Innovations in Harvest of Pelagic Resources

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INTRODUCTION

Alverson and Wilimovsky (1964), in describing futuristic developments in fish harvesting methods, wrote, "If man is to realize the full protein harvest from the seas, he must devise methods to utilize the great diversity of forms throughout a large geographic segment of the oceans. Many of the latent resources may not form aggregations but may be widely dispersed throughout the seas. Maximizing the harvest of the oceans thus confronts man with several alternatives: a) he must devise extremely efficient straining systems, or b) he must devise artificial methods which will cause fish to aggregate where they can be easily captured."

World fisheries production for 1973 was 65 million tons and in the future is predicted to be potentially capable of sustaining an annual catch of 100 million tons. This figure does not include increases from mariculture, nor from exploitation of unconventional resources such as krill, pelagic crabs, squid, etc. The almost twofold increase in conventional fisheries production is expected to result principally from higher exploitation in tropical and southern temperate latitudes, greater utilization of unfamiliar species, and better use of presently known and harvested resources (Robinson and Crispoldi, 1975). Rathjen (1975) noted the necessity of expanding fishing effort in the Southern Hemisphere, increasing exploitation of the ocean beyond the continental shelf, and developing new fisheries products as being essential to double the present world catch.

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Table 1.—Estimated potential harvest of underutilized species from the oceans in millions of tons (from Suda, 1973).

	Resources			
Oceans	Pelagic fish	Demersal fish	Cephalopod	Total
Northern	4.2-5.7	1.8	1.7	7.7-9.2
Southern	6.8	1.8-2.3	1.8	10.4-10.9
Tropical	10.9-17.2	11.9-14.5	2.2-3.5	25.0-35.2
Total	21.9-29.7	15.5-18.6	5.7-7.0	43.1-55.3

The potential harvest of the underutilized species from the oceans (Table 1) has been estimated by Suda (1973).

These figures show that from 25 to 31 percent of the future increases will be from pelagic species of the tropical oceans. The underutilized pelagic resources include first-stage carnivores such as flying fish and sauries and second-stage carnivores such as rainbow runners, dolphins, and small tunas.

Gulland (1971), in his general review of the fish resources of the world, assigned potential catch figures for oceanic species. His figures for the second and higher stage carnivores (other than whales, large tunas, and skipjack tuna) were as follows (in thousands of tons):

Small tunas (excluding skipjack)	Frigate mackerel	(1,000)
	Bonito	(500)
	Little tuna	?
	Thynnus tonggol	?
Sharks		(500)
Coryphaenids		1,000
Squids		10,000-100,000

There is ample evidence to suggest the most abundant species group of the open oceans is squid. In a review of the cephalopod resources of the world, Voss (1973) defined the potentially important species and estimated the potential catches of oceanic squids. These estimates were based on the probable virgin stocks of sperm whales and their likely consumption rates of squids. Potential capture figures derived from these assumptions ranged from 100 to 300 million tons and probably as high as 500 million tons.

The above-cited papers indicate the potential catch of second- and higher-stage carnivorous pelagic fish (excluding large tunas and skipjack) to be 2.5 million-plus tons and that of oceanic cephalopods to be between 10 and 500 million tons. These resources generally are sparesely dispersed throughout the warm-temperate and tropical oceans. The basic problem in harvesting these resources is essentially one of localizing and/or concentrating individuals scattered over a wide area. Gulland (1971) stressed the necessity of technological research on catching and processing methods as well as biological research on the distribution and behavior, especially occurrences of oceanic species. Voss (1973) confessed, with regard to the oceanic squid resources, that the problem of harvesting is unsolved, but that imaginative experimentation in this field has a high chance of success.

The purpose of this review is to present the author's concepts of possible means of localizing and concentrating pelagic species for harvesting at economically feasible rates. This paper is divided into two parts: The first part presents suggestions for demonstration fishing with up-to-date equipment in areas of established fisheries and experimental fishing with modified or innovative gears and methods for unutilized species; in the second part, the author presents his concepts of the type of vessel most appropriate to carry out the proposed demonstration and experimental fishing trials.

SUGGESTED DEMONSTRATION AND EXPERIMENTAL FISHING INVESTIGATIONS

The neritic[1] and oceanic regimes are discussed separately as different fishing tactics will have to be employed in catching pelagic species from these respective areas. The fishing gears and methods currently employed in capturing neritic and oceanic species are briefly reviewed as well as pertinent information on the ecology and behavior of the species involved. This background information is given to support the various suggestions for demonstration and experimental fishing to be executed in devising means of increasing the harvest of pelagic predator resources.

[1]Environment over the continental shelves.

Neritic Regime

Surface Multiple-Line Trolling

There are established multiple-line troll fisheries for albacore tuna, *Thunnus alalunga,* off the west coasts of North America and Europe. Vessels used in the North American fishery typically have the wheelhouse forward and clear deck aft. Two trolling poles are rigged outboard of the mast which is usually fixed immediately aft of the wheelhouse. The numbers of lines fished by these vessels range from 11 to 14 (Yoshida, 1966). Vessels in the European troll fishery usually have the wheelhouse slightly aft of midships with well deck forward and stern deck aft. Some of the European trollers are rigged with two long poles on the forward mast aft of the forecastle, whereas other vessels are fitted with two short poles on the forward mast and two longer poles on the mast aft of the wheelhouse. Vessels with four trolling poles fish as many as 19 lines (Le Gall, 1974).

