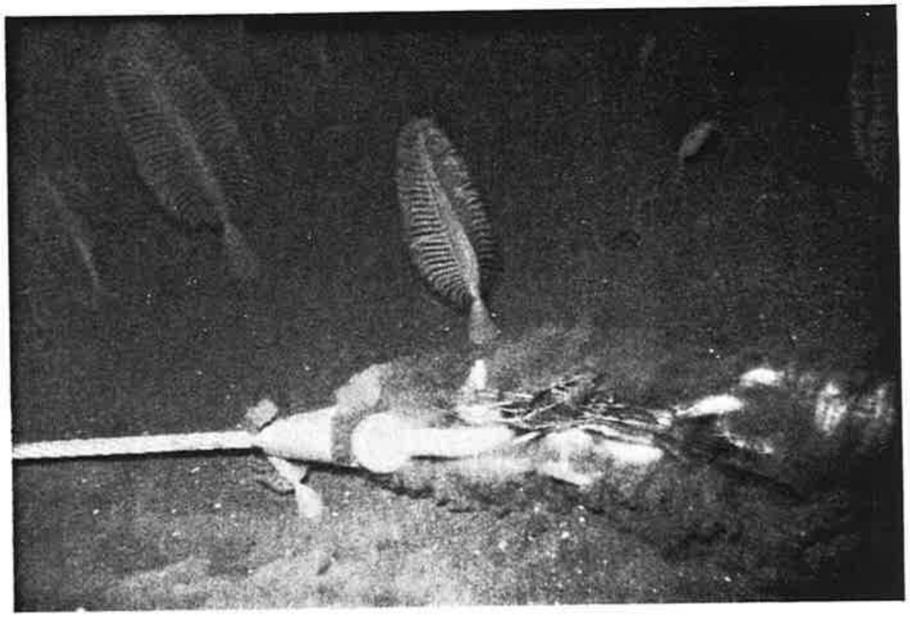
Example of excellent web distribution on mid-breastline towing point.



Open meshes along footrope wing tip.

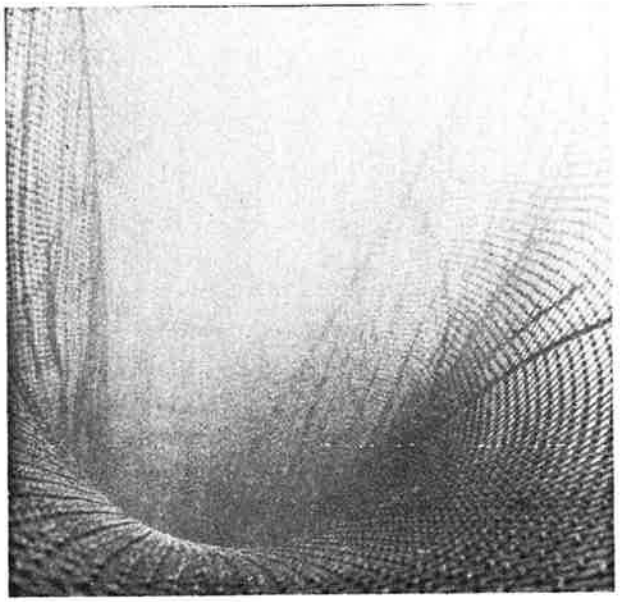


Experimental clam dredge.



Bridle/wing tip contact with seabed.

Diver measures vertical opening of a trawl wing.



Interior view of trawl body.

Our findings should not be applied to all nets. Numerous factors influence water flow in and around nets (e.g., mouth opening dimensions, mesh and thread size, diameter of the body, intermediate and codend, and size of chaffing gear. Most bottom trawl designs that we evaluated had portions of the intermediate, codend, and bag collapsed until fish entered the codend and blocked water passage out of the bag meshes.

Gill Nets

Our interest in gill nets was, for the most part, limited to sunken and off-bottom gill nets (setnets). However, when surface gillnets were abandoned after snagging underwater objects, we studied their ghost fishing potential and recovered many harmful ones.

Sunken Gill Nets

During the late 1970s some Southeast Alaska fishermen expressed interest in deploying bottom-tending gill nets (sunken) for Pacific cod. This fishing method, although not then generally allowed in Alaska, was used in Europe, the U.S. northeast coast, and for a minor cod fishery which operated in Puget Sound. Alaska fishing regulations were proposed to allow near-bottom gill nets that fished a minimum of 18 inches off bottom. Some Alaska fishing interests were concerned that such nets would adversely impact Dungeness and king crab populations.

My assignment was to test the concept that some form of gill net could be fished off bottom in a manner which allowed crabs to pass beneath but the net would still remain within the near-bottom zone inhabited by the cod. Following a cruise aboard a Gloucester, Massachusetts, based setnet vessel to further my knowledge of this type of gear, I fabricated and tested several designs, including those suggested by the interested Alaskan fishermen. The nets were tested both in Alaska aboard the RV *John N. Cobb* and in Puget Sound using the NMFS gill net vessel RV *Sea Urchin*.

The net having the greatest potential, in the eyes of interested Alaska fishermen, separated the leadline from the bottom line of the net by dropper lines up to 3 feet in length. By design, the leadline anchored the net to the seabed while the pressure-proof floats lifted the web off the sea floor to the length of lines tied at intervals between the leadline and the web bottom line.

Initial tests in Puget Sound appeared successful according to diver observations. However, at the local test site, the tidal current was nominal, there were no crabs, no juvenile halibut, nor large quantities of other marine species. Each of these factors impacted the Alaska field tests.

Underwater observations of the gill nets were made by divers and from a submersible. We learned that moderate, near-bottom currents in Frederick Sound, Alaska, and several locations along Icy Strait produced a variety of problems. Only during short, slack-water periods did the nets float upright off bottom to the height allowed by the dropper lines.

Once the current began to move, the nets were pushed over until the web contacted the sea floor. Flounders and other small fish trapped in the meshes became bait for crabs which walked onto and became entangled in the web. Entangled marine animals and bottom snags prevented the net from rising off bottom as currents slackened or until it was retrieved. Therefore, most of its intended fishing time was ineffective except to continue trapping flatfish, crabs, and other bottom-dwelling species.

The nets, in several fishing locations, caught large numbers of juvenile halibut and other flounder. The probable damage to halibut stocks, if similar nets were used in commercial numbers, was far too great to pursue the tests further or to allow commercial set nets.

Net Dropout

We knew, based upon other scientists' salmon gill net studies, that some dead or injured fish dropped out of gill nets and were lost. One useful fact, when determining the consequences of establishing a new setnet cod fishery, was the volume of fish wasted from dropout.

