The Atlantic and Gulf Menhaden Purse Seine Fisheries: Origins, Harvesting Technologies, Biostatistical Monitoring, Recent Trends in Fisheries Statistics, and Forecasting

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Origins

The menhaden fishery is one of the oldest and largest commercial fisheries in the United States. Beginning in colonial times, seine fisheries for Atlantic menhaden, *Brevoortia tyrannus*, were established at various sites along the New England coast. Beach seines were the principal gear, the fisheries were localized, and whole fish from the catch were sold for fertilizer. Frye (1978) recounts that techniques for boiling and pressing menhaden were developed in Rhode Island by 1811. Press machinery yielded fish oil which was used in various industrial processes and as a fuel oil, while the dried, pressed fish mass known as fish scrap was sold as fertilizer. By 1845 purse seines were introduced to the New England area (Frye, 1978) and the fishery, no longer dependent on localized abundance of fish schools or beach seining sites, expanded into nearshore coastal waters. After the Civil War menhaden reduction plants were established in Virginia and North Carolina. By about 1895 a scarcity of fish north of Cape Cod caused a collapse of the fishery in New England, and by the early 1900's the industry was concentrated in the Middle and South Atlantic states (Nicholson, 1971). During this period fish "scrap" was still the principal product of the industry, with each company producing its own formula of fertilizer. Harrison (1931) reported that by the late 1920's much of the menhaden catch was milled into farm animal feed, while the amount of fertilizer produced declined, fish oil was used "in the manufacture of soap, linoleum, water-proof fabrics, and certain types of paints".

Spurred by increased demand for fish meal mainly from the burgeoning "broiler" poultry industry, the years immediately following World War II mark the birth and development of the modern menhaden industry and purse seine fleet. This period also marks the inception of the Gulf menhaden, *B. patronus*, purse seine fishery, as many established companies on the Atlantic coast moved some or all of their operations to the U.S. Gulf coast to fish that virtually unexploited stock.

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ABSTRACT—With its genesis in New England during the 1800's, the purse seine fishery for Atlantic menhaden, Brevoortia tyrannus, *expanded south and by the early 1900's ranged the length of the eastern seaboard. The purse seine fishery for Gulf menhaden,* B. patronus, *is of relatively recent development, exploitation of the stock beginning in the late 1940's. Landings from both fisheries annually comprise 35-40% of the total U.S. fisheries landings, ranking menhaden first in terms of volume landed. Technological advances in harvesting methods, fish-spotting capabilities, and vessel designs accelerated after World War II, resulting in larger, faster, and wider-ranging carrier vessels, improved speed and efficiency of the harvest, and reduction in labor requirements. Chief products of the menhaden industry are fish meal, fish oil, and solubles, but research into new product lines is underway. Since 1955 on the Atlantic coast and 1964 on the Gulf coast, the NMFS has monitored the fisheries for biostatistical data. Annual data summaries of numbers-of-fish-at-age harvested, catch tonnage, and fishing effort of the fleet form the basis of routine stock assessments and annual catch forecasts to industry for the upcoming fishing season. After landings declined in the 1960's, the Atlantic menhaden stock has recovered through the 1970's and 1980's. Exceptional year classes of Gulf menhaden in recent years account for record landings during the 1980's.*

The crew of a schooner, in an old-style seine-boat, throws the purse seine around a school of menhaden.

Due to corporate consolidations, acquisitions, and plant closures in recent years, the present-day menhaden fishery is comprised of only a few major companies. Vessels, gear, and to some extent spotter aircraft are company owned. Vessels, in particular, are specifically designed for menhaden fishing, and as such are generally not used in other fisheries. The menhaden industry is vertically integrated with most companies marketing their chief products—fish meal, fish oil, and solubles—directly to brokers or feed milling companies; compared to most other U.S. fisheries, handling and processing technologies in the menhaden industry are relatively advanced (GSMFC, 1983).

Harvesting Technologies

Purse seine fishing for menhaden is a daylight activity, prosecuted in nearshore coastal waters, generally less than 15 m (50 feet) deep. The basic pattern of fishing begins with a carrier vessel which searches for or is directed to concentrations of menhaden schools. Upon location, two purse boats, each carrying one-half of the seine, are lowered from the carrier vessel. The purse boats encircle the school with the seine (Fig. 1), then tighten the purse line, which runs along the bottom of the seine, enveloping the school. Hydraulic power blocks assist retrieving the wings of the seine. The fish are concentrated into the bunt of the net, then loaded onboard the carrier vessel, and at day's end they are transported to the reduction plant. Catch per purse seine set (which is a good estimate of school biomass) may range from a few to over 50 t (Nicholson, 1971), and sets of over 150 t are not uncommon.