Several attempts to exploit the pelagic resources of the Caribbean region by multiple-line trolling have demonstrated significant catch rates, including the results of the Jamaican Fisheries Department vessel *Bluefin* (Oswald, 1963) and the Caribbean Fishery Development Project vessels *Calamar* and *Fregata* (Yesaki[2]). The encouraging results of these vessels prompted the emphasis of trolling activities during Phase II (September 1969-August 1971) of the Caribbean Fishery Development Project. Catches varied markedly in the different areas involved during these investigations and ranged from a high of 14.0 kg/hour around the Leeward Islands to 1.2 kg/hour off the Guianas. Wagner and Wolf (1974) concluded that very little success was realized in harvesting the pelagic resources of the Caribbean with this method of fishing. Catch rates high enough to support trolling as an independent fishing means were obtained only around the banks of the Leeward Islands and this only for 2 months of the year. On the other hand, trolling was a good secondary fishing means to be employed when running to and from fishing grounds and during slack periods for other fishing methods.

[2]Yesaki, M. 1969. Troll fishing catches in the Caribbean Sea and adjacent Atlantic Ocean. Mimeogr. pap., UNDP/FAO Caribbean Fisheries Development Project, 25 p.

Pelagic species characteristically exhibit marked fluctuations in abundance during the year. The landings of pelagic predator species can be increased during peak periods of abundance from many regions with the introduction of multiple-line trolling.

Trolling is practiced with one to three lines by artisanal fishermen off the Windward Islands in small motorized craft and off north-central Brazil in sailing vessels. Fishing trials with multiple troll lines are advocated in areas of established artisanal troll fisheries to demonstrate the practicality and greater efficiency of trolling many lines, especially during peak periods of abundance.

This method of fishing is not practiced in some parts of the world where available information indicates high indices of pelagic predator fish. High catch rates were realized by Regional Central American Fisheries Development Project vessels while incidental trolling in various areas off the Pacific Coast of Central America (Magnusson, 1971). Handline vessels fishing off the south-central coast of Brazil land over 200 tons of dolphin, *Coryphaena hippurus,* during the austral spring season (unpublished data). Fishing trials with multiple troll lines in areas of known pelagic fish concentrations are needed to demonstrate the economic viability of this method of fishing.

Subsurface Multiple-Line Trolling

Commercial trolling for tunas and related species is practiced with surface lines. Le Gurun[3] (pers. commun.) conducted simulated production trolling in the Gulf of Aden, where catches of up to

[3]Jean Francois Le Gurun, FAO Masterfisherman.

1,000 kg were made while surface trolling a few hours during dawn and dusk. He is of the opinion that pelagic fish move up to the surface during hours of subdued sunlight and down to midwater depths during the day. Trolling at midwater depths may be a means of increasing catches during the period of the day when the fish are down deep. Fragmentary evidence does indicate that captures may be increased by subsurface trolling. Sport fish charter boat fishermen sometimes prefer to fish whole round scad trolled below the surface (Wickham et al., 1973). Van Pel[4] conducted subsurface trolling off Tonga in the South Pacific and obtained encouraging results. He employed a diving kite with three subsurface branchlines and five surface lines. The ratio of subsurface to surface line catches was 3:1. There were no differences in bait preference between fresh mullet, salted mullet, and tuna belly strips used during these trials.

Fish are generally located by surface activity, birds, flotsam, and tidal rips when surface trolling. Alternate means have to be employed to assist in locating subsurface fish.

Echo sounders are used in fisheries principally to determine depth, nature of the bottom, and detect concentrations of fish. Auto-scanning sonars are used almost exclusively for locating fish schools in mid-water. Experimentation with these electronic fish-finding aids while subsurface trolling is suggested to assess their usefulness in locating areas where pelagic carnivorous fish are likely to aggregate (e.g., sea bottom irregularities, concentrations of forage species), and in pinpointing schools or individual fish in the water column.

Subsurface Trolling for Large Pelagic Fish

Surface trolling speeds of about 6 knots appear to be the optimum velocity for capturing tuna and related species. Commercial trolling for albacore is usually performed at average vessel speeds of 6 knots (Yoshida, 1966). Exploratory trolling by the Caribbean Fishery Development Project vessels was practiced at 6-knot speeds, which were considered adequate for tuna species but not too fast to preclude catching other species (Wagner and Wolf, 1974). Van Pel (see footnote 4) conducted trial subsurface trolling runs at 4, 5, 6, and 7 knots and reported the optimum speed to be 6 knots.

Heavy weights or large depressors are required to maintain midwater depths while subsurface trolling at 6-knot speeds. Also, strong cables and heavy-duty winches are necessary to withstand the strain imposed by drag and for setting and hauling the gear. Technological research is required to develop the equipment and system for subsurface trolling for large pelagic fish at 6-knot speeds. For subsurface trolling at these speeds, a hydrodynamically efficient depressor is probably the best device for maintaining midwater depths. A system to facilitate fishing operations would be a towline to hold the depressor on station while trolling and a mainline for attachment of branchlines. A clothesline retrieval system of the mainline would permit checking the branchlines without having to raise the depressor. Two subsurface lines could be fished, one port and another starboard, with branchlines spaced widely on the mainline to minimize tangling (Fig. 1).

Subsurface trolling with heavy gear may be especially interesting in areas of high captures of wahoo *Acanthocybium solanderi*, such as Mouchoir Bank, Morant Bank, and Decca Ridge in the northern Caribbean region (Wagner and Wolf, 1974; Yesaki, footnote 2). Fishing trials with heavy subsurface trolling gear is suggested in such areas to ascertain its effectiveness for harvesting large pelagic fish in midwater depths.

