Deep Water Fishing Potential Off Southern New England

A report prepared by

Captain Malvin Kvilhaug
Michigan Fishing Corporation
2 Middle Street
Fairhaven, MA 02719

And

Ronald Smolowitz
Coonamessett Farm
277 Hatchville Road
East Falmouth, MA 02536

A report of the Michigan Fishing Corporation pursuant to National Oceanic and Atmospheric Administration Award No. NA46FD0326.

January 31,1996

CONTENTS

II. ABSTRACT

The commercial fishing vessel Contender (106' LOA), operating out of Fairhaven, Massachusetts, conducted twelve exploratory fishing and gear development trips (90 DAS) to the upper continental shelf waters of Southern New England and the Middle Atlantic Bight. The gear consisted of commercial bottom trawls and towing depths ranged from 200 to 1800 m. The fishing periods were from November 12, 1994 to January 27, 1995 and from September 14, 1995 until November 7 1995. Commercial landings from these trips included four species of hake, monkfish, grey sole, squid, royal red shrimp, butterfish, summer flounder, and lobsters. Other commercial and potentially commercial species present in the catches included turbot, redfish, red crab, black dogfish, grenadier, and blue hake. The report discusses the significant operational and managerial problems that need to be overcome to successfully fish the upper slope in a sustainable manner. Forty references on deep water fishing are annotated and included in the report.

III. EXECUTIVE SUMMARY

Due to the overfished condition of virtually all the traditional commercial stocks on the continental shelf of New England, the fishing industry is investigating the possibility of fishing deeper waters. This government supported study was designed to examine some of the economic potential and operational problems associated with expanding the fisheries into deeper water. The F/V Contender, a typical offshore New England dragger/scalloper, was refitted to be able to tow to depths of 1800 m (1000 fms). This refitting entailed purchase and major modifications to a main winch (drums, and level winds), upgrading the fish finding electronics, and acquisition of new trawl warps. Two trawls were designed and tested during the project and two additional trawls were also used.

Primary attention was focused on the economics of extending the existing continental shelf fisheries of southern New England into deeper water (>200 m). This goal was constrained by the fact that the vessel was prohibited from landing regulated multispecies available in deep water such as redfish, grey sole, and white hake. Initial work, using a lined trawl, focused on an area between 300-400 m in depth where there was a commercial concentration of royal red shrimp. Even though catch rates better than 25 kg/hour were obtained, the grounds seem to be of limited extent. The last four trips of the project focused on targeting the highly valued monkfish using a standard 6-inch mesh trawl. Catch rates of 120 kg/hour were obtained in water depths greater than 350 m and the monkfish commercial concentration within its depth range seems extensive. However, very few monkfish over 60 cm were caught which may indicate an already depressed stock in deep water. Commercial concentrations of monkfish during our operations seem to end at about 450 m.

The attempts to develop a fishery on deeper non-traditional demersal stocks were met with many significant problems. The first was weather. This project was conducted during the period that is least profitable for the traditional offshore scallop and groundfish fisheries; late fall and early winter. Sea states and wind conditions consistently hampered the project by restricting the use of electronic fish finding equipment and restricting tow direction. A second major problem was drifting longline gear. The surface over the upper slope regions are virtually covered with this gear, targeting large pelagics such as tuna and swordfish, for considerable periods of time. The buoys marking the gear are hard to see in the typical fall/winter sea states, effectively blocking access to these grounds. The bad weather, deep tows, and hard bottom took their toll on gear, machinery, and crew. A strong and unpredictable mixed current regime along the shelf edge south of Hudson Canyon is also an impediment that needs to be overcome.

There were however significant signs of large biomass on and near bottom in water depths greater than 500 m. Much of this biomass may consist of hakes. Identification of what this biomass consists of is of primary importance. Offshore and blue hakes may be a significant untapped resource. In addition, many of the specimens collected from the deep water tows are rare in museums and some indicated range extensions. Future efforts will have to concentrate on distinguishing between echo sounder targets. Gear will need to be evaluated that can fish near-bottom as this may be a better way to selectively harvest some of these deeper demersal stocks.

The key issues in extending the shelf fisheries into deep water are related to resource management. Decisions will have to be made on gear types and selectivity that would allow a viable deep water fishery to be conducted. For example, should traps or trawls be used for red crab? What mesh size and/or other bycatch controls should be used in the deep water shrimp fishery?

As part of this project, a literature search was conducted to find papers related to the development of deep water fisheries. Forty papers were selectively annotated to provide the reader with a basic introduction into what species may be available in this region and how they might be harvested.

IV. PURPOSE

A. Identification of problem

Groundfish and scallop resources on the continental shelf of New England and the Mid-Atlantic are heavily fished and have reached the point of being severely over-exploited. Stocks have been reduced to such extent that most offshore groundfish and scallop vessel operations are on the verge of economic collapse. Individuals that comprise the groundfish and scallop fishing industry are desperately seeking alternative fisheries. Under these conditions, history has shown that fishermen will seek out and exploit any resource that is economically viable, regardless of the ecological consequences. Many vessels are considering re-rigging to tow in deeper water. Some are not only already towing deeper but consider their results proprietary information.