By present standards purse seining in the nineteenth century was laborious and inefficient, with carrier vessels being

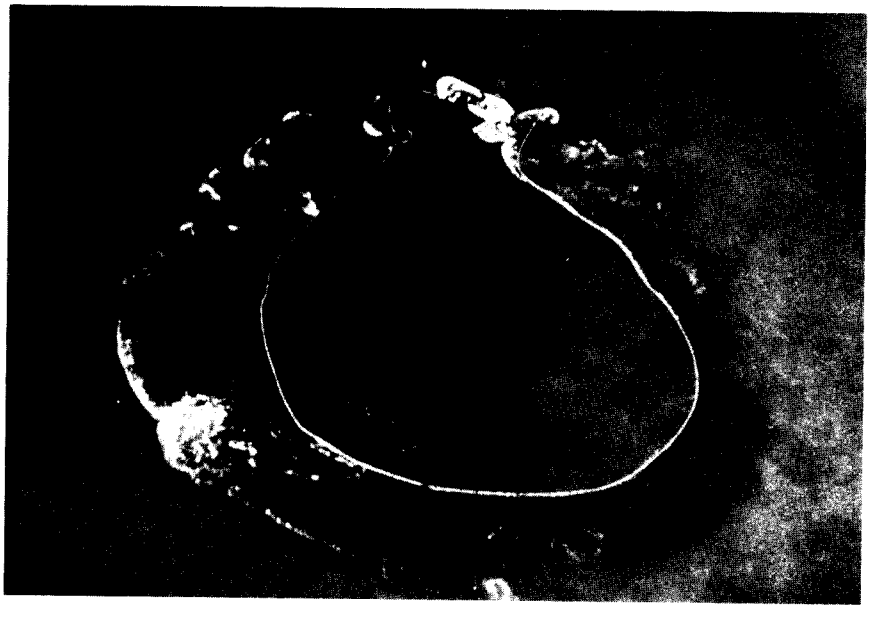
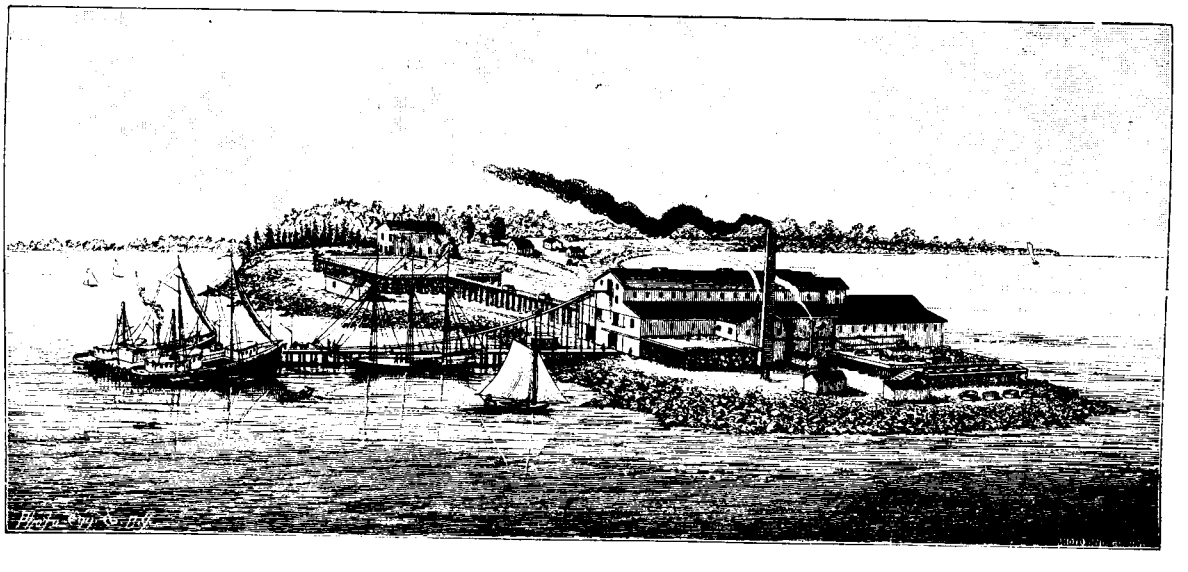
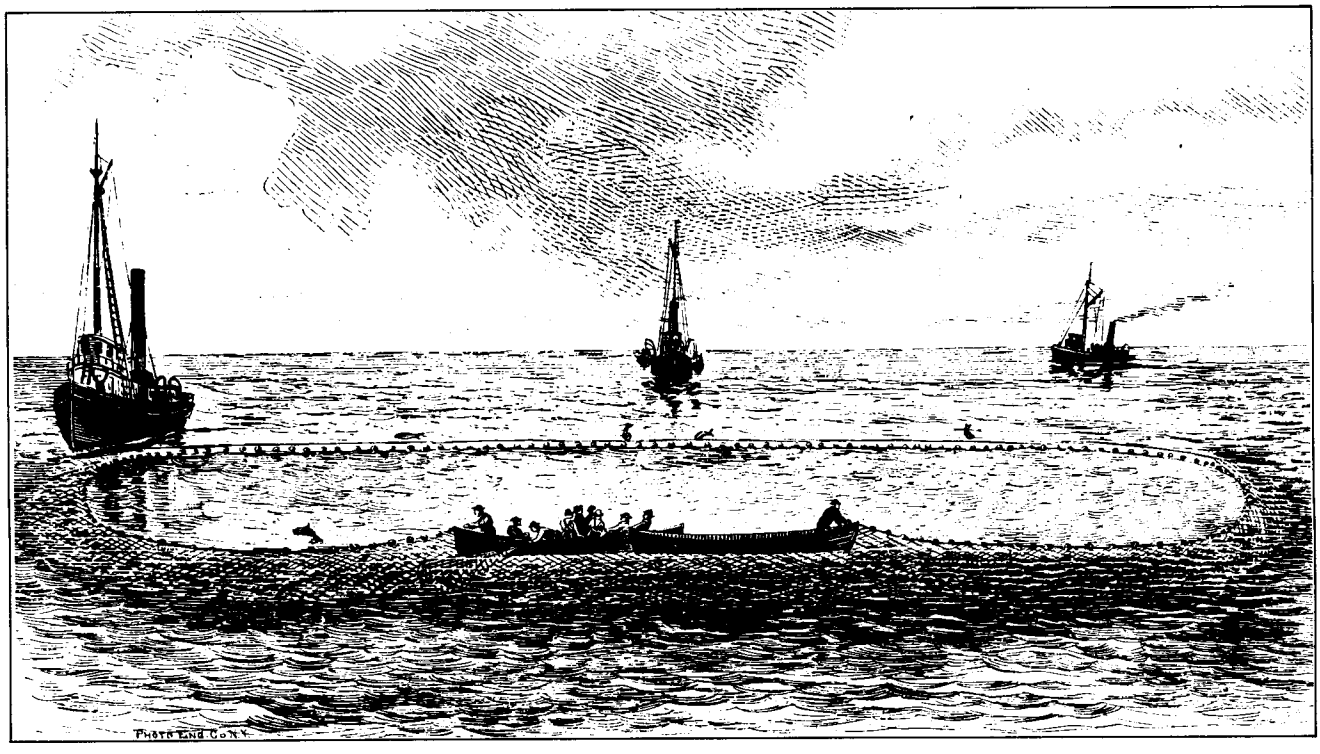