Subsurface Trolling for Small Pelagic Fish

Sightings of large schools of rainbow runner, *Elegatis bipinnulatis*, have been reported by Caribbean Fishery Development Project personnel on Navidad and Silver banks north of Hispaniola and by Le Gurun (pers. commun.) from the Gulf of Aden. The Jamaican Fisheries Department vessel *Bluefin* captured this species surface trolling at rates of 9.0 kg/hour over "Salmon Bank" in the northern Caribbean Sea (Yesaki, footnote 2). Catches of this species by surface trolling were negligible in the other bank areas investigated in the Caribbean region (Wagner and Wolf, 1974).

Surface trolling with artificial lures presently used for tunas and related species does not appear to be an efficient method for harvesting rainbow runners. Salmon troll lures and trolling methods may be more efficient for this species. Rainbow runners resemble superficially the salmon species in body form and in mouth shape and size, so much so that the common name for this species is "salmon" in Jamaica. This resemblance suggests these species inhabit similar ecological niches and have corresponding food habits. Also, the observations of Wolf (1974) regarding the capture of rainbow runners at slow trolling speed with flying fish strips lend support to the argument that trolling with salmon fishing methods may be an effective method of harvesting this species.

It is desirable to undertake investigations with salmon troll gear, especially in areas where rainbow runners are known to concentrate, to assess the effectiveness of slow-speed subsurface trolling for this species and other small pelagic fish. Suggested areas in the Caribbean region are "Salmon", Navidad, and Silver Banks, and the Central American shelf.

Fish Attraction to Moored Objects

Fishermen in various parts of the world have taken advantage of the attraction of flotsam to pelagic fish by mooring artificial structures in the sea. Materials used for rafts appear to depend primarily on the materials available; bamboo, cork (or more recently styrofoam), and palm fronds are used

[4] Van Pel, H. Undated. Deep trolling off Tonga. Mimeogr. rep. to South Pacific Commission, 3 p.

by Japanese, Maltese, and Indonesian fishermen, respectively. Dolphin is the principal target species of the Japanese and Maltese fishermen, whereas clupeoids, scombroids, and carangids are the important species captured by Indonesian fishermen.

Many aspects of the association of organisms with naturally occurring flotsam, moored surface structures, and moored midwater structures have been studied by various authors (Hunter and Mitchell, 1967, 1968; Kojima, 1967; Hunter, 1968; Wickham et al., 1973; Wickham and Russell, 1974). These studies have shown recruitment of prey species around an object soon after mooring, followed by larger prey and predator species. Essentially the same genera of predators were attracted to floating objects in the Japan Sea and eastern central Pacific Ocean. These predators included dolphins, (*Coryphaena*), tunas (*Auxis, Euthynnus, Katsuwonus, Thunnus*), and jacks (*Caranx, Elagatis, Seriola*). On the other hand, the genera of predators observed around mid-water artificial structures in the northwestern Gulf of Mexico differed considerably from the Pacific areas. Gulf of Mexico predators included dolphin (*Coryphaena*), tunas (*Euthynnus*), mackerals (*Scomberomorus*), jacks (*Caranx*), cobia (*Rachycentron*), and barracuda (*Sphyraena*).

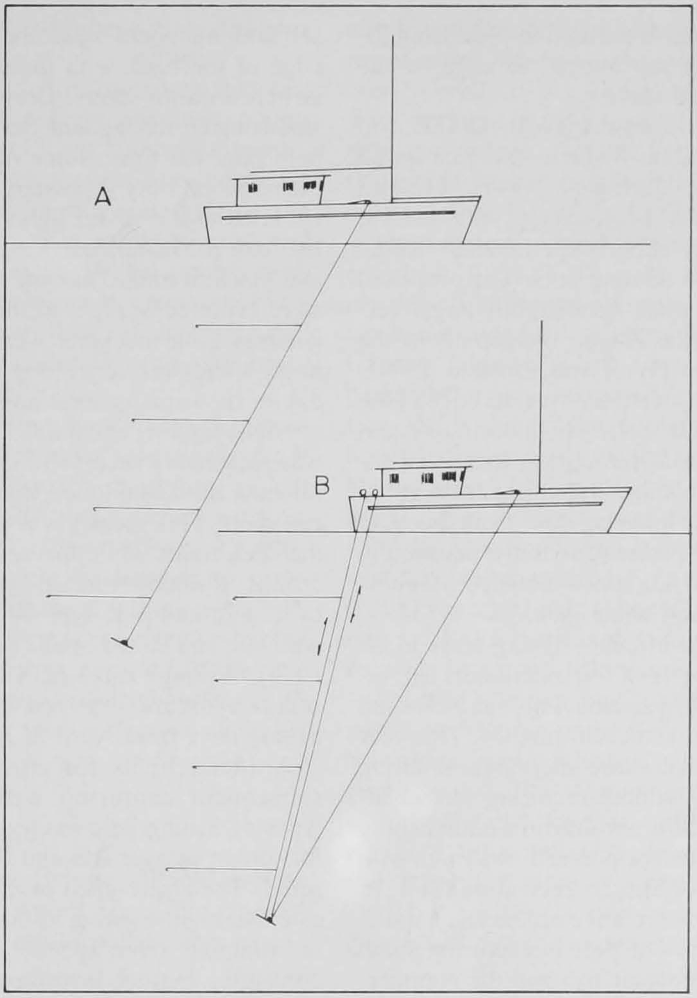


Figure 1.—Deep midwater trolling. A. Depressor (or heavy weight) on mainline with attachment of branchlines on the mainline. With this type of system, the depressor has to be raised to check the branchlines. B. Depressor on a towline to maintain fishing depth and a pulley mechanism on the depressor for attachment of a double mainline. The pulley mechanism and double mainline permit checking the branchlines without raising the depressor.