During 1978 and 1979, EF&GRU conducted cod dropout studies near Port Townsend, Washington. Divers located cod entangled in commercial and experimental setnets as the nets fished and we compared those entanglements with the number of cod retrieved aboard the fishing vessel. About 14% of the snared cod escaped or dropped out (High 1981). Of that number, 35% dropped out during the net retrieval. No estimate of survival for fish escaping the net was made although several fish found dead or dying in the net underwater did not reach the vessel. Our several visits to the net while it fished throughout a 23-hour soak, allowed us to discover that 45% of the catch occured during the 0600 to 0900 time period. That short interval was only 13% of the total fishing time.

Ghost Nets

Nets, primarily gill nets, which are accidentally lost or intentionally abandoned by fisherman and have the potential to continue fishing are called ghost or derelict nets. Recreational divers and EF&GRU divers found many salmon nets lost by fishermen in Washington State waters.

When a net cannot be pulled up, fishermen cut all accessable valuable parts (the corkline, buoys, etc.) free and allow the non-buoyant web to carpet the snagging object. Therefore, rarely are ghost nets found in the water column fully extended and fishing as designed. Their fishing efficiency usually drops rapidly, or the impacted species changes as was the case of a net at Point Roberts, Washington, which ceased catching salmon but began entangling crab.

Independent observations at several lost nets revealed the variety and magnitude of animal entanglement and loss (High 1985). Over a period of 6 years, I observed numerous sea birds entangled at depths of 60 feet and deeper. Many individuals of the common local fish and crab species were killed in the web during the 6 years it took for the web to deteriorate significantly.

Washington State fisheries managers several times requested the EG&GRU dive team to remove destructive ghost nets. Although these nets were not the responsibility of the NMFS, I had considerable experience working around dangerous webbing and had established a relatively safe method for ghost gill net removal.

Of all the ghost nets we inspected, one 300-foot-long net abandoned by a salmon fisherman on the Point Roberts Spit, adjacent to the Canadian border, was by far the most destructive

(High 1991b). Not only did the net entangle about 1,000 female Dungeness crab in the 4 or 5 days it was down, it would have continued to snare many thousands more crab for a year or longer.

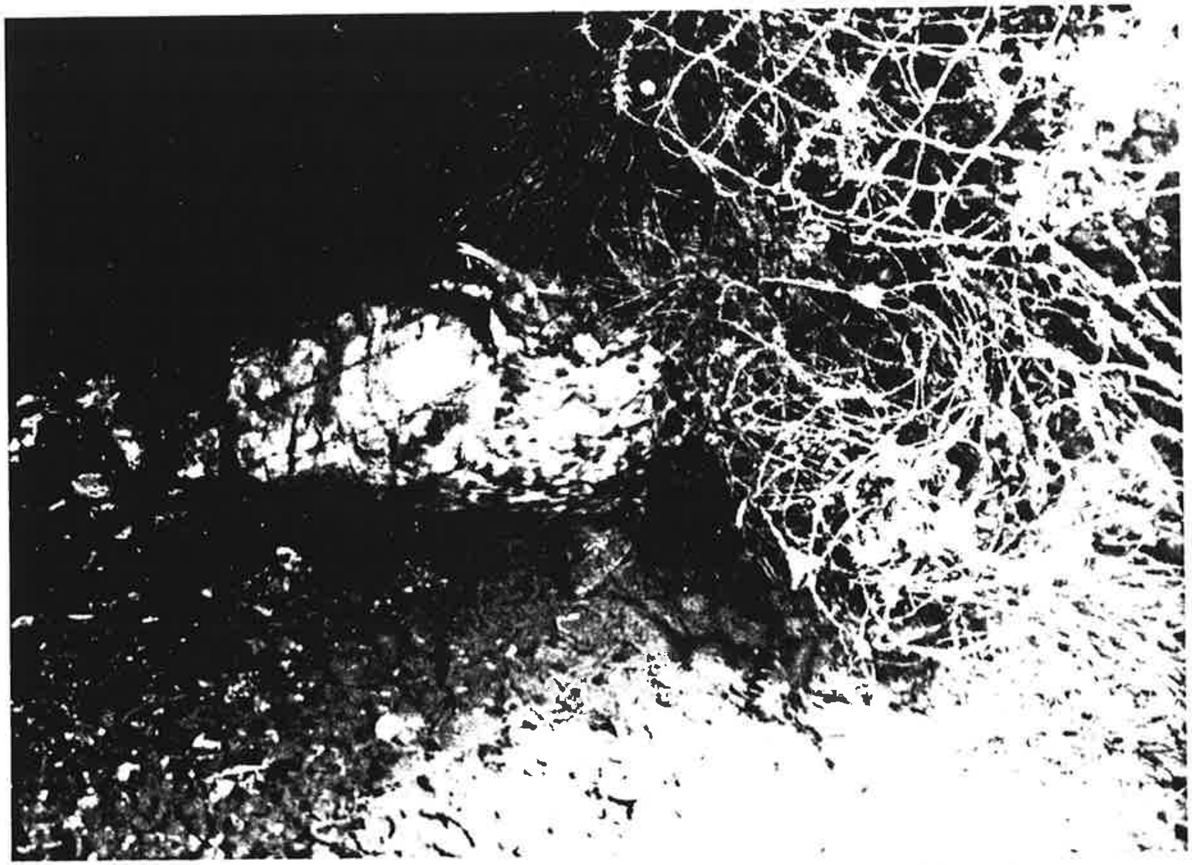
Numerous gill nets were found by recreational divers snagged and abandoned on a sunken vessel in Puget Sound, Washington, at depths of 70 to 105 feet. The vessel's high off-bottom profile allowed the nets to drape across large structural expanses, forming vast canopies of entangling meshes. Three harbor seals, numerous sea birds, and fish were in the net when our dive team surveyed the site. Only a small portion of the multiple nets could be removed. Fortunately, parts creating the most destructive canopies were cut free by our divers and pulled to the surface by cooperating commercial fishermen.