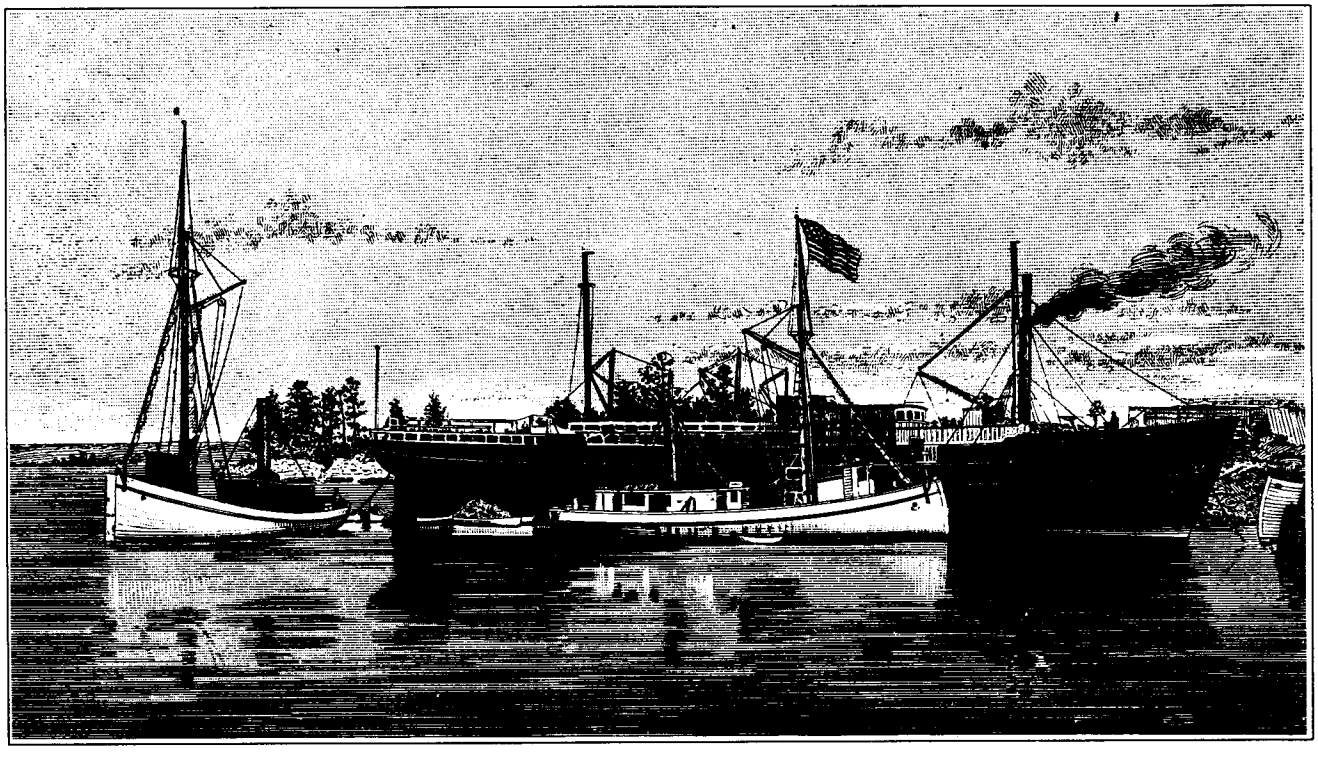
Figure 1.—Aerial view of a menhaden purse seine set. Photograph by Hall Watters, formerly of Standard Products Co., Reedville, Va.