Wickham et al. (1973) assessed the efficiency of midwater structures for attracting pelagic predators by trolling around these structures and in adjacent control areas. Troll catches (principally of little tunny, *Euthynnus alletteratus*, king mackerel, *Scomberomorus cavalla*, and dolphin) were significantly higher around single and multiple structures than in the control areas.

Several attempts were made by the Caribbean Fishery Development Project to evaluate the potential of surface artificial structures for increasing fisheries production (Wolf, 1974). These attempts were frustrated by natural loss of structures and interference from local fishermen. Hunter and Mitchell (1968) experienced similar losses and/or theft of moored floating structures, whereas such problems were not encountered by Wickham et al. (1973) with mid-water structures.

All available evidence shows moored artificial structures to be highly effective in concentrating pelagic species. Landings of pelagic predator fish can probably be increased from many areas with introduction of the use of moored structures. Introduction of this method of concentrating fish would entail experiments to determine the local materials best suited for fabricating these structures. Also, demonstration fishing would be essential to prove to local fishermen the effectiveness of moored structures in increasing catches of pelagic predator fish.

Floating Fish Pots

Fishermen in Papua New Guinea use large dirigible-shaped floating pots made of bamboo strips to catch rainbow runners (Anonymous, 1968). This pot is fished a few meters below the sea surface and is moored in promising locations at sea out to the edge of the continental shelf.

While a consultant with the U.S. National Marine Fisheries Service based in Jamaica during early 1971, I had an opportunity to converse with a local fisherman about experimental fishing trials with floating pots. The pots used for these trials were slightly larger versions of the Z-type indigenous to the Caribbean (Wolf and Chislett, 1974). These pots were set over the edge of the continental shelf. The mooring system used to hold the pot on location consisted of a short branchline from pot to buoy and mooring line from buoy to anchor. Species reportedly captured in these floating pots included rainbow runners and white jack.

Pots are efficient fishing gears in the sense that very few man-hours are required for operation. Pots can be set and lifted in a matter of minutes. This gear is fishing the entire interval from setting to lifting without requiring further attention, during which time other fishing methods can be pursued. Research with floating pots is recommended to evaluate the relative efficiencies of different types of pots in capturing small pelagic predator fish and the commercial potential of this gear in areas where these species are known to concentrate.

Fish Attraction to Night-Lights

Night-lighting is practiced around the Caribbean Leeward Islands to capture king mackerel. This fishery is conducted at night from small boats anchored in suitable locations with an artificial light source. Pelagic forage species are soon attracted to the light, which are subsequently dipnetted and used as live bait for handlines. The live bait is allowed to take the line out with the current. King mackerel attracted either to the light or the concentrations of forage species, are captured with the handlines.

Incidental night-lighting was practiced aboard the RV *Fregata* during a cruise conducted in spring 1969 on Anguilla Bank in the northern Caribbean. After a day's fishing operation, the vessel was anchored near the northeast edge of the bank with the deck lights switched on for safety. Crew members stood watch throughout the night. To help pass the time, some of the crew members on duty dipnetted flying fish attracted to the vessel lights for use as live bait for handlines. King mackerel and blackfin tuna, *Thunnus atlanticus*, were captured at night in this manner, whereas king mackerel were not captured while surface trolling during the day in the same general area.

Night-lighting aboard the RV *Alcyon* was reasonably successful in capturing rainbow runners on the Central American shelf. This species was attracted to the deck lights while the vessel was at anchor. Rainbow runners were caught by a cast-and-pull type of operation with line and baited hook (Kawaguchi, 1974). Average catch rates of 147 kg/man/day were realized during 47 fishing days from April to June.

Artificial lights for attracting and subsequent capturing with various types of fishing gear is used primarily for forage pelagic fish and the smaller squid. The above-cited examples indicate that night-lighting also is effective in attracting some species of pelagic predators. Further investigations with night-lights is recommended to define the pelagic carnivorous species which can be attracted.

Oceanic Regime

Drifting Flotsam and Vessels

It is well known that certain species of pelagic fishes are attracted to drifting objects in the open sea. Japanese live-bait and American seine fishermen have capitalized for years on this knowledge by actively searching for and fishing around drifting objects. Hunter (1968) estimates that American fishermen caught 180,000 yellowfin, *Thunnus albacares*, and skipjack tuna, *Katsuwonus pelamis*, around floating debris during 1961 in the eastern central Pacific Ocean.

Heyerdahl (1950) observed pelagic fish from the first to the last day of the *Kon-Tiki*'s 102-day voyage across the Pacific Ocean. This balsa log raft rigged with a 4.6 by 5.6-m sail drifted from Peru to the Tuamoto Archipelago at an average speed of 1.9 knots for the duration of the passage and a maximum of 3.0 knots during a 24-hour period. Fish most frequently attracted around the raft were pilot fish, flyingfish, dolphins, sharks, triggerfish, and tunas. Underwater observations made beneath the raft revealed thick concentrations of fish up to the limits of visibility. A steady supply of flyingfish for the galley was usually found on the deck of the raft every morning, as were occasional squid. Dolphin were ever present as stragglers numbering 2-3 during some days, in groups of 5-7 during most days, and in schools of 30-40 on other days. Dolphin, shark, and tuna were readily captured with handlines baited with flyingfish and squid.