Fish Traps

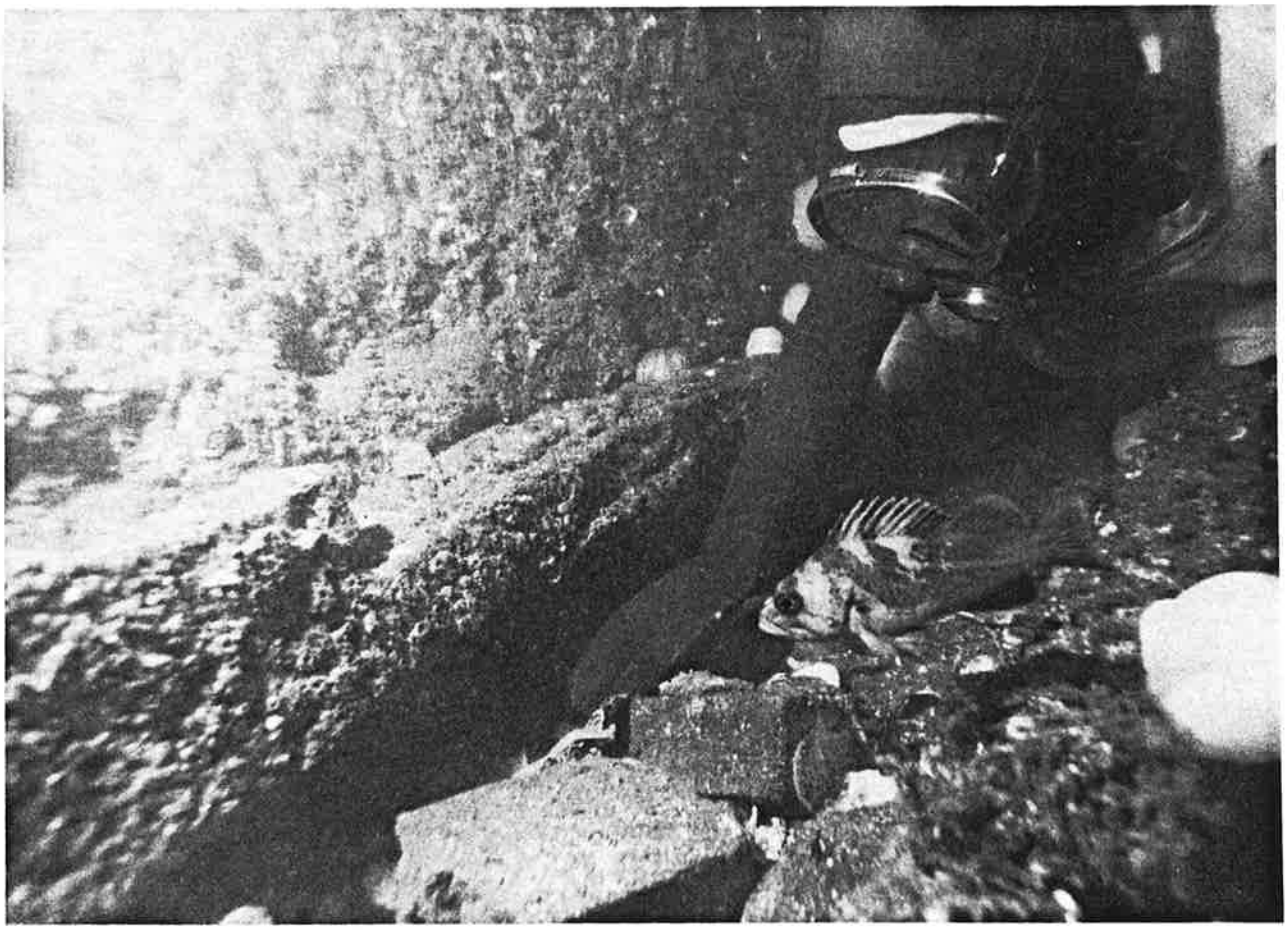
In 1968, our BCF gear research team began experimenting with several trap designs. The initial objective was to modify king crab pots to effectively capture halibut. The first test, conducted by team member Fred Hipkins, failed to produce halibut. However, Fred did catch enough blackcod (sablefish) to redirect our effort to that species.

The team, under the guidance of Dick McNeely, decided a sablefish trap should be lightweight and cheap to make so that numerous traps could be joined to a single groundline at appropriate intervals. An early design consisted of several 3 foot diameter hoops wrapped with heavy gauge 2 inch by 4 inch wire. Each trap end was fitted with a web tunnel for fish to pass into the enclosure. A lifting bridle was attached to one end. Polypropylene groundline was used as it would float off the bottom between the traps, thereby reducing the likelihood of snagging on objects.

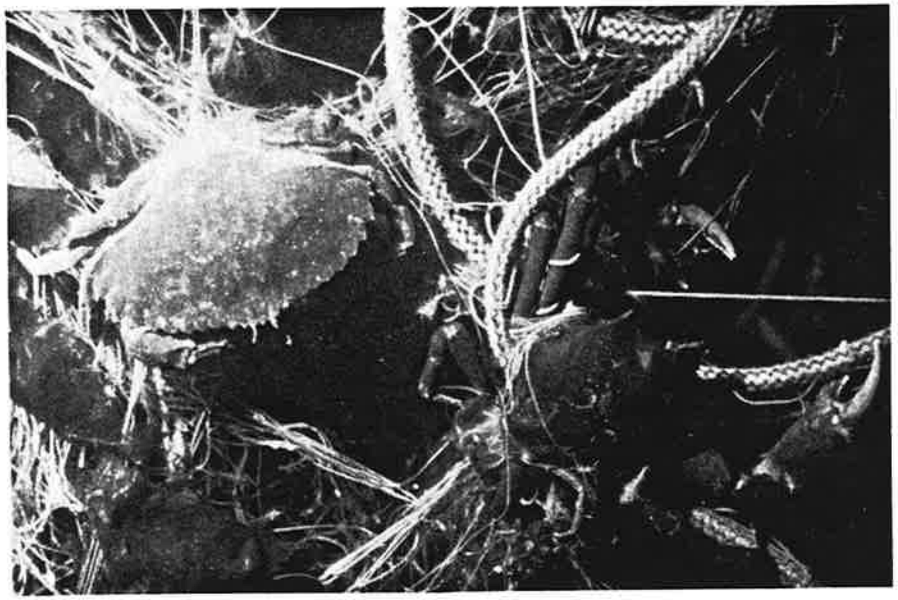
Early test results were erratic. On a string of 10 traps fixed at 50 fathom intervals along the groundline, several traps captured up to 50 blackcod each while adjacent ones were empty. The tunnel design was such that it should have allowed entry no matter which part of the trap's circumference lay horizontally on the sea floor.



Harbor seal entangled in lost salmon gill net.