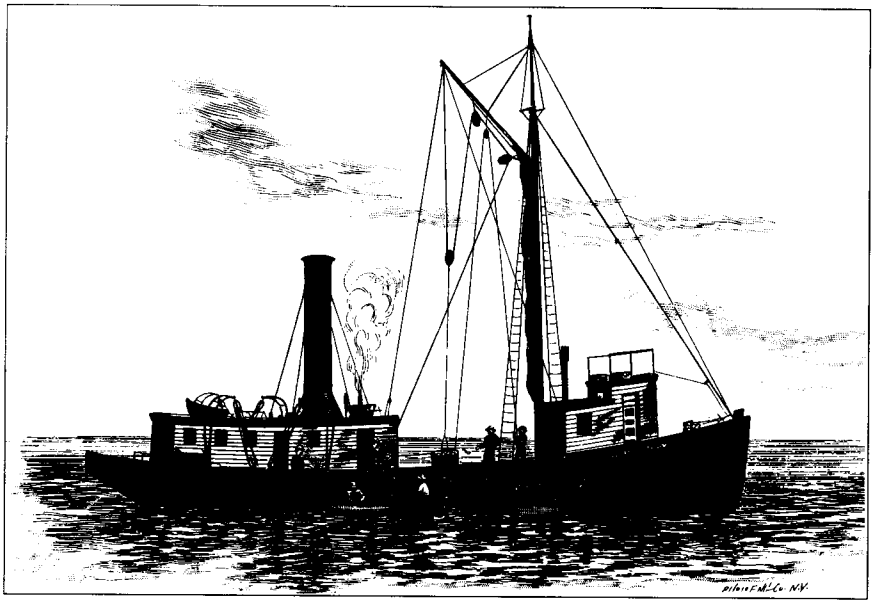
An early menhaden and guano factory at Milford, Conn., showing steamers unloading fish at the wharf, an incline railway for carrying fish to cooking tanks on the upper floor of the factory, oil tanks and storage sheds in the foreground, and a platform for drying scrap in the rear of the factory connected with the building by elevated railway.



Menhaden strike the net as a school is surrounded with a purse seine.



Floating menhaden factory: An old vessel was fitted as an oil factory and was moved from place to place near the fishing grounds.



An early menhaden steamer bails in the catch.

sailed and purse boats being rowed (Nicholson, 1971). By the turn of the century, larger carrier vessels were fitted with steam engines, and the purse boats were powered by gasoline engines. After World War I, diesel and gasoline engines powered the carrier vessels. Following World War II and paced by the rising demand for fish meal, numbers and sizes of vessels increased.