A vivid account of six people stranded aboard a rubber life raft during the first part and a 9½-foot dinghy during the latter part of a 38-day ordeal in the eastern central Pacific Ocean was given by Robertson (1973). During this passage, dolphin were recorded from the first night through the following 37 days. He described in detail the frustrating attempts to catch dolphins on a spinner lure and with a hook baited with a piece of fish. Dolphin would not take these lures so he gave up fishing and instead concentrated on gaffing as a means of capturing these fish. Robertson succeeded, after three prototypes, in fashioning a gaff strong enough and with which he was able to land several dolphins. The impression one gets from reading this adventure is that dolphin, flyingfish, and scavenger fish were quite abundant, whereas sharks were less common around the raft throughout the duration of the 38-day float. During this period, the raft had drifted over 750 miles for an average speed of approximately 0.9 knots.

Potthoff (1969) recorded the sequential attraction of organisms to the research vessel, *Discoverer*, which drifted for 2½ weeks in the central tropical Atlantic. The vessel's rate of drift varied from 1.1 to 1.7 knots throughout this cruise. An 800-watt light was rigged on the leeward side of the vessel for night-lighting and collection of organisms by dipnetting. Prey organisms attracted to the vessel were blanket octopus during the first 4 days, flyingfish in large numbers after the second day, and lantern fish in lesser numbers for the duration of the cruise. Dolphin was the dominant predator species attracted around the vessel and increased in numbers with each passing day. It was estimated at the end of the cruise that there was one dolphin per square meter of sea surface within a wide area of the vessel. Other predators included squids and large sharks usually accompanied by rainbow runners.

Observations made aboard the *Discoverer* prompted the exploratory fishing personnel of the Caribbean Fishery Development Project to undertake a drift fishing cruise (Wolf, 1974). The objectives of this cruise were to determine if a drifting vessel could attract pelagic species in commercially significant numbers and to test various fishing gears and methods for harvesting the attracted species. On this cruise, the average drift rate of the RV *Calamar* for the 14-day cruise was 1.1 knots, with higher rates of 1.5 knots for a 24-hour period and 2.5 knots for a shorter period.

Flyingfish was the first species to be attracted to the vessel. Ocean triggerfish was very abundant and captured by dipnetting or handlining and squid was captured at night by hand-jigging. Predator species were captured from the first day of the drift to the last. The most important species, in terms of weight captured, was dolphin. An estimated 90-plus percent of the catch was dolphin, as this species appeared to remain around the vessel even after being hooked and lost. Yellowfin tuna was almost always present around the vessel and was the second most commonly captured species. Rainbow runners were abundant under the vessel, but very difficult to capture. Wahoo were seen jumping in the vicinity of the vessel; however, this species was captured only by trolling. Predator species least commonly captured were skipjack tuna, shark, and bigeye tuna, *Thunnus obesus*.

This drift cruise demonstrated that commercial pelagic predators aggregated in significant numbers around a vessel, but that these species could not adequately be harvested with the fishing gears and methods employed during this cruise. Higher catches were believed possible with greater mobility to conduct trolling, gillnetting, and longlining without disturbing the established colony.

Drift fishing has interesting possibilities for further investigations. It would be especially interesting to drift at speeds of 2.5 and 3.0 knots and possibly higher. These velocities would double and triple the distance traversed by the RV *Calamar*, with possible corresponding increases in the numbers of pelagic predators attracted to the vessel. Also, surface and subsurface trolling may be more effective at higher speeds.

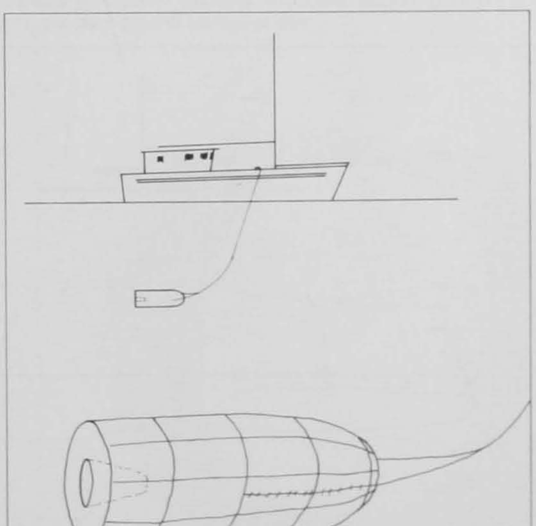
Towed Midwater Pots

Caribbean Z-type and Australian D-type pots were utilized for artificial structures to attract pelagic species and also to test their effectiveness in capturing attracted fish during the second drift cruise (Wolf, 1974). Ocean triggerfish were captured in the Z-type pots fished near the surface, but the D-type pots suspended deeper caught nothing.

A handline fishery for Caribbean red snapper is operating off the northeastern coast of South America. Some of the vessels participating in this fishery are commanded by skippers from the Canary Islands. These vessels use hemispheric pots supposedly brought from these islands. The pot has the entrance in the center of the flat end of the hemisphere. This pot is fished by drifting at 2.5 to 3.5 knots near the bottom with the entrance facing upward. The best catches reported by Fourmanoir (1968) were 100 red snappers (average size 1.5 kg) for drifts of 9-16 minutes duration in a good fishing area.