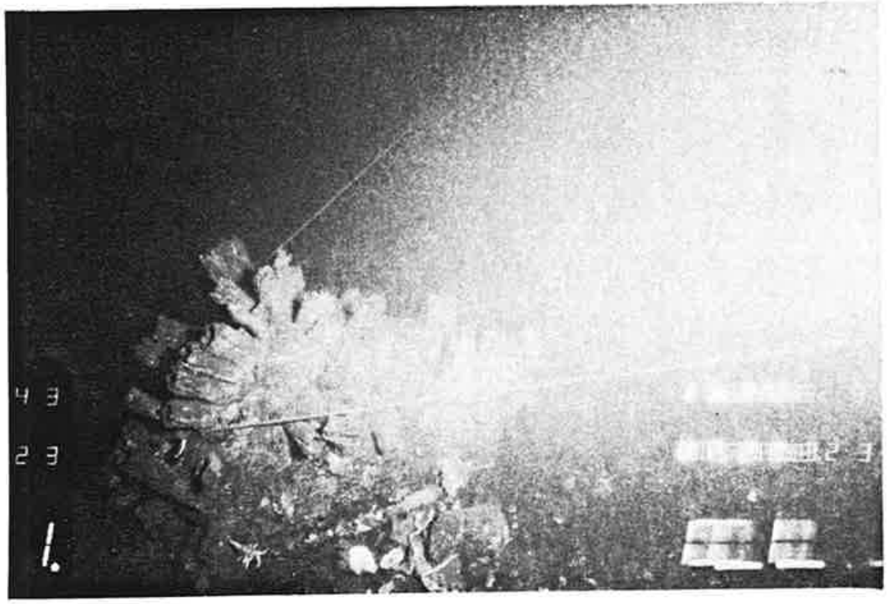


Diver investigates octopus cave beneath MV Dauntless.
A copper rockfish is poised to capture disturbed prey.

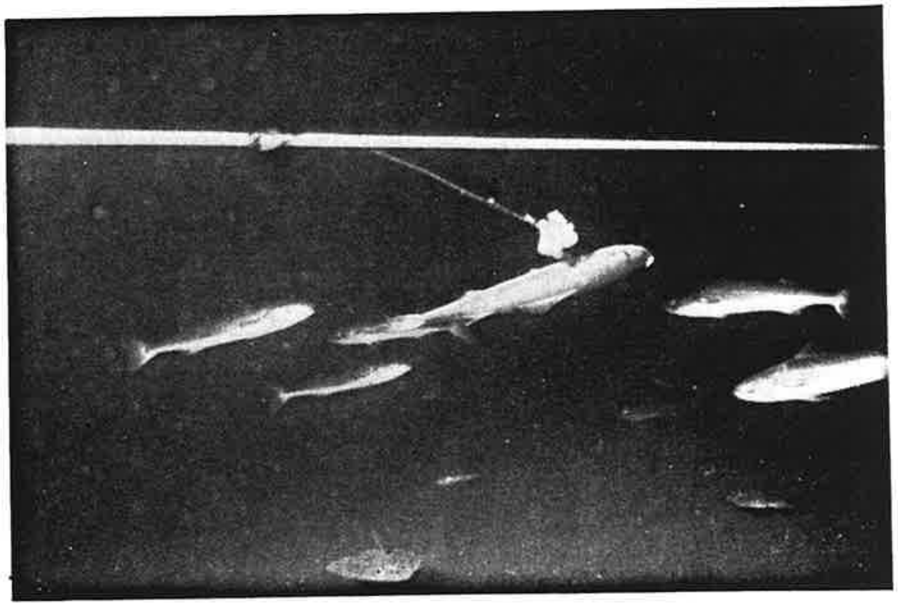


Crabs tangled in ghost gill net.

Experimental setnet pushed to the seabed by currents.

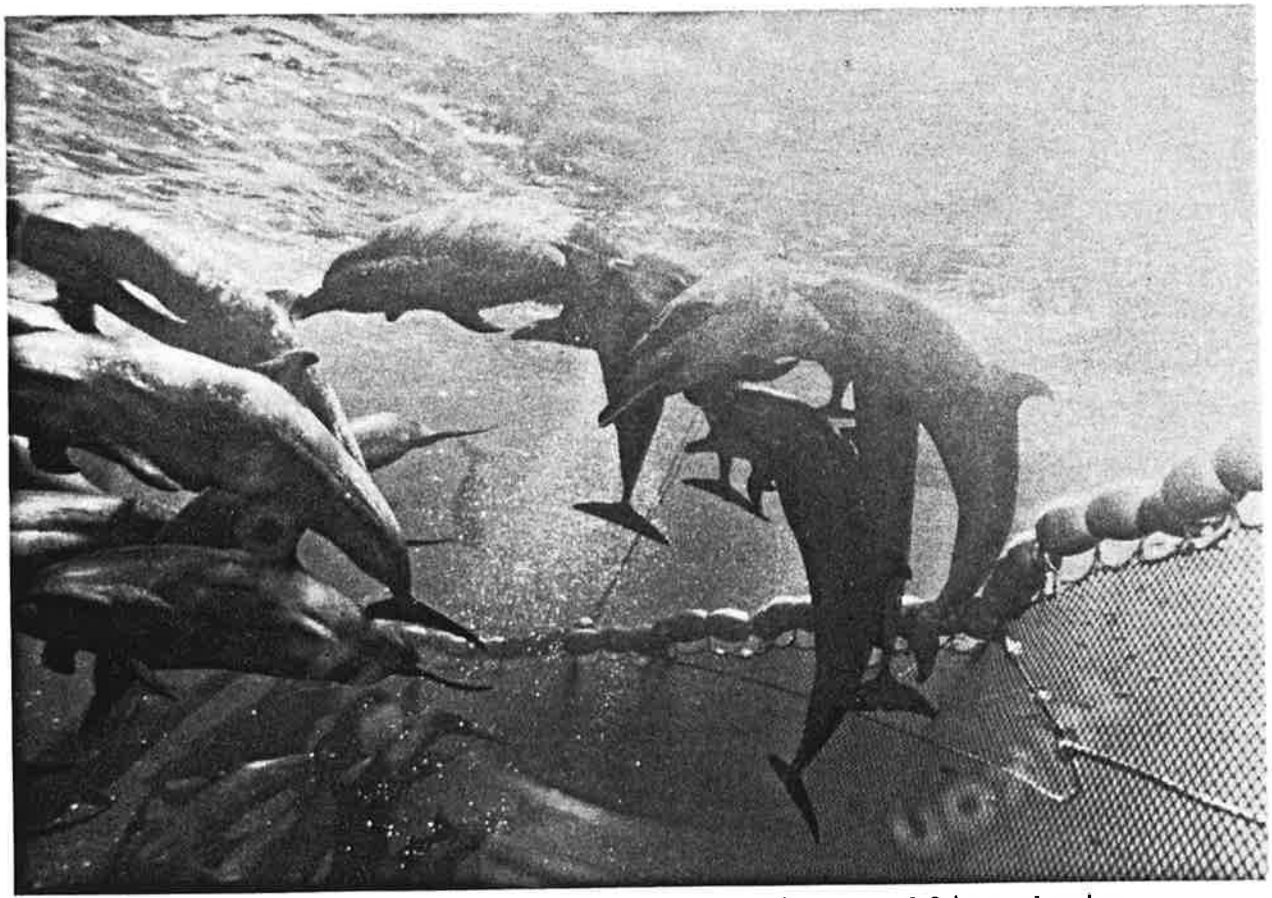


Halibut longline snagged on barnacle encrusted boulder.