Although basic menhaden purse seining methodologies have remained unchanged for decades, innovations in gear, handling, and vessel design and technologies have vastly improved the efficiency of the modern menhaden fleet. Major changes in harvesting technologies after World War II were chronicled by Nicholson (1971, 1978). In 1946 spotter airplanes were introduced into the fishery. Initially, they directed the fleet to large concentrations of fish, but later they were equipped with two-way radios and airplane pilots actually directed the setting of the net. Spotter aircraft are single-engine, overhead fixed-wing planes; some are privately owned by the pilots, while others are owned or leased by the menhaden companies. Pilots usually fly a "patrol" in late afternoon or early evening to locate concentrations of fish for the next day's fishing activities. Vessel captains are alerted to the approximate locations of the fish schools, and are expected to be on fishing grounds at dawn where they are joined by the spotter. Pilots are adept at judging not only the size (volume) of the fish school, but also the size of the fish within the school. One aircraft may guide several vessels.

By the late 1950's aluminum purse boats began replacing wooden purse boats. Aluminum purse boat hulls are lightweight and much more maneuverable and faster than the wooden design. Modern purse boats measure about 11-12 m (36-40 feet) long, 3 m (10 feet) wide, and are powered by a diesel engine which also furnishes power to the hydraulics. Most carrier vessels transport their purse boats aft on davits swung overboard. A recent modification to a few menhaden vessels features davits that not only raise and lower the purse boats via hydraulic winches, but additionally the davits pivot inboard so that the purse boats rest in deck cradles on the stern (Anonymous, 1987). With this design, purse boat crews can board and disembark the purse boats more easily and safely, and time and effort are saved when docking and undocking (most carier vessels must disembark their purse boats coming to dockside). Also, a recent modification to menhaden vessels features purse boats that rest on an inclined stern ramp while in transit, again eliminating the danger of boarding purse boats at sea (Anonymous, 1988).

Hydraulic power blocks (Schmidt, 1959) were introduced to the fishery in the mid-1950's and were utilized by nearly the entire fleet by the mid-1960's. A power block, mounted on a hydraulically operated crane in each purse boat, facilitates concentrating the catch in the bunt of the net and the quick retrival of the "wings" of the net after a set. The difficult task of retrieving the net by hand was eliminated, and purse boat crews were reduced from about 22 to 12 deckhands.

Nylon seines replaced natural fiber nets by the mid-1950's. Synthetic netting is stronger, has less tendancy to burst when a large catch is made, and hence requires less repair time. Approximate dimensions of modern purse seines used by the menhaden fishery are 19-22 mm (¾-⅞ inch) bar mesh, up to 365 m (1,200 feet) long, and 18-27 m (60-90 feet) deep.

After the catch is concentrated or "hardened-up" in the bunt of the net, the carrier vessel comes alongside the net and purse boats to load the fish into the hold. Large fish pumps, standard equipment on most carrier vessels since the mid-1950's, rapidly transfer fish to the hold and replace the laborious method of brailing the catch. A flexible, 10-inch hose is lowered into the bunt and suction draws fish and water onto the carrier vessel. Fish pass over a de-watering screen, then into the hold.

With the evolution of the menhaden fleet in the Gulf of Mexico came the need to refrigerate the catch and prevent rapid decomposition of menhaden during the warm Gulf coast summer. As developed, chilled seawater is constantly sprayed over the catch and recirculated to a refrigeration unit through screens in the floor of the hold. Refrigerated fish holds were introduced to the Gulf menhaden fleet in 1957 (Nicholson, 1978), and by 1972 all Gulf menhaden vessels had refrigeration. Presently, most vessels in the Atlantic fleet have refrigeration, the benefits of which are twofold: Not only

is the quality of the catch preserved, but trip duration and range from home port are increased.

Since the mid-1950's the number of carrier vessels in the Atlantic menhaden fleet has declined dramatically from about 150 to 22 to 1987; the Gulf menhaden fleet has been more stable, numbering about 60-80 vessels over the same period (see the Recent Trends section). Despite the downward trends in total number of menhaden purse seiners, since the 1950's trends in vessel construction have been toward larger, faster, and more efficient carrier vessels. After World War II, decommissioned military craft, many of which were steel-hulled, were retrofitted and became the progenitors of the modern menhaden fleet. By about the mid-1950's, larger steel carrier vessels designed specifically for menhaden fishing began replacing the smaller and aging wooden-hulled vessels of 1930's and 1940's vintage (Fig. 2). Modern steel purse seiners are longer, have greater fish hold capacities, are faster (greater main engine horsepower ratings), and have better amenities for the crew than their earlier counterparts (Table 1). Most modern menhaden vessels are company-owned, and since some companies manage several plants at different ports, occasionally vessels are reassigned to alternate plants depending upon the availability of fish. Crew size is generally 15-16, with captain, mate, pilot, engineers, cook, and deckhands. All of the innovations above have served to reduce search time, loading time, and labor costs, while increasing vessel range, trip duration, and load capacity and quality.