It would be interesting to experiment with modifications of the Canary Island hemispheric pot while drift fishing. An elongated, bullet-shaped pot fished with the flat end down-current may be effective for small pelagic predators and especially rainbow runners (Fig. 2). This species is captured around Papua New Guinea in pot gear and has

Figure 2.—Drifting midwater pots. Fish pots set for small carnivorous fish, such as rainbow runners, while drift fishing in the oceanic regime.



been seen concentrated under drifting vessels by Potthoff (1969) and Wolf (1974).

Drifting Artificial Structures

A second drift fishing cruise was conducted under the Caribbean Fishery Development Project to evaluate the feasibility of a series of drifting artificial structures for attracting pelagic species in commercially significant numbers and the effectiveness of monitoring and fishing around these structures at regular intervals (Wolf, 1974). This cruise was completed in two almost equal periods. Three structures spaced 2 miles apart were released during the first period, whereas six structures were released 1½ miles apart during the second period. The usual method of monitoring these structures was to troll a feather jig close around them. If a fish was captured, handlines were fished either drifting with live flyingfish for dolphin and wahoo, or slow trolling with whole flyingfish for wahoo, and flyingfish strips for rainbow runners. Tunas were taken by trolling lines with artificial lures and sharks by hand-lining with bait. Predator species, in decreasing order of attraction to the drifting artificial structures were dolphin, wahoo, sharks, usually accompanied by rainbow runners, and tunas. Flyingfish and ocean triggerfish were the first species to be attracted to the structures.

Difficulties were encountered in keeping track of the artificial structures which drifted farther apart as time passed and ultimately resulted in the loss of some of the structures. It was concluded that fish were probably attracted to these structures in greater numbers than to a drifting vessel (first drift cruise), but that the increased numbers did not compensate for the difficulties involved in keeping track of these structures.

Drifting artificial structures offer possibilities for concentrating and retaining pelagic species in the open sea. The problems of tracking and losing structures may be overcome by connecting a series of these structures in a long line along with the use of radio buoys. Radio buoys used by the tuna longline fishery are available commercially (Fig. 3). Further investigations with drifting artificial structures are required to determine their practicality.

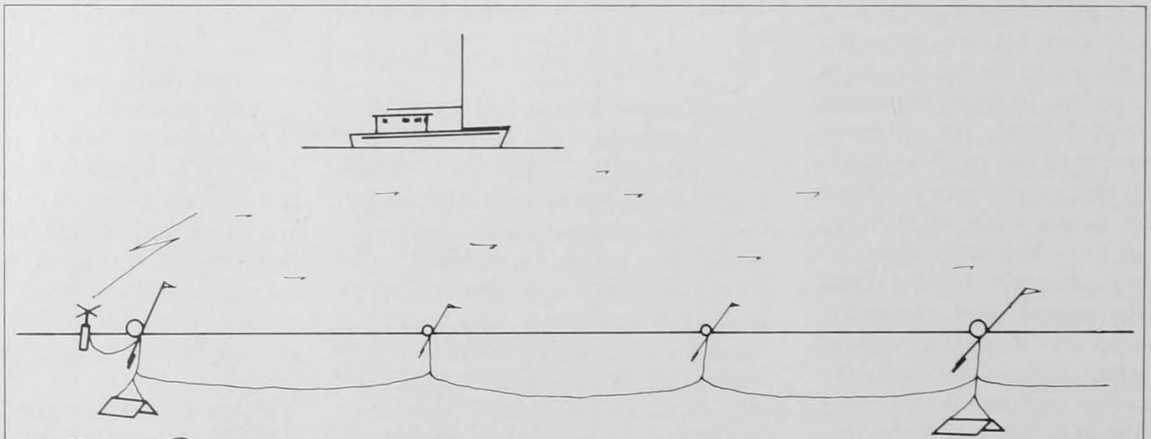
Night-Lighting

Harvey R. Bullis, Jr. (pers. commun.), in commenting on night-lighting experiences aboard the RV *Oregon* in the Gulf of Mexico and Caribbean Sea, stressed the effect of a quick switchover from a white to a red light in concentrating squids. These squids generally stay outside the periphery of white-light illumination, but a change to a red light causes the squid to aggregate in the immediate vicinity of the light source.

I participated in a squid fishing cruise conducted by the RV *Diadorin* in the southwestern Atlantic Ocean. During this cruise, three fishing stations were monitored in oceanic waters over depths exceeding 1,000 meters. At each of these stations, the 6-kilowatt lighting system was switched on after stopping the main engine. Oceanic squids appeared around the vessel a few minutes after the lights were turned on. These squid traversed the sphere of illumination singly, in groups of 2-3 individuals and in small schools (estimated to consist of 20-30 individuals). Jigging was initiated with automatic squid-jigging machines.

Ommastrephids were lured by the squid jigs and some grabbed the lures. A few ommastrephids were brought aboard, but the majority were lost due

Figure 3.—Drifting longline of artificial structures. Collapsible midwater structures strung at regular intervals on a longline to prevent the structures from drifting apart and a radio buoy to aid in localization.



to improper hooking because of small jig size and breaking of arms and tentacles because of the heavy weight of the animals. The few ommastrephids captured at the three oceanic fishing stations represented only a small fraction of the numbers observed around the vessel and the numbers lost. What impressed the author most about this experience was the almost instant appearance of squid around the vessel after the night-lights were switched on at these oceanic fishing stations.