Deep water resources may be very susceptible to fishing pressure. Inappropriate harvesting technology and excessive fishing effort may destroy what resources exist in deep water before resource managers have a chance to react. There are two possible approaches that resource managers can pursue. The first is to stop any development of new fisheries in deep water. This approach will only serve to keep fishing pressure on the shelf resources as well as hasten the demise of many fishing operations. The second, and preferred alternative, would be to systematically develop the deep water fisheries in an ecologically sound and responsible manner. This will help to diversify the fishing industry and increase total resource yields with the resulting economic and social benefits.

One of the largest obstacles to the wise development of the deep water resources is our almost total lack of knowledge concerning what species might be commercially available, and how to appropriately conduct the harvest. There have been relatively recent research cruises covering areas of the upper continental slope south of New England (Haedrich et al. 1975, 1980; Haedrich and Merritt 1988; Markle and Musick 1974, Wigley et al 1975). These trips primarily focused on gathering qualitative information. The small trawls used, and other operational limitations, prevented the collection of the quantitative data needed for commercial fisheries evaluation. The exception was the red crab survey reported by Wigley et al (1975), however, the fish and shrimp catch data from this survey has not been examined (Theroux, personal communication).

The Canadian Government commissioned a study of potential deep water resources off Atlantic Canada (Pohle et al. 1992). This study serves as an excellent starting point for evaluation of commercially available resources in our area. The following is a preliminary analysis of available resources based on the Canadian study, as well as the limited sampling that has taken place in our area.

Shrimp

The Canadian study (Ibid 1992) concluded that shrimp may offer the best development opportunity in upper continental shelf waters primarily due to their high value. The scarlet shrimp, Plesiopenaeus edwardsianus, is considered one of the best prospects due to its large size and attractive appearance. Scarlet shrimp are mostly found between 400-900 meters from the Gulf of St. Lawrence down to the Gulf of Mexico. Other possible commercial candidates include crimson pasiphaeid (Pasiphaea tarda), deepsea sabineid (Sabinea hystrix), Acanthephyra sp., and Pandalus sp. Information regarding the geographic range, preferred depth, and temperature regimes are presented in the various referenced studies.

Fish

Potential deep water fish resources addressed in this project fall into two broad categories; extension of the continental shelf fisheries (200-500 m), and development of deep water demersal fisheries (500-1800 m). The extension of continental slope fisheries into deeper water is a process that is already underway; albeit, uncontrolled. New England fishing vessels are harvesting monkfish (Lophius americanus) in depths greater than 400 meters. The European relative of the monkfish has been reported in depths greater than 1600 meters (Bigelow and Schroeder 1953). Other shelf species being pursued in deeper water include witch flounder (Glyptocephalus cynoglossus), redfish (Sebastes sp.), silver hake (Merluccius bilinearis), and possibly offshore hake (Merluccius albidus). Little is known biologically and virtually nothing is known about the population structure of these "deeper" fish. In most cases it is unclear whether these deeper populations represent different stocks, spawning concentrations, nursery areas, etc.

Deep water demersal finfish population size presented another major unknown in this project. The presence of a number of possible commercial species has been documented in scientific sampling. Among these species are black dogfish (Centroscyllium fabricii), blue hake (Antimora rostrata), cutthroat eel (Synaphobranchus kaupi), grenadiers (Macrourus berglax and Nezumia bairdi), and orange roughy (Hoplostethus atlanticus).

The most important point to be made here is that none of the scientific sampling has used the commercial practice of targeting fish concentrations using vessel-mounted echo-sounders and net-mounted instrumentation. Most successful deep water commercial fisheries are based on this method which is used to locate and harvest dense aggregations of fish. The point is well made by Pohle et al (1992) regarding orange roughy as follows:

> "In both Australasian and European waters, however, roughy occur in spatially small but very dense aggregations. This aggregatory behavior makes them hard to detect during research and exploratory surveys, even when they are sufficiently abundant to support significant fisheries. Roughy were not recorded off New Zealand, even as a taxonomic

curiosity, until 1972 (McKnight 1972), yet within a decade over 20,000 tons per year were being landed in that country. Thus, the rarity of catches of orange roughy in Canadian waters cannot be considered proof of the absence of commercially exploitable aggregations."

Although successful deep water fisheries are being carried out in European and Australasian waters, there is insufficient information on target fish behavior to optimize trawl design. Extensive government sponsored research is being conducted in Europe, Canada, and Australasia to assess opportunities for deep water fishing. Existing fishing system design efforts are dominated by the physical limitations of trawling in deep water (ie, winch capacity, wire strength, fish detection, etc). There were efforts underway in Europe to improve deep water or vertical longline gear (Forster 1968, 1971, 1973; Leite 1989). The project design we chose would first concentrate on finding and assessing the deep water stocks and then work towards gear optimization for the target species.

B. Project Objectives

The primary mission of the project was to conduct exploratory fishing and gear development in the upper continental slope waters of Southern New England and the Mid-Atlantic. The following were specific objectives accomplished by the project:

1. The project identified potential commercial deep water resources both by researching the literature from earlier explorations in the New England/Mid-Atlantic region, and examining fisheries in similar areas around the world.

2. Several possible gear and operational strategies were identified for the resources of highest potential. This included determining requirements for vessel mounted hydro-acoustic equipment, net-monitoring electronics, environmental sensors (eg, XBT units), winch capacity and wire specifications, trawl design(s), and other gear (eg, vertical longlines).

3. The F/V Contender was outfitted to conduct deep water fishing operations. Tows were made to depths of 1800 m. Many valuable specimens were collected for museums.