Sablefish strike at baited hook.

Octopus attempts to remove crab from pot.



Dolphins escape over submerged seine corkline during the backdown procedure.

Our dive team decided to follow a trap string during a set in about 100 feet of water. We hoped the cause for some traps to not capture fish might be observed during that shallow descent. We were not disappointed. As the traps sank, most slowly began to turn vertical in the water column. This was caused by the trap bridle at one end being attached to the more slowly descending buoyant groundline. Upon reaching the sea floor, several traps remained upright. The tunnel at one end was 8 feet high pointing to the surface while the other was sealed against the substrate. Fish could not enter. Other traps in the string, upon reaching the bottom, hovered for a moment off balance and slowly fell onto their side, the normal fishing position. A quick change in the bridle location corrected this flaw.

Hook and Line

My interest in observing hook-and-line fishing gear was stimulated by two events. While swimming to a diving site, I passed a fisherman in a boat. He became verbally abusive because, in his view, I was scaring "his" fish away. My initial attempt to correct his thinking was fruitless.

Underwater, I passed a school of perch located about 8 feet or more off bottom. I saw the fisherman's baited hook quickly lowered through the school to the sea floor. Several perch dashed after the bait but stopped short before descending deeper than the depth selected by the school. Later, as the angler retrieved the hook, the same unsuccessful chase took place.

I surfaced to his temporary wrath. I explained where the fish school was and what individual fish were doing. His manner implied he accepted none of my suggestions but, a few minutes later while I was again watching the action underwater, I noted that he stopped his baited hook at the suggested depth. Immediately one or more fish dashed to the bait. Once one fish took interest in the bait others quickly joined in. Of the several fish seen hooked, most were those which tried to snatch the bait away from another fish that was approaching or just nibbling on the bait.

Once hooked, some previously disinterested members of the school actively chased after the hooked fish trying to take away any parts of the bait exposed around its mouth. Where multiple hooks are allowed, anglers seeking smaller, school-type fish might do well to have several baited hooks closely spaced and not be too quick to retrieve the first fish hooked.

As the population of lingcod declined throughout the 1960s in Puget Sound and adjacent waters, the WDF decided that removal by sport divers was the cause. In the WDF's view, divers could readily spear males as they guarded eggs during the winter spawning period. That fact is undisputable as is the fact that line fishermen also catch guarding males. Once the male is gone, by whatever means, the eggs are quickly devoured by nearby predators.

The WDF chose to ban winter lingcod spearfishing by divers but continued to allow line fishermen to fish. In an effort to draw attention to the inequity of the regulation, I began fishing for lingcod underwater with hook and line. It was legal, but circumvented the intent of the ban. I hoped my findings would prompt a winter closure for all anglers. I learned that male lingcod guarding eggs were quick to attack both bait in the form of fish pieces and artificial lures. Once my activity and results were brought to the attention of a WDF administrator, he continued to yield to the pressure of sport fishing groups by only banning all forms of winter lingcod harvest by divers including underwater rod and reel. It wasn't until some years later, when the lingcod population virtually disappeared that line fishermen were also barred from fishing during the spawning period.

The EF&GRU's most significant work with hook-and-line gear (setline, longline) was the multi-year effort using a deep submersible to study halibut longlines. In concert with IPHC investigators, we tested the effectiveness of several baits and, during 1983, compared the traditional "J" type hook to the virtually untried tuna circle hook with dramatic results. Direct observations of the gear and fish allowed us to see events not available to biologists and fishermen confined to a surface ship. Part of the near 100% catch increase using the circle hook was from its ability to retain hooked fish. About 47% more fish escaped from "J" hooks.

Two reports on our success precipitated the switching of over five million "J" hooks to circle hooks before the 1984 halibut season. While still making our underwater observations, I reported our initial results by radio to a wide fishermen audience. Also, at the request of the fishing industry, I presented a more complete report during the 1983 Seattle Fish Expo. Manufacturers were hard pressed to quickly supply even part of the demand for circle hooks.

Herring, the most common halibut bait, although effective at attracting halibut, was often lost from the hook before reaching the seabed. A variety of fish and invertebrate feeders quickly stripped the remaining herring pieces from the hooks. Salmon pieces were, overall, the most effective bait while tough octopus pieces stayed on the hook for the longest period. As a result, when the hooks remained on the bottom (soaked) for some hours, octopus pieces continued to fish.

Clam Dredge Investigations

A study of a hydraulic clam dredge, similar to those used commercially on the U.S. East Coast, was pursued by the BCF Gear Unit in 1968-69. Some scientists and fishermen believed commercial quantities of clams existed along the Washington coast and the Alaska Peninsula shore of the Bering Sea. Our dive team (composed of Larry Lusz, Ian Ellis, and myself) assisted the project engineer by observing all components while the dredge was towed across the hard, rock strewn, gravel sea floor. Dredge dives were especially dangerous because visibility aft of the leading edge was usually zero. Most assessment was done by feeling the heavy metal structure and its contact with the substrate.

Several concerns could not be adequately judged from aboard the dredge tow vessel. Underwater, we easily determined how deep the pressurized water jets penetrated into the substrate. We learned where clams forced from the substrate by those jets were deposited, either in or over the retainer bag or blown beyond the dredge frame back onto the bottom. The dredge path was sampled to learn what percent of the clams remained after the dredge passed.

The divers also investigated a mechanical problem which arose during the tests. While a heavy nylon hawser was used to tow the dredge, water serving the multiple jet array positioned along the dredge's leading edge was pumped through a large, heavy-duty hose from a pump on deck. For no known reason the water hose frequently pulled free of its connection at the dredge (High 1971d). We were asked to identify the cause and offer a solution; once we divers were on site underwater the problem was obvious. The engineer had calculated the length of tow hawser needed for various dredge operating depths and had allowed additional amounts for nylon stretch. He deployed a length of water hose calculated to ensure it took none of the towing strain. We immediately saw the calculations were in error as the hose pulled from the dredge fitting when excess stretch in the nylon tow hawser allowed the hose to pull too tight. Letting more water hose out at each depth solved the problem.