Most modern carrier vessels homeported along the Gulf coast, in Chesapeake Bay, and to some extent New England and the South Atlantic, have retained the classic lines of a menhaden purse seiner (Fig. 3), that is, bridge, mess, crew's quarters and crows' nest forward, fish holds amidships, and engine room aft; these vessels generally range from 43 to 52 m (140-170 feet) long and 250-375 net t. Exceptions to the traditional menhaden purse seiner design occur on the Atlantic coast. In Chesapeake Bay a few smaller carrier craft (less than about 30 m (100 feet) and 100 net t) employ a purse-seine variation called a "snapper rig" in which usually one purse boat is used. These vessels are unrefrigerated and generally fish in areas where larger carrier vessels cannot venture. Most of the catch is sold as bait, although some is sold for reduction. In New England, since menhaden are usually only available during summer, carrier vessels until recently were multiple-use craft (generally trawlers or draggers) that convert to purse seining in summer. The catch is not refrigerated, but is offloaded for reduction at day's end. In recent years

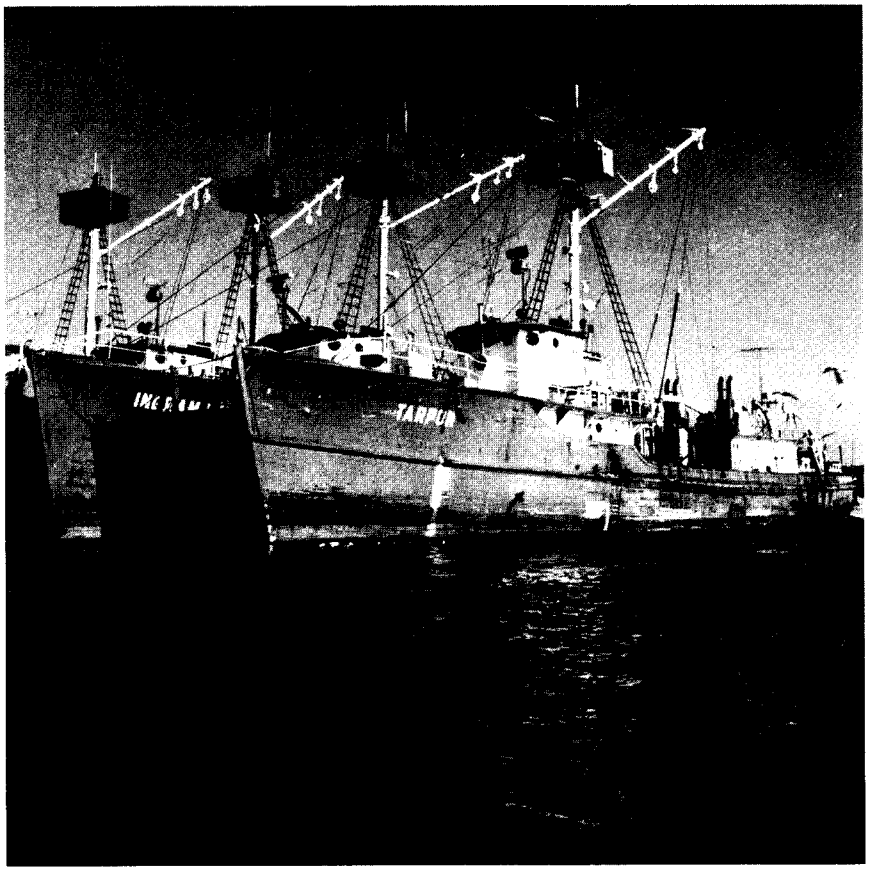


Figure 2.—Wooden-hulled menhaden purse seine vessels of about mid-1940's vintage.

Table 1.—A comparison of fleet characteristics for the Atlantic and Gulf menhaden purse-seine fisheries, 1980 vs. 1988.