The catch of ommastrephids by the RV *Diadorin* could have been greatly increased with larger jigs. However, slow trolling with night-lights may be a more effective method than jigging for harvesting oceanic squids. A vessel under way trolling even at slow speeds would cover a much greater area than a vessel adrift jigging, and theoretically attract a correspondingly higher number of squids.

Trolling for squid with artificial shrimp lures is practiced in the Philippines (Flores, 1974). Also, a type of trolling is conducted for cuttlefish in the Mediterranean area and for octopus in the Polynesian region (Voss, 1973). Since trolling is effective for capturing many species of cephalopods, there is no known reason why this method would not be effective for the fast-swimming oceanic squids. Slow-speed trolling with night-lights is recommended to ascertain the effectiveness of this method for capturing oceanic squids (Fig. 4a, 4b).

SUGGESTED DEMONSTRATION AND EXPERIMENTAL FISHING VESSEL

The suggested demonstration and experimental fishing investigations outlined in the foregoing section require a research vessel with capabilities for surface and subsurface trolling, handlining, night-lighting, and some pot-fishing, with trolling as the principal activity. Trollers of the North American and European albacore fisheries generally range in size from 14.0 to 21.0 meters. A vessel of 20.0 meters long is probably the optimum size for

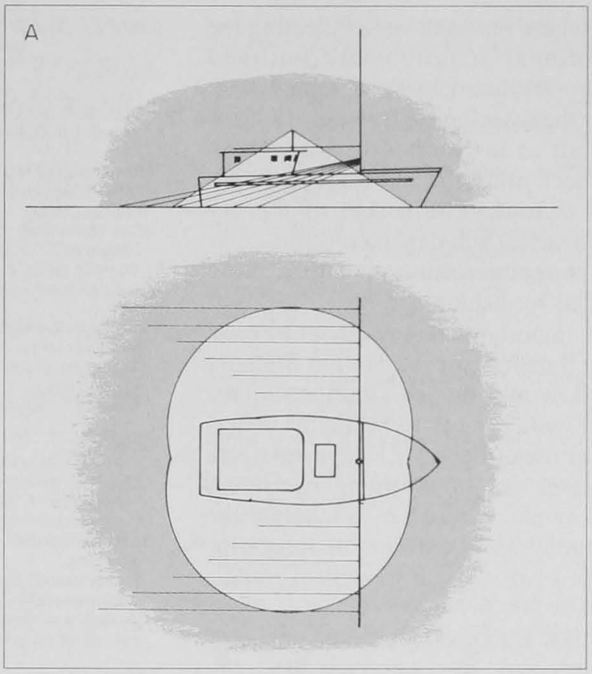


Figure 4a.—Drift trolling with night-lights. Vessel under way at low speeds with night-lights illuminated to attract oceanic squids. Multiple troll lines with squid jigs on each line.

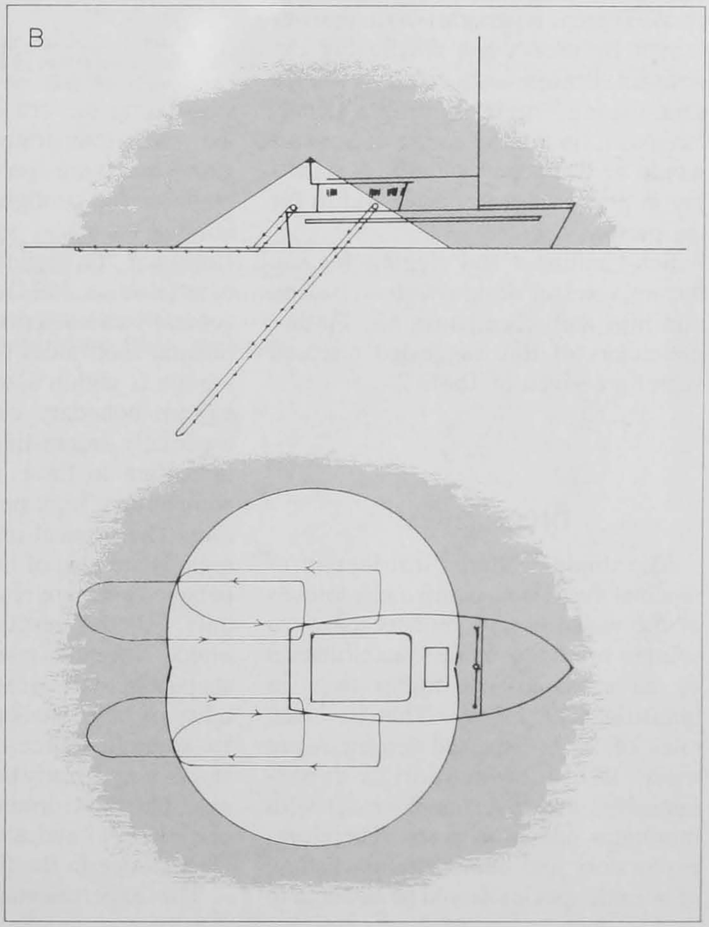


Figure 4b.—Drift trolling with night-lights. Continuous lines revolving non-stop from the vessel. Squid jigs spaced regularly on the lines with a series of plastic jigs for surface fishing and metal jigs for midwater fishing.

an offshore research vessel meeting the operational requirements outlined above. Trollers can be designed with either the wheelhouse forward and clear deck aft as in North America or with well deck midships and wheelhouse aft as in Europe. The design of this research vessel will depend on consideration of requirements other than those dictated by fishing activities.