After all dredge tests were completed in Puget Sound and the device demonstrated it could efficiently gather clams, the system was taken to the proposed commercial harvest site on the Washington coast. Variables such as rough seas and possible different substrate type were expected to require some adjustments for greatest success.

Following nearly 2 weeks of tows and adjustments, the outlook for success was bleak. Almost no clams were collected. Our dive team was again called upon by the clam dredge project leader. A wide range of possible causes for the dredge failure were posed for us to investigate. Our first dive was made in the open ocean to assess the bottom type at a depth of about 70 feet. It was believed waves and surge packed the material to a hardness the dredge could not penetrate. Once on bottom, we observed that the relatively smooth sand sea floor to be almost concrete-like. However, by pressing our hands against the sand and waving it rapidly, our hand quickly sank several inches. The bottom was hard but could be readily liquified.

Our next task was to observe the dredge in operation. Mostly by feel, we determined the runners were in full contact with the sea floor. The water jet nozzle array blew sand in all directions which created, as planned, a deep hole beneath the jets sufficient to expose any clams. We looked beyond the sand cloud to see whether clams were thrown clear of the dredge. Then we lay in the pathway between the water jets and the retainer bag to feel (we could see nothing) whether clams were in some manner avoiding the bag. Finally, we swam from the dredge along the track left by its passing. Slowly the visibility improved as the sand settled so we could view the nearly 18 inch deep by 3 foot wide dredge track. Sand was soft and loose within the track. The sea floor adjacent to the track was carefully scrutinized. We returned to the tow vessel with the cause for the dredge's failure after only 4 dives. In fact, the dredge worked as designed- there were no clams.

Throughout the dredge research effort the dive team gathered data by direct observation and physical contact. Rapid adjustments to the water jet array angle of attack was possible for improved efficiency. We recommended changes to the towing point to achieve better dredge contact with the seabed. However, the two major findings (cause of water hose failure and absence of clams at the coastal study site) clearly sped the progress of the investigation and perhaps were the dive team's most dramatic and quickest solutions to distressing problems.

Geoduck Sampler

The clam dredge had a devastating effect upon geoducks two or three times when test harvesting occurred where the large clam was present. The animal's extraordinarily long neck allowed the clam body to lay up to 18 inches or more beneath the substrate while the siphon opening was at or near the seabed surface. A heavy knife blade affixed to the leading edge of the dredge cut through the substrate just ahead of the water jets. The blade severed the necks from nearly 700 geoducks during a single 10 minute tow and, to the dismay of the project leader, neatly deposited them in the collection bag.

In an effort to learn more of the geoduck's distribution beneath the seabed surface at a time before significant commercial exploitation, we constructed a simple means to measure their depth. An airlift was made from an 8 foot long, 3 inch diameter PVC (polyvinyl chloride) pipe. A short piece of flexible high-pressure air hose was threaded to the pipe 1 foot above one end. The other hose end was fitted with a quick connect to a scuba cylinder.

Upon locating a geoduck neck or a slight depression in the sand/mud usually indicative of a geoduck's presence, our diver raised the pipe to vertical. The suction end was placed over the neck and the air supply turned on. Considerable suction was created as the air expanded upward through the pipe. Sediment was quickly pulled away from the clam, allowing us to measure the depth of its shell. While the body was usually 15 to 18 inches (and as much as 24 inches) deep, the neck could not rapidly withdraw to more than about 12 inches into the substrate. Consequently, the large hydraulic dredge, designed for smaller clams, severed the necks of nearly all geoducks encountered. The airlift pipe caused no damage. A single scuba cylinder, containing about 70 cubic feet of air, generated suction to expose between two and five geoducks. Water often entered the cylinder after the air was depleted. For that reason, the cylinders used for this purpose were promptly inspected and cleaned to preclude corrosion damage.

IMPACT UPON ENVIRONMENT

Aquatic exploiters, environmentalists, and researchers alike have often inquired of divers about the effect that various intrusions have upon the water, substrate, and inhabitants. The answers are often difficult to come by since we have fewer tools and perhaps more limitations while working underwater when studying cause-and-effect relationships than do land investigators.

Does the presence of a diver, submersible, or harvest gear present a bias, altering animal behavior or the way fishing gear functions? Several examples have been recorded in this report to illustrate some effects or the absence of a relevent effect. Many fish species give no hint of reacting in any altered way unless the intruder ventures too close. Beyond a critical distance, which varies among species, every measure we employed suggests little impact among marine animals. Schooling fish for example, such as herring, anchovy, and rockfish, simply move aside when a relatively slow-moving object comes near.

Diver Impact

Flatfish can often be caught by hand and seldom dart away until diver, submersible or trawl component is closer than 5 to 8 feet. Spearfishing success indicates that divers can closely approach a variety of species. We have seen marine animals stalk prey, be stalked by predators, feed, be eaten, spawn, guard eggs, protect offspring, defend territory, and swim to the diver to satisfy their curiosity. In general, divers can avoid impacting the marine animals and topography they go underwater to study.
I have no evidence which suggests our divers had any measurable impact upon the habitat itself. That is not to say other divers at other locations have not damaged the habitat. Quite the contrary, as fragile coral habitat is readily damaged by impact with divers and, during our saturation dives from undersea habitats, it was necessary to avoid harming the study area. In regions of British Columbia where vast numbers of large brittle sponges and fragile corals once occupied rock walls, many were crushed and broken by careless divers.

Marine Mammals

Divers in the water do seem to influence marine mammals. Our divers have only occasionally encountered them. Harbor seals (<u>Phoca</u> <u>vituliua</u> seem suprised at meeting a diver and usually quickly depart. Both California (<u>Zalophus</u> <u>californianus</u>) and Steller sea lions (<u>Eumetopias</u> <u>jubatus</u>) are often attracted and choose to entertain both themselves and the divers with mock attacks and underwater ballet.

Until killer whales (<u>Orcinus</u> <u>orca</u>) were captured and studied in detail, it was generally believed they posed a great hazard to divers. Eventually a number of diver-whale contacts demonstrated the hazard to be more theoretical than real. I made a number of dives during the capture and holding of Namu, Shamu, and other individuals. Ample opportunities arose for these animals to attack various members of the dive team since the marine mammals knew at all times when and where divers were located underwater. When, on rare occasions, divers and killer whales meet, the whale is in full control of the situation. The diver's only impact is to serve as the subject of the whale's investigation. Apparently once satisfied the diver is not a source of food, the whale continues on about its business.