4. Commercial fishing operations were conducted on the upper continental shelf in depths from 200-1000 meters. These operations included hydro-acoustic transects and bottom tows. Catch and discard records were maintained. Samples of fish, molluscs, and crustaceans were saved for identification and museum collections.

5. The commercial catch was marketed through New Bedford seafood buyers. Records were kept for economic evaluation. This detailed final report was prepared covering all aspects of the project.

V. APPROACH

A. Work Performed

1. Preliminary data collection

This stage of the project entailed a literature search to determine the most likely species to target. The literature search was an ongoing activity through much of the project as new information from discoveries made during the field work required. A total of forty references were annotated as part of this literature search and are attached as Appendix 1. Information on gear and equipment was solicited from fishermen, researchers, fishing gear suppliers, equipment manufacturers, and others. The exploratory fishing and survey strategy was developed and refined with the assistance of the NMFS Northeast Fisheries Science Center.

2. Gear and equipment acquisition

Trawl winch specifications were finalized and the gear ordered. Trawl designs were investigated and two trawls were constructed. The first trawl was a Victory 800 x 3" (76 mm) with a 1 1/2" (38 mm) cod end liner. The second trawl was a Yankee 41, 310 x 6" (152 mm) with 8" (203 mm) wing extensions. Cutting diagrams and mesh component table are provided as Appendix 2. The Yankee 41 trawl was outfitted with a 4" (101 mm) rubber disk sweep. The sweep on the Victory trawl was continually modified but basically consisted of 8" (203 mm) diameter plastic bobbins, referred to as mud rollers, on a wire sweep. Data and log sheets were acquired from NMFS.

3. Vessel Outfitting

The F/V Contender has a 106 ft (35 m) LOA , 25 ft (8.2 m) beam, 12 ft (3.9 m) draft. The vessel is powered by a EMD C645 with 1500 BHP; carries 16,000 gallons of fuel; has 16 berths; and a trip duration of 25 days.

The existing winch on the Contender was a double drum Hathaway mechanically powered by a GM871 (300 HP) with an empty drum line pull of 35,000 lbs and a full drum pull of 12,000 lbs. The original 30" drums could each hold 700 fathoms (1280 m) of 7/8" (22 mm) wire. The new winch is a hydraulically driven Marco powered by a GM892 Turbo (450 HP). This winch was modified to increase the amount of 7/8" wire that each drum could hold to 1000 fms by increasing the size of the drum flanges. For the deepest towing operations we planned to use 2000 fathoms (3600 m) of 1/2" (12 mm) wire because of the great lengths of wire that would have to be set and its corresponding weight. This required the level wind gears to be replaced to allow for proper spooling; a very critical consideration.

The vessel has a Furuno fish finder and Furuno scanning sonar. The fish finder has 1 kw output that was upgraded to 5 kw for use with frequencies of 50 and 200 khz by installing a new transducer. The manufacturer also suggested upgrading the existing 50 kHz unit by adding a 28 kHz board which was accomplished in 1995. The CH12 scanning sonar can scan vertically and horizontally 1400 meters using 60, 88, and 150 khz. The vessel also carries a Scanmar acoustic link net monitoring system. This system was used to observe the operation of the Victory trawl in 100 m of water at the beginning of the project.

4. Exploratory Fishing

The F/V Contender commenced a series of 12 trips of about 8 days each, but not necessarily back to back. A total of 316 tows were made between the Canadian line (south of Georges Bank) westward to Tom's Canyon (off New Jersey). The fishing and survey strategy, developed with the cooperation of NMFS, changed considerably as the project progressed. When commercial concentrations were found, the vessel switched into a commercial fishing mode and catch records maintained. Ten trips were made without a scientific party; the catch records were maintained by the captain. All station data and catches are presented in Appendix 4. Charts showing tow locations are included as Appendix 5.

When it became clear that the Contender would not be permitted to land regulated species the commercial development efforts for shelf fisheries expansion (200-500 m) focused on monkfish. We did find a commercial concentration of royal red shrimp in this depth zone which we fished in order to define the limits of the grounds. Bad weather towards the end of the project period thwarted plans to investigate the offshore and blue hake fishery potential in depths deeper than 500 m.

5. Marketing

Once commercial catches were made, and identification of potential economically important species and quantity determined, processing and marketing arrangements were developed. All sales were recorded for economic analysis. Weighout slips with ex-vessel prices can be found in Appendix 6.

6. Report Preparation

This final report was prepared on all facets of the project including gear, equipment, exploratory survey efforts, catch and discard data, marketing, etc. An economic evaluation was also performed as part of this report. The following sections identify the work accomplished on a quarterly basis:

August 1, 1994 to December 31, 1994

During the first quarter new winches were specified and procured at a cost of $120,000. Specifications were written for the removal of the old winch and installation of the new winch. Enough wire was ordered and received to place 1000 fathoms on each winch drum at a cost of $10,080.

A meeting was held with Tom Azarovitz, the project monitor, to plan the survey strategy. Plans were made to conduct a short cruise at the end of October to test the new winches and to develop data recording procedures. NMFS provided the necessary log sheets and sampling equipment.

A meeting was held at Levin Marine Supply and a preliminary net design was discussed. The net was specified and ordered. Efforts were started to identify suppliers of vertical handline equipment. Information was gathered on rigging options for this gear, which will be species dependent. Presentations were made to the Atlantic Fisheries Technology Conference and to the New England Fisheries Development Association on the project objectives.