An important prerequisite of a vessel of 20.0 meters for research in offshore waters would be sea-kindliness. This vessel would have to routinely undertake cruises of about 21 days duration. A vessel design affording maximum stability and comfort to ameliorate the monotony and hardships of long trips on the open sea are of utmost importance in this instance.

This research vessel should be rigged to carry sail; to economize fuel consumption, give greater stability, and facilitate slow trolling speeds with minimum turbulence. A vessel rigged with sail for auxiliary use while steaming and fishing would reduce operating costs. There is no reason why sailpower cannot be used when conducting experimental slow subsurface trolling, drift-fishing, night-lighting/trolling, etc. Also, the rolling action of a vessel would be dampened under sail, resulting in greater stability and comfort for the persons aboard.

Sea-kindliness and rigging for sail dictate a vessel design with well deck midships and wheelhouse aft. Further particulars of this suggested research vessel are given in Table 2.

Table 2.—Design characteristics of proposed research vessel.

Dimensions
Length, overall: 20.0 m
Breadth, moulded: 6.0 m
Scantling draft, moulded: 2.5 m
Normal complement
Officers/fishermen: 2
Engineer/fisherman: 1
Cook/fisherman: 1
Fishermen: 2
Scientific party: 2
Total on board: 8
Power, speed, endurance at sea
Maximum continuous horsepower: 180
Sea speed, sustained: 8.5 knots
Cruising radius: 1,000 nautical miles
Capacity for sustained operation: 24+ days
Capacities
Fish hold: 15-ton capacity, iced (or refrigerated) fish
Diesel oil: 10,000 liters
Fresh water: 4,000 liters
Electronic navigation and fishing aids
SSB radio
Radio-direction finder
Automatic pilot
White-line echo-sounder
Auto-scanning sonar
Ancillary fishing equipment
Long-line hauler
Two, vang winches
Two, three-spool trolling gurdies
Two trolling poles

DISCUSSION

The thinly scattered distribution of much of the pelagic carnivore resources of the world oceans renders these resources more amenable to exploitation by an artisanal-type rather than an industrial-type fishery. That is, catch rates of such dispersed resources are more likely to support a labor-intensive, low-investment vessel with minimum operation costs. Therefore, exploratory and demonstration fishing of oceanic species should be oriented to stimulating the artisanal fishermen of the warm-temperate and tropical regions, and more specifically those fishermen living contiguous to the eastern boundary current systems (Cushing, 1969) and the tropical insular environment (Robins, 1971). These regions are generally characterized by narrow continental shelf areas so that the oceanic regime is within a short distance. The eastern boundary current regions are especially interesting because of the upwelling in these areas and the accompanying high pelagic fish production. The tropical insular environment regions are also of interest because the pelagic carnivore resources may be the only fisheries resources of any magnitude since the restricted continental shelves in these areas negate the possibility of large stocks of demersal fish. In some instances, these demersal stocks may already be overfished, as for example, those around Jamaica (Munro et al., 1971) and also Martinique and Guadaloupe in the Caribbean region.

The experimental fishing methods suggested in this paper are simple and require a minimum of capital outlay for gear and equipment. Multiple surface trolling can be accomplished with two poles, lines, and lures; handlining with lines and hooks; night-lighting with lights, lines, and hooks; fish-potting with homemade pots of natural materials and/or wire mesh; fish-attracting with mooring lines and structures made of native materials. Ancillary line hauling equipment is available but is not mandatory for practicing subsurface trolling. Troll lines can be fished at midwater depths with weights or depressors from small vessels. The suggested fishing methods can be conducted with almost any type of powered craft in the neritic region on a day-operation basis. Larger vessels capable of extended periods at sea and equipped with electronic navigational aids and ancillary fishing equipment would be necessary to effectively exploit the oceanic regime.

A very high-expense item of fishing vessels in the future will be fuel oil. This will result in the survival of only those vessels engaged in capturing very high-unit-priced species, the most efficient vessels, or vessels capable of operating with minimum fuel consumption. An important function of an exploratory fishing and gear research vessel is to demonstrate the economic feasibility of harvesting underutilized and/or unconventional fishery resources. The pelagic predator resources are generally dispersed so sparsely throughout the world oceans that it is unlikely that these resources can be economically harvested with high-fuel-consuming vessels. A vessel rigged with sail would have reduced operating costs, thereby increasing the probability of demonstrating the economic viability of harvesting these resources.

Heyerdahl (1950) stressed the advantage of keeping one's nose at water level day after day in detecting phenomena generally overlooked while traversing the seas in large, high-speed vessels. One's nose would virtually be at water level on a 20.0-m vessel running under steadying sail. Investigations from this type of vessel may be the key to opening the vast pelagic carnivore resources of the warm-temperate and tropical oceans for exploitation. At any rate, investigations with a 20.0-m vessel rigged with sail would be the least expensive method of assessing the fishery potential of the open seas.

Whales, deep-swimming tunas, and schooling surface-swimming tunas are the only oceanic species being exploited at present. The demonstration and experimental fishing investigations suggested in this review are urgently recommended as a first step in determining the possibility of commercially harvesting the underutilized and unconventional second-stage and higher pelagic carnivore resources of the world oceans. The results of these investigations will at best be the development of new fisheries and at worst the addition of fundamental knowledge of oceanic species.

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