	1980				1988			
	Atlantic menhaden fishery, 44 Vessels[1]		Gulf menhaden fishery, 78 Vessels[2]		Atlantic menhaden fishery, 21 Vessels[1]		Gulf menhaden fishery, 72 Vessels[2]	
Item	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Length (feet)	68-200	148	124-195	156	87-200	164	126-195	161
Gross tons	92-754	427	181-648	445	151-754	531	199-746	493
Net tons	64-615	286	103-453	304	115-564	363	139-615	337
Horsepower	480-2,000	1,384	440-2,320	1,381	720-2,000	1,638	440-2,450	1,534
Age (years)	11-46	39	1-36	14	1[3]-44	35	1[3]-44	22
Season's catch (t)	1,560-16,000	8,700	1,300-16,500	9,000	2,700-18,900	13,900	1,100-15,400	8,600

[1] Includes only vessels that landed regularly in the summer fishery; excludes vessels added in fall and converted trawlers in the North Atlantic area.
[2] Includes vessels that landed fish 9 or more weeks of the 26 week season.
[3] Newest additions to the menhaden fleet are former oil rig supply boats converted into purse seiners (see Anonymous, 1987).

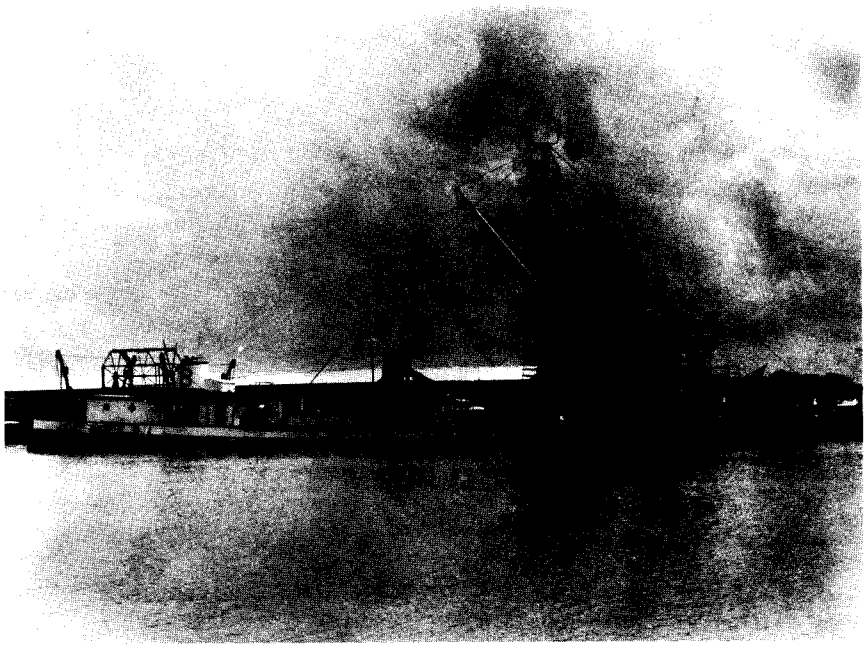


Figure 3.—F/V *Carl Burton* at dockside prior to offloading a full fish hold of Gulf menhaden (Photograph by R. B. Chapoton, 1968).

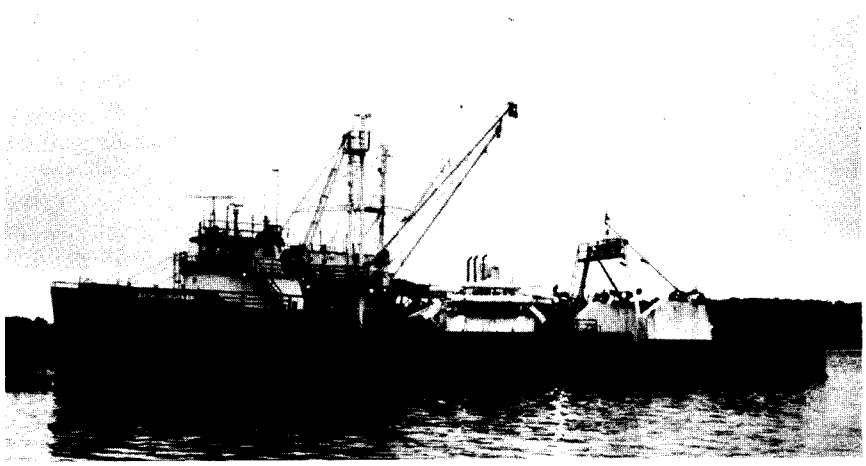


Figure 4.—F/V *Coastal Cruiser*, a menhaden purse seiner, formerly an oil-rig supply vessel.

several steel-hulled, modern purse seiners have joined the menhaden fleet in New England. In the South Atlantic, a few shallow draft vessels less than 30 m (100 feet) long fish primarily in sounds and large bays. They are unrefrigerated and tow their purse boat. A recent innovation in the fleet has been the conversion of surplus oil rig supply vessels to purse seiners (Fig. 4) (Anonymous, 1987, 1988). By 1989, about 12 of these converted vessels had joined the menhaden fleet.

Industrial Processes and Major Products

The wet reduction process whereby menhaden are processed into fish meal, fish oil, and fish solubles varies from plant to plant mainly in the manner which fish are shunted through the facility (Fig. 5, 6). Despite increased efficiency and capacity within certain menhaden plants, the basic réduction process has changed little since outlined by June and Reintjes (1976). The following descriptions of menhaden reduction facilities and processes are gleaned from their work, ASMFC (1981), and GSMFC (1983).

At dockside with a day's catch, the hold of the carrier vessel is partially flooded with water. Fish and water are evacuated through openings in the floor of the fish hold, and moved shoreside via suction through a large diameter hose primed by a fish pump. Several "bailers" constantly agitate and direct fish toward the drain in the fish hold using jets of water sprayed from hoses. This washdown water is recycled through the entire offloading process and is eventually moved to storage tanks as "stickwater" (see below). On shore, fish pass over a dewatering screen and then into a rotating hopper. Each compartment of the hopper volumetrically contains 0.36 m^3 (22,000 $inches^3$). In industry jargon, one compartment or "dump" of the hopper holds 1,000 "standard" fish, or gravimetrically 304 kg (670 pounds); a few plants on the Gulf coast employ hoppers that hold 1,500 "standard" fish or 456 kg (1,005 pounds). By convention one "standard" fish weighs 0.3 kg (0.67 pound). Wages of captains, crews, and to some extent airplane spotter pilots, are based on the number of "dumps" offloaded.

Fish are transferred from the hopper by conveyor belts, draglines, or augers to either the cookers or a temporary holding bin called the "raw box". Fish usually are not held over 12 hours in the raw box. Drag lines in the floor of the raw box convey fish into the cooker where fish are subjected to jets of steam. Cooked fish mass is then transferred to screw presses where water, oil, and soluble elements (i.e., press liquor) are squeezed out. Cooked fish mass after pressing is called press cake. Press liquor from the presses is pumped into centrifuges where aqueous and oil fractions are separated. Fish oil is eventually pumped to storage tanks, while the aqueous fraction or "stickwater" passes through evaporators which concentrate

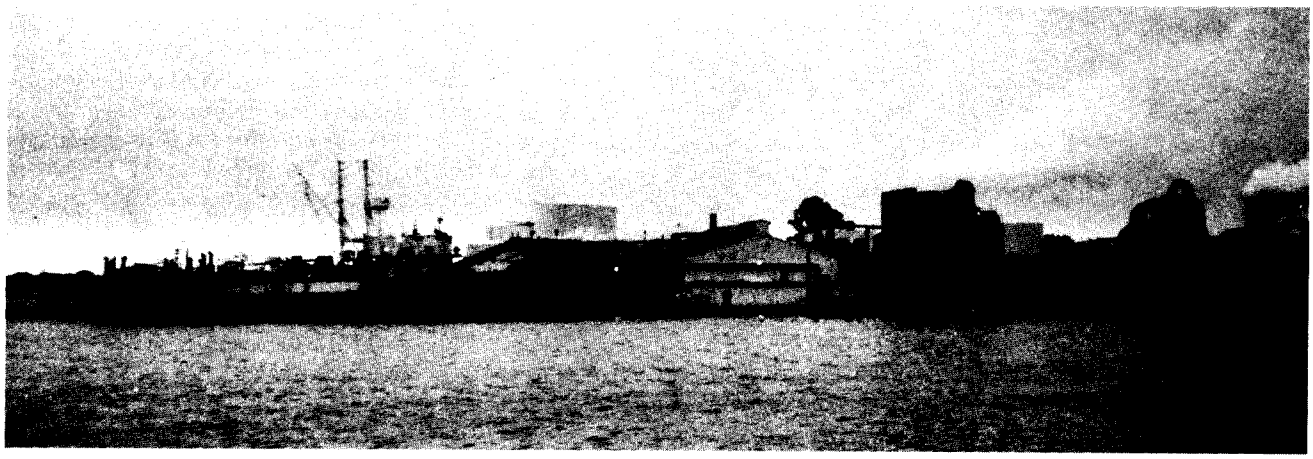


Figure 5.—A modern menhaden reduction factory in Reedville, Va.