Four trips were made during this project quarter for a total of 32 days at sea. Don Flescher (NMFS Resource Surveys Investigation, Woods Hole) participated on the first seven day trip to help set up the sampling protocols. The four trips examined an area from the Canadian line (near Munson Canyon) westward to Hudson Canyon. We were unable to go further west due to extensive longline gear sets in the area but expected this gear to be gone next quarter. The deepest set was to 932 m (518 fms) which caused most of the headline floats to implode. New floats were ordered which allowed towing down to 2000 meters.

Many samples of deep-water species were collected and brought to Woods Hole. The samples were distributed to the following researchers for identification: Dr. Austin Williams (crustaceans) and Dr. Mike Vecchione (cephalopods) of the NMFS Systematics Lab, Dr. Karsten Hartel (finfish) of the Museum of Comparative Zoology, Harvard University, and Dr. Jim Craddock (finfish) of the Woods Hole Oceanographic Institution.

The commercial landings consisted of shrimp (several deep-water species), monkfish (tails and livers), hakes, Illex squid, and grey sole. On the eastern most tows there was an indication of redfish potential however the bottom is exceptionally hard and would require a rock-hopper sweep. The F/V Settler, which was rigged to fish hard bottom, was notified of our findings but did not attempt to fish the area. Large catches of red crab were made in many areas and may represent a significant bycatch problem if they cannot be processed onboard for market.

January 1, 1995 to March 31, 1995

Two trips were made during this project quarter for a total of 20 days at sea bringing the project total to 52. At the beginning of the project period new groundfish rules went into effect that restricted the ability to land hakes, monkfish, and grey sole. We requested a research exemption from NMFS which was placed on hold by NOAA General Council due to a legal problem. Without this exemption we could not accomplish the economic goals of the project. The project was designed with landings offsetting some of the operational costs. It was decided to wait for the research exemption before continuing with the project. This allowed time to meet with NMFS scientists to review progress to date and design a detailed plan for the remaining sea days. Preliminary discussions indicated that it would be best to resume the project in the late summer for a number of reasons (better weather, availability of scientific personnel, exemption resolution, availability of preliminary results from other deep-water projects, etc.)

At this point in the project deep-water potential for commercial fishing seemed to include hake, whiting, shrimp, and red crab. The potential daily catches were 2000 lbs of hake, 2000 lbs of whiting, and between 1000 and 2000 lbs of shrimp. Red crab seemed to be in great abundance throughout the surveyed area but had to be discarded due to lack of onboard processing capability. There was a marked absence of large monkfish deeper than 250 fathoms. Redfish were found on hard bottom south of Georges Bank near the Canadian line. There were many difficulties with fishing in deep water. The most obvious difficulty was keeping the gear on the bottom. Difficulties arise at depths of 300-400 fathoms and become worse at 400-500 fathoms. The color sounder could not pick up the ocean floor at 400 to 500 fathoms with winds between 20-25 knots.

April 1, 1995 to June 30, 1995

During this quarter no sea time was accomplished on the project as we were waiting for NMFS to issue an Experimental Fishing Authorization Letter. The letter was finally issued by NMFS on June 23, 1995. The delay in receiving this authorization, and other factors outlined in the last progress report, required Michigan Fishing Corporation (MFC) to seek a no-cost time extension for this project.

During this quarter MFC acquired extra trawl warp to reach greater fishing depths. Also a winch was acquired for the deep water vertical longlining and planning was underway to outfit the winch with fishing line. The F/V Contender was hauled-out and a new transducer installed for deep water sounding. Other modifications to the sounding system were made, including a new electronic board.

July 1, 1995 to September 30, 1995

During this quarter six sea days were spent attempting to tow deeper than 500 fathoms between Veatch and Baltimore canyons. The scientific party included Ronald Smolowitz, Karsten Hartel (Harvard Museum of Comparative Zoology), and John Galbraith (NMFS). Ten tows were made, one exceeding 1000 fathoms, but we were plagued by operational/gear problems. Even so, some very significant scientific collections were made.

For this trip the trawl warps consisted of two, 2200 fathom long pieces of 3 x 19 galvanized torque-balanced wire with a diameter of 1/2" (12 mm). The wire had a rated breaking strength of 25,000 pounds. This relatively small diameter wire worked well but there was some kinking at the ends. The impact on the gear is unknown. Deepwater trawl floats were purchased and there were no problems with leaks. A kite was designed and built and placed on the headrope and seemed to function well.

We had significant gear problems on most tows including crossed-doors, twisted trawl, fouled legs, etc. Other problems included hangs and hydraulic failures. For some reason the gear was not setting properly. This may be caused in part by the complex current regimes along the shelf edge combined with weather limitations. Another problem was the significant amount of drifting long-line gear in the area. We made extensive use of the 50 khz sounder which worked well to 700 fathoms (1260 m) in wind speeds up to 20 knots. There were numerous dense targets even in depths greater than 500 fathoms (900 m). Some turned out to be snipe eels or very small shrimp.

No promising commercial species were found in quantity. There are indications of commercial sized shrimp. There is also an indication of commercial quantities of offshore hake though they are small compared to white hake. Blue hake were also present and had a nice size and look to them. Many new distribution records were found for deep water fish species (some only previously reported from Florida). Collections also included several species that have been recognized but not described. These are now being worked on by participating scientists. We have collected samples of nearly 200 species of fish and invertebrates.