Jay Riffe's encounter in 1963 supports this opinion. I observed the event from a cliff overlooking the dive site. Jay, a breath-hold diver, was competing for a position on the U.S. Spearfishing team. The competition was conducted along the west side of San Juan Island, Washington, during the summer when killer whale pods frequent the area. While divers were hunting in the water, I saw a pod of killer whales ambling south several hundred yards offshore. Jay, too deaf to hear the warnings sounded, continued to make dives searching for fish. As the pod came abreast of his location, the apparent dominate male made a 90-degree turn toward the diver. The pod milled around as the killer whale approached Jay. Oblivious to the on-coming whale, Jay dove. He was diving to a depth of about 80 feet and remaining for 1 to 2 minutes. The whale dove adjacent to Jay and apparently followed him during his short hunt. The whale surfaced a few moments after Jay and returned directly to the waiting pod. The entire pod continued swimming south.

Jay Riffe was unaware of his momentary dive partner. The diver's impact upon the whale was negligable, the killer whale's impact on the diver would have been great had it been seen. In the same location several years earlier, I was told by observers that a killer whale descended where my air bubbles rose to the surface. My partner and I did not see the creature underwater.

There should be little need to further verify that a diver working directly on full-sized seines, trawls, dredges, etc. do not alter their function. Normal forces applied to those active gear types negate any effect of diver presence. Therefore, what we saw and measured on commercial fishing gear did not suffer from observer influence. However, divers were limited to depths less than 150 feet and submersible operations near moving gear were unsuccessful, so we were not able to study the gear at the greater fishing depths.

Harvest Systems

The impact of harvest systems mentioned in this report to the environment (beyond the target species) in which they are fished vary from no effect to extensive damage. Relevant factors include widely varying gear types, bottom type, target and non-target species, and currents. Perhaps the single greatest concern beyond overfishing and wasted bycatch is incidental damage to the sea floor and associated sedentary plants and animals.

Nets

Purse seines and surface gill nets can alter the sea floor when contact is made. Sometimes contact is intentional because the target species is in water shallower than the depth of the net. Other times the net may be carried by tide and wind onto shoals allowing chains, rings, leadlines, or warp to drag on the bottom. Kelp may be torn from its holdfast, small rocks overturned and invertebrates displaced. Infrequently a serious snag may result in some web remaining behind as a ghost net. Occasional sweeping of the bottom by seines and surface gill nets appears to have no lasting affect.

Trawls

Obviously pelagic trawls have little potential to harm the sea floor. When fished in midwater, we saw large numbers of sticklebacks (and fewer small herring) injured but not retained by the net. Jellyfish are captured with many shredded as they are forced through meshes.

Bottom trawl systems, including doors, bridles, tickler, footrope and net belly do, in various ways, impact the sea floor. Most often objects struck by trawl components yield to the power of the towing vessel. However, our observations suggest the long-term impact to be less overall than some critics have proclaimed.

Door intrusion into the bottom depends on the door's size and weight, as well as composition of the substrate. Light-weight material and marine animals are picked up by door turbulence and resettled varying distances downcurrent. Near-bottom turbidity temporarily increases, although probably no more so than is generated by a passing school of feeding cod or pollock. Any creature struck by the door is likely to be crushed. Many Dungeness crab and various bottomfish species have been seen in the path of doors. All easily escaped. While king crab are much slower moving than are Dungeness crab, and I have not personally observed king crab in the path of a trawl door, their ability to avoid being struck by a submersible suggests that they could also routinely avoid an on-coming door.

The largest door that I have observed operating underwater was a steel, 6 foot by 9 foot model. Like smaller types, it created a mark on the sand/mud bottom about 4 inches deep. The track was discernable for several days but was not observed after 2 weeks (Dive log entry- "noticed door track from last week [6-days], very few torn sea pens seen").

Bridles, ticklers, and footropes in contact with the sea floor obviously disrupt the seabed surface. Sedentary animals like sea pens and anemones when present on trawl grounds are frequently pulled loose from their attachment whether on hard surfaces or in the substrate. Low-profile anemones were usually passed over by the sweep, but tall anemones (up to 3 feet in Alaska) faired less well. Although we did not study mortality of these animals, we did frequently note that most were simply bent over or pulled free and not noticably torn apart. Some promptly fell away from the snag line while many were held against the cables and chains for long periods.

Our most frequently used study area was north of Meadow Point, along the east shore of Admiralty Inlet, Washington. A nearly straight tow for about a mile was available at selected depths between 50 and 120 feet. After 15 years and several hundred bottom tows, we found sea pens to be still abundant. Fewer sea anemones were present. However, the reason for the decline of sea anemones is important. Discarded glass bottles were common in the tow area when we began using the location near Seattle in 1964. The bottles provided the primary solid surfaces desired by anemones on an otherwise rather uniformly inhospitable sand/mud bottom. Sea anemones often were seen attached to the bottles. Over time, the trawls (and occasionally the divers) picked up the bottles, thereby removing the needed habitat.

We saw many hundreds of Dungeness crab come within the influence of trawl components. Initially, most crab ran away from on-bottom bridles, thereby remaining in the path of the on-coming trawl. When contacted by the bridle, Dungeness crab invariably were carried over the cable and escaped. Similarly, when unable to avoid a tickler chain, the crab was pushed up into the water column and the chain passed beneath. When there were more than a few inches between the footrope and the sea floor, most crab escaped. Most crab struck by the on-bottom footrope were carried over and into the net. Infrequently, when a slightly off-bottom footrope allowed crab to pass beneath, the net belly dragging on the seabed struck the crab.

Longline Gear

Four deep submersible expeditions to Alaskan inside waters and the Gulf of Alaska included more than 60 dives to observe operating halibut longline gear. In addition, on numerous dives for a variety of objectives, we encountered longline gear that had been lost for some time.

The EF&GRU longline gear was set upon a wide variety of bottom types, including across canyons, on lava plateaus, in boulder patches, as well as on less hazardous mud, sand, gravel, and shell areas. Usually the gear meandered in the general direction of set, but it sometimes took extreme angle turns for some distance as currents, snags, and even large hooked fish managed to affect its location. At times halibut were seen to pull portions of the groundline 15 to 20 feet across or over the bottom. Halibut twice lifted the line more than 10 feet off bottom and entangled it in the submersible, an extremely hazardous event.

I made numerous longline fishing trips to British Columbia, Canada, and Alaska's Southeast, Gulf, Aleutians, and Bering Sea during the 6 years that I was employed by the IPHC. Frequently, non-target species were captured on the hooks and by entanglement with the groundline or gangions. Seldom did unwanted hooked fish survive. At certain locations, particularly east of Kodiak, weathervane scallops (Patinopecten caurinus) were encountered clamped onto the groundline. Their presence demonstrated that the longline gear swept the sea floor. From submersible and diver sightings, we know weathervane scallops, as well as smaller varieties, lay upon the sea floor or within small depressions in the sediment with shells parted when undisturbed. As the longline was pulled across the sea floor, it passed between the shells before the scallops could close. The scallops clamped around the groundline and were lifted to the surface.