We replaced the Victory trawl with a Yankee 41 modified with extended wings. We started to concentrate on the commercial catch of deepwater monkfish on good bottom (200-250 fms) and then planned to explore for Greenland halibut in 400-500 fms east of Veatch Canyon.

October 1, 1995 to December 31, 1995

During this quarter all field work on the project was completed. Four trips were made for a total of 40 additional days at sea putting the project about 8 days over the original plan. The four trips used a Yankee 41 trawl and concentrated on deepwater monkfish stocks south of New England. Whole monkfish samples were brought in and given to NMFS scientists for detailed measurements. Hopefully, this data will be used to answer some of the questions regarding monkfish stock separation. Weather had been extremely bad this quarter limiting measurement activities at sea and preventing tows and longlining east of Veatch Canyon as planned. An 80 pound oceanic squid was captured and shipped to the Smithsonian Institution for identification. Additional deepwater fish samples were also delivered to NMFS.

B. Project management

Malvin Kvilhaug	The project was managed by Captain Malvin Kvilhaug. Captain Malvin Kvilhaug is the President of Michigan Fishing Corporation and owns four offshore vessels. He has over thirty years of commercial fishing experience. He also sailed as captain during the project.
Brian Kvilhaug	Captain Brian Kvilhaug, the Master of the F/V Contender, is a 1987 graduate of Mass Maritime Academy. He alternated as captain during the project and also collected the scientific data.
Simon Kvilhaug	Simon Kvilhaug, brought over from Norway for the project, was the trawl master during the start up of the experimental period. Captain Simon Kvilhaug is a Norwegian Fishing Captain with over thirty years of fisheries experience including consulting and gear design.
Ronald Smolowitz -	Data collection and report writing was overseen by Ronald Smolowitz. Mr. Smolowitz has a Bachelor of Engineering degree in Marine Engineering and Naval Architecture. He has more than twenty years of experience in fishing gear design and operation.

VI. FINDINGS

A. Accomplishments and findings

Our findings suggest that there are several bottom species that offer an attractive near-term potential for commercial bottom trawl fishing. These species are located on the uppermost portion of the continental slope, 200-500 meters, and thus do not require significant investment in deepwater harvesting technology. These species include monkfish, red crab, royal red shrimp, and hakes. The catch rates of red crab during this project may be misleading. We were attempting to fish in areas with minimum red crab bycatch. They were hard to avoid. The red crab would require expensive at sea processing capability if harvested by trawl gear. There are commercial quantities of royal red shrimp present, however, we did not find them over a wide range of bottom. Silver and white hake are available in all size ranges. Grey sole is very common over areas of the deep shelf and slope, but the sizes are very small. There is also the distinct possibility of commercial concentrations of redfish and Greenland halibut (turbot) east of Veatch Canyon stretching to the Canadian line. These fish are on very hard bottom and thus may be best harvested by other gear types.

In deeper depths we did confirm the presence of many commercial species including black dog fish, grenadiers, offshore hake, and blue hake. There are significant technological problems that need to be resolved to economically fish these populations along our portion of the continental slope. The following is a species by species discussion of the potential deepwater fisheries identified during this project. General biological information from the literature search is provided as well as a summary of the catch results from this project.

Red Crab

The deep sea red crab, *Chaceon quinquedens* (formerly *Geryon quinquedens*), ranges from southeastern Nova Scotia to Argentina mostly in water depths between 300-900 meters. The potential for a commercial fishery on this species in USA waters has been recognized since the 1950's, but development has proceeded at a slow pace due to many harvesting and marketing constraints. Nonetheless, the potential for a successful fishery still exists. We will expand our discussion on red crab compared to the other species because we feel it has the best potential for immediate sustainable exploitation as described below.

The carapace, or body, of the red crab is relatively square with long and slender walking legs. The body color ranges from dark red to reddish brown. The male crab may reach a maximum size of 178 mm (7 in) in carapace width and a weight of 1.36 kg (3 lbs). Females are smaller, rarely exceeding 135 mm (5.3 in) in carapace width and 0.57 kg (1.25 lbs) in weight. The red crab is a walking crab and lacks the large muscle (lump meat) found in swimming crabs. Little information is available on age and growth, but indications are that this species is slow growing.

Red crabs can be found on most bottoms off the USA east coast, but the preferred substrate seems to be soft mud and silty clay. In the Gulf of Maine the crabs can be found as shallow as 200 meters, but the largest concentrations off southern New England are between 300 and 600 meters. Bio-mass concentrations are found slightly deeper further south off the coast of Maryland. Temperature preference seems to be in the range of 5-8 degrees C.

The only significant large scale survey of red crabs was undertaken by the National Marine Fisheries Service (NMFS) in 1974. At that time, NMFS estimated the population consisted of 43 million crabs of harvestable size (at the time defined as >114 mm carapace width) having a biomass of about 26,700 mt (59 million lbs). This was 24 percent of the total estimated population of red crabs in the surveyed area. The confidence limit ranges from one half to double these numbers. Southern New England waters contained 46 percent of the harvestable total followed by Georges Bank with 31 percent of the total. NMFS conservatively estimated an annual sustainable yield of about 2,700 mt (6 million lbs) which is 10 percent of the harvestable bio-mass in the surveyed area. NMFS did not survey south of Maryland or deeper than 1645 m. The red crab population seems to be segregated by sex and by size. Female crabs occur shallower than male crabs (300-500 m). Larger male crabs occur in shallower waters (300-600 m) than smaller young crabs which are deeper (>600 m). The minimum commercial size crab (114 mm) weighs about one pound.

The red crab fishery began as a bycatch in the offshore lobster fishery. Directed efforts began in 1973 off New England as offshore lobster catches declined. In 1973, 112 mt (248,000 lbs) were landed. In 1977 this number had grown to 1245 mt (2.8 million lbs). Since then the annual landings information has been kept confidential by NMFS due to the fact there are only a few operators in the fishery. In 1984, researchers estimated that about 5 million lbs were being landed annually in this fishery, but the validity of this estimate is difficult to confirm. Some of these landings came from waters off Maryland and Virginia. Landings were probably below sustainable levels. The last company harvesting red crabs, Bay State Trading, filed for bankruptcy this year. To our knowledge, and NMFS (pc, Pat Gerrior, NMFS, Woods Hole) there are very limited red crab harvesting operations underway at present. This may soon change. Recent trips from trap boats have landed live red crab and received between $0.70 and $1.00 per pound, a very good price.

Initially, some of the red crabs were caught by trawl, but crab mortalities were high. Trapping became the preferred method early in the process. The fishery has directed most of its efforts on male crabs larger than 114 mm (carapace width). Females and small males are returned to the sea. There is some evidence that traps are sex and size selective for the large males. The difficulty in landing the crabs alive required this fishery to go to onboard processing and freezing at sea. Where live transport in RSW was successful, economic problems with shoreside processing of large but intermittent landings were significant.

Early exploratory efforts with otter trawl gear yielded catches as high as 500 to 3000 pounds of red crab per hour of towing. During this project we did not direct our fishing effort on red crab; we tried to avoid them. Even so we had one tow that exceeded the highest catch levels of the early NMFS explorations (Tow 3-14 caught more than 3000 pounds per hour of bottom time.) and more than 20 tows within the NMFS highest catch range. However, many of the crabs caught were not in very good condition for purposes of live transport.

A variety of trap types were tried in the early 1970's by NMFS, with catches averaging 55 kg (122 lbs) of crab per day per trap. On one occasion a single king crab trap caught 700 lbs in an 18 hour set. Red crab were last harvested using modified versions of the offshore lobster trap or pot. These pots were set in strings that contained between 50-70 pots. The pots were hauled daily except between trips when they were left in the water for longer periods. The pots were baited with fish and when the bait was gone the crabs left the traps. Pots designed to prevent the crabs from leaving did not fish as well as the more open design. Pot life ranged from 6 months to a year.

Attempts to land live crab found that holding in refrigerated sea water was the best method of transport available. The live crabs were landed for processing ashore. Initially, red crab was picked the same way as blue crab. The crab was steamed and handpicked with an oyster knife. This was very time consuming. This method was soon replaced by boiling, quick chilling and shaking the meat out of the shell. This shore based processing was plagued with problems related to plant capacity not matching landing volumes. In addition, refrigerated sea water systems were expensive, difficult to maintain and had occasional high crab mortalities associated with them for a number of reasons.

The approach shifted to one of butchering at sea and holding the meat containing sections on ice. This resulted in the problem of meat darkening due to enzyme activity. Chemical dips were introduced to mitigate this problem. High labor costs associated with butchering onboard lead to mechanization of the butchering and meat separation process. Meat yield from the red crab is about 20 percent of the live weight.

There are a number of similar crab fisheries around the world. Canadians have been trying to develop a fishery for the same species of red crab over the years and still consider the possibility viable, though the estimated crab abundance is much lower than in USA waters. Canadian landings of red crab were as high as 500 mt per year. *Chaceon fenneri*, known as the golden crab, is very similar to the New England red crab. The golden crab occurs in depths from 300-1800 meters from South Carolina around into the Gulf of Mexico. The crab is beige and on average larger than the red crab weighing 2-3 pounds each. Meat yield is about 25 percent. Development of the golden crab fishery began in 1982. Extensive gear trials and processing experiments were conducted in support of the fishery. The largest red crab fishery is conducted on *Chaceon maritae* off the African west coast. This fishery had peak catches in the 1980's of about 10,000 tons per year taken with about 1,300,000 traps set per annum. The fishery has been conducted by Japanese vessels fishing standard Japanese crab traps. As many as 1500 traps are attached to a line that can extend over 30 km. The crabs are processed onboard into a number of products including sections, legs and claws, and flake meat.

The southern New England/Middle Atlantic Bight red crab fishery probably can support a number of full time crab vessels given the current market prices for crab meat ($2.50 to $4.00). In addition, red crab fishing does have the potential to augment the earnings of vessels involved in other fisheries on a seasonal basis. Based on the last NMFS estimate of 6 million pounds annual sustainable yield this fishery could yield 1.2 million pounds of processed meat worth about $4 million annually. This is not an insignificant figure in today's economic climate. A vessel rigged for fishing red crab with trawl gear can also catch and process deep water shrimp, monk fish, and other species. The success of this type of venture will depend on containing costs, primarily crew and fishing gear expenses. It may be best to replace the hard to handle and expensive trap gear with a light weight beam trawl. The beam trawl will require a smaller crew than a trap vessel. The beam trawl, because of its fixed opening, makes an excellent survey gear. The beam trawl will also have a much lower bycatch of fish due to its low height and no herding effects.

There is another reason to use towed gear for this fishery. In 1993, the Mid-Atlantic and New England Fishery Management Councils convened a Monkfish Advisory Committee comprised of industry members to resolve gear conflicts in deep water. The agreement currently in effect prohibits trap gear in bottom that red crab are likely to be found in commercial quantities.

Most of the pitfalls to red crab harvesting and processing have been identified so there is limited risk compared to more nascent enterprises. There is a need to improve upon the past operations by purchasing state-of-the-art processing and freezing equipment. J & M Fishing Corporation has already conducted a preliminary trial of an at sea harvesting and processing concept (New Bedford Standard Times). The preliminary trial indicated that a vessel can successfully process trawl caught crabs even when the crabs were damaged. A beam trawl used by the company did not damage many crabs and had little bycatch when compared to an otter trawl used during their trial.

Monkfish

Monkfish (*Lophius americanus*) are also known as goosefish or angler. They range from the Gulf of St. Lawrence and the Grand Banks south to Cape Hatteras. They occur in all water depths from the shoreline out to over 800 m. They are harvested for their tails and their livers.

The monkfish has an enormous mouth with many teeth. Adults have been known to grow over four feet in length and weigh upwards of fifty pounds. The color of the upper portion of the body runs in shades of brown and underneath is white. During our project we noticed some distinct colorations. European studies on a related species suggest that this might be related to bottom type; the monkfish matching itself to its surroundings. There is the possibility of several species of monkfish being present in our waters as well as the possibility that the species is the same as its European counterparts. Females grow larger than males normally reaching a size of about 100 cm compared to 90 cm for males. Sexual maturity occurs around age four in females (49 cm) and age three in males (37 cm).

Monkfish are tolerant to a wide range of salinity and temperature; though the preferred temperature range may be 3 to 11 degrees C. They normally inhabit smooth sand and the harder mud bottoms. There is some discussion among fishermen whether or not the deep water stock of monkfish is different than the shallow water stock. Currently there is no estimate of population size.

Monkfish have traditionally been a bycatch of the bottom trawl and scallop dredge fisheries until recently. The popularity of recipes utilizing monkfish tails has greatly expanded the domestic market. A highly profitable directed fishery has developed based on the value of the tails combined with the value of the livers (exported primarily to Japan). This fishery is prosecuted by bottom trawl, scallop dredge, and gill net. During our project prices as high as $1.80 per pound for tails and $12.00 per pound for livers were received for the Contender's catch.

Our economic analysis of the last four trips of the project demonstrates that a profitable fishery can be conducted on the monkfish found in deep water. What the relationship of this stock is to that of fish further inshore is unclear in the minds of the fishermen. The livers are smaller in the fish from deep water but this may not indicate any stock separation. There were few fish over 60 cm in the catch (see Appendix 7) which would possibly indicate that this is not a virgin untapped resource or the fish do not grow large. While commercial size catches can be taken over much of the upper slope we explored, this is still a relatively small amount of bottom compared to the shelf itself. There were many places we could not fish because of the presence of fixed gear (ie, lobster traps) and hard bottom. These areas may act as protection for the monkfish stock from trawling activities. We can only conclude that there is not much potential for major expansion in the existing monk fishery.

Grey Sole

Grey sole (Glyptocephalus cynoglossus), or witch flounder, is a right-handed small mouthed flounder. They are common in the Gulf of Maine and in the deep water along the upper slope from Georges Bank to Cape Hatteras.

The grey sole is three times as long as it is wide and it is very thin. The color is grey on top and white on bottom. They reach a maximum size of 25 inches (63.5 cm) and about 4 pounds (1.8 kg) in weight. The grey sole is usually found in deep water generally below 55 m depths. They are normally found in commercial quantities on fine muddy sand in depths from 110 to 275 m. The literature strongly suggests that the juveniles of the grey sole stay in deep water until they are 3-5 years old, then they migrate up-slope. If this is in fact the case, the deep water may act as a protected nursery area for this species.

During our project 231 grey sole were measured from the lined trawl catches. Over 93% of these fish were smaller than 37 mm (14"). Twenty-seven percent were over 30 cm; the largest caught was 47 cm. The large mesh unlined trawl had virtually no bycatch of grey sole. These data would indicate that there is not a potential fishery for grey sole in water depths greater than 200 m in southern New England. However, grey sole could become a bycatch problem in a small mesh shrimp, squid, or whiting fishery.

Shrimp

A bed of royal red shrimp (*Pleoticus robustus*) was located in 350-400 m of water at latitude 39-00 N and running from about 70-40 to 71-00 W longitude; a total of about twenty square miles of grounds. The larger shrimp numbered about 22/kg (10/lb). Heading the shrimp reduced the weight by about 40%. There was also some additional sign of this species in our catches south of Hudson Canyon. All literature to date indicates this is about the northern most extension of this species range; none have been reported east of the Great South Channel. Beds of these shrimp have been fished commercially in the past off of Florida, the Tortugas, and the Mississippi Delta. There still is a small and ongoing fishery down south for this species.

Small catches of scarlet shrimp (*Aristaeopsis edwardsianus*) were also taken at many stations. This is a very large deep water shrimp but does not seem to be very abundant. The most interesting thing about this species is that its excellent condition when caught indicated it was taken in the water column on the way up. It may be possible that this species is in abundance up off the bottom.

Appendix 3 presents some more detailed information about these shrimp. All evidence to date indicates that these shrimp are not available in large enough numbers to sustain a continuous, even small scale, fishery.

Hake

A number of species of hake were caught during the project but species identification was far from complete. The hake can be placed into two general groupings; the true hake group consisted of white hake (*Urophycis tenuis*), red hake (*Urophycis chuss*), and spotted hake (*Urophycis regius*). These hakes resemble each other and as far as the market was concerned they were sold together; price based on size rather than species. The red and spotted hakes are small and occur in shallower depths. There was also some confusion in marketing the second grouping; the silver hake (*Merluccius bilinearis*) and the long-finned hake (*Urophycis chesteri*) as they have a casual resemblance to each other. The offshore hake (*Merluccius albidus*) could fall into either group depending on its size after being headed. The blue hake (*Antimora rostrata*) is readily identifiable and would probably sell independent of the other two groupings.

Unfortunately, there was not enough time to examine the potential of a hake fishery.

Based on the catches made there does seem to be a large biomass of the various hakes in deep water. The market price for the hakes landed was promising. The large offshore hake can be sold as king whiting.

Other Species

One group of elasmobranches we were interested in were the species of *Centrophorus, the* black dogfish, since we heard they were being marketed for their flesh as well as squalene extracted from their liver. We did not catch any large concentrations or large specimens of these species. We also found out that squalene is now being synthesized. More on these sharks can be found in Appendix 9.

We have not given up on the presence of commercial concentrations of one or more roughy species. We caught one specimen and a number have been caught in the past, all south of Hudson Canyon (see Appendix 9.)

B. Significant problems

There were quite a few problems as was expected with deep water work of this nature. We expected to have problems related to towing based on our literature review. Other projects of this nature had similar rates of unsuccessful tows in deep water; sometimes in excess of 50%. The only cure seems to build up experience with the area fished and the gear towed. This is difficult to do when exploring new grounds. The time involved to conduct tows in water depths greater than 200 m is high. We only averaged about five tows (4 hours long) per day in depths of 300-400 m. Other time was lost to searching for targets using the fish finder and in finding towing ground between drifting longline gear. Ninety sea days clearly was not enough time to accomplish what we set out to do.

A second problem is that we were not able to get the at sea scientific support we hoped for due to constraints on NMFS personnel. The large number of different and difficult to identify species was beyond the capabilities of a fishing crew to handle. During cruise 8 a highly trained four man scientific party could barely process a relatively small catch in the four hour tow period.

C. Need for additional work

The following are recommendations for additional work based on the results of this project:

- There needs to be exploratory fishing conducted between Veatches Canyon and the Canadian line. Our gear was not capable of towing on the hard bottom between 500 and 1000 m. There may be better bottom deeper than 1000 m. Gill netting and vertical longlining may be appropriate exploratory methods on the hard bottom areas.

- Technology for processing red crab at sea needs to be developed and demonstrated.

VII. EVALUATION

This was a very extensive project that accomplished much on one hand, but barely scraped the surface on the other hand. There are reasons why so little is known about the waters just 100 miles off some of the most populous coastline of the country. In brief, it is very difficult and costly to conduct deep water fishing operations. We were led to believe by equipment manufacturers and others that the technology available would make this project economically feasible. This was not the case. For example, we talked to one deep water ichthyologist who related to us the story where they used a very expensive and highly instrumented small sampling trawl in the Middle Atlantic bight. They set the trawl and watched it settle towards the bottom when all of a sudden the trawl started moving faster than the vessel and became hopelessly tangled. It will take much effort to learn how to fish these complicated current regimes in a commercial successful way; ie, with few costly foul-ups.

However, we cannot overlook the fact that we accomplished a significant amount of work on this project that more than justified the effort. Briefly, the accomplishments of our goals and objectives can be summarized as follows:

- We were able to economically modify a New England scalloper/dragger to fish to 1000 fathoms (1800 m).
- We identified and confirmed the existence of a number of commercially available species in depths greater than 200 m including shrimp, red crab, monkfish, and many species of hakes. We also provide information on the extent and condition of some of these stocks.
- We found indications that there are commercial concentrations of redfish and turbot east of Veatch Canyon that are worth developing. The deep water blue hake may also be an attractive commercial species for the fillet market.
- We compiled an extensive annotated literature search that will help future investigators and fishermen to proceed from where we have come today.
- We found large biomasses in water depths greater than 500 m, on and near bottom, that will need to be identified.

The most important conclusion is that deep water biological assessment and fishery development work is too complicated and expensive to be accomplished by simple grant funded programs such as S-K alone. Examination of deep-water research efforts in other countries finds large well-funded programs attempting to accomplish what we set out to do on a shoe-string budget. The work can best be accomplished as a joint industry/NMFS project in our opinion as follows:

- Improve the F/V Contender by further hydroacoustic equipment upgrade.
- Purchase a near-bottom trawl with sensors. Upgrade the vertical longline system.
- Man all trips with a minimum of 3 NMFS trained sea-samplers.
- Provide adequate funding so the work can be accomplished during April to October.
- Place emphasis on species/biomass identification; not commercial economics.