Further east, corals were brought to the surface. Both small fragile corals clinging to rocks and large branch corals were snagged by loose groundlines, or hooks. During our submersible-supported studies of longline gear, we observed groundlines in contact with or snagged on a variety of objects including coral. Unless lifted off bottom, sturdy flexible corals usually appeared to be relatively unharmed by contact with longline components while more fragile hard corals often had portions broken off.

Man's Discards

Undoubtedly, some of whatever man has produced has been dumped into the ocean intentionally or, less often, accidentally. Most people, including me, agree that the ocean should not be an unregulated dump site. However, some un-natural material on the sea floor has value. I first embraced this view in the late 1950s when dive clubs decided to clean up certain underwater areas as a perceived public service. After watching a wide variety of marine animals destroyed along with the retrieved objects at these events and studying underwater some of the beneficial habitat created by such material, I concluded that underwater there is good and bad garbage.

Featureless mud bottom has a balanced ecosystem. This system produces far less for humans (to harvest) than similar aquatic environments having rock or other hard surfaces to support a greater range of life. The shipwreck Dauntless is, in my view, just one example of good garbage. It hosts a great increase in marine life. I also found the Japanese fleet lying beneath the waters of Truk Lagoon in Micronesia to support a phenomenal multitude of invertebrate and vertebrate species that were not present before the war ships came to their final rest.

Artificial reefs made from ships, rubble, tires, etc., support marine life and often concentrate harvestable species for successful sport fishing. Tires also make excellent shelters for octopuses, shrimp and fish. Even kelp may attach to non-toxic man-made materials where it could not otherwise survive.

Glass in the form of bottles may be unsightly to divers when seen strewn upon an otherwise untouched sea floor. However, these containers often harbor a wide variety of small marine animals, particularly octopuses. As previously mentioned, anemones also find bottles a suitable attachment site. When divers remove long discarded bottles as well as some other objects, many creatures die.

CONCLUSION

Advanced technology in the form of self-contained remote video cameras and acoustic measuring devices, along with changing research focus, has reduced the need for scuba diver-supported research at the Resource Assessment and Conservation Engineering Division of the Alaska Fisheries Science Center. Nonetheless, through the late 1980s and into the 1990s, our few remaining divers were occasionally called upon to assist with short-term projects. We monitored the impact of an experimental net barrier for sea lions at the Hiram M. Chittenden Locks in Ballard, Washington, and later installed experimental sound transducers designed to drive the marine mammals out of an area where steelhead concentrate. For the foreseeable future, scuba will provide a useful window to the aquatic environment.

CITATIONS

High, W. L. (Bill). 1991a Underwater study of dolphin and tuna behavior in a seine.
Conference Proceedings for the 1991 NAUI International Conference on Underwater Education, Miami, Florida, March 15-17, 1991: 148-158.

High, W. L. (Bill). 1991b. Ghost fishing gear.
Conference Proceedings for the 1991 NAUI International Conference on Underwater Education, Miami, Florida, March 15-17, 1991: 141-147.

High, W. L. 1987. Biological and technical observations of halibut longline gear from a submersible.
NOAA Symposium Series for Undersea Research 2(2),1987: 93-100.

High, W. L. 1985. Some consequences of lost fishing gear.
Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu Hawaii.
NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54, 1985:430-437.

High, W.L. 1981. Wreck-netters capture more than they know.
National Fisherman, 61(11): 122.

High, W. L. 1980. Bait loss from halibut longline gear observed from a submersible.
Mar. Fish Rev. 42(2): 26-29.

High, W. L. 1976a. The giant Pacific octopus.
Mar. Fish. Rev. 38(9): 17-22.

High, W. L. 1976b. Escape of Dungeness crabs from pots.
Mar. Fish. Rev. 38(4): 19-23.

High, W. L. 1971a. Submersibles for marine biological research.
IEEE 71 Eng. In The Ocean Environ. Conf.:37-40.

High, B. 1971b. Underwater grasshoppers.
Skin Diver, 20(6): 70.

High, W. L. 1971d. Underwater fishery studies are valuable.
Comm. Fish. Rev. 33(10): 1-6.

High, W. L. 1967a. The submarine Pisces as a fisheries tool.
Comm. Fish. Rev. 29(4): 21-4.

High, W.L. 1967b. Scuba diving, a valuable tool for investigating the behavior of fish within the influence of fishing gear.
Conference on Fish Behavior in Relation to Fishing Techniques and Tactics. FR:FB/67/E/2 Bergen Norway 19-27/10/67 14p.

High, W.L., and L.D. Lusz. 1965. Net tally.
Skin Diver, 14(8): 24-6.

High, W. L. 1963. 1963 World octopus wrestling championship.
Skin Diver, 12(7): 20-21.

High, W.L. 1963. The Pacific octopus.
Southern Outdoors, April: 37.

High, W. L. and D. D. Worlund. 1979. Escape of king crab _Paralithodes camtschatica_ from derelict pots.
NOAA Tech. Rep. NMFS SSRF-734: 1-11.

High, W.L. I.E. Ellis, W.W. Schroeder, and G. Loverich. 1973a. Evaluation of the undersea habitats- Tektite II, Hydrolab, and Edalhab- for scientific saturation diving.
Helgolander wiss. Meeresunter. 24: 16-44 (1973).

High, W.L., and I.E. Ellis. 1973b. Underwater observations of fish behavior in traps.
Helgolander wiss. Meeresunter. 24: 341-347 (1973).

High, W. L., Ian Ellis, and Larry D. Lusz. 1969. A progress report on the development of a shrimp trawl to separate shrimp from fish and bottom-dwelling animals.
Comm. Fish. Rev. 31(3): 20-33.

High, W.L., and L.D. Lusz. 1966. Underwater observations of fish in an off-bottom trawl.
J. Fish. Res. Bd. Can. 23(1): 153-4.

Sand, R.F. 1956. New diving sled.
Comm. Fish. Rev. 18(10): 6-7.

Snow, C.D. 1970. Two accounts of the northern octopus, _Octopus dofleini_, biting scuba divers.
Fish. Comm. Oreg., Res. Rep. 2(1): 103-104.

Voss, G.L., and R.F. Sisson. 1971c. Shy monster, the octopus.
Natl. Geogr. Mag. 140: 776-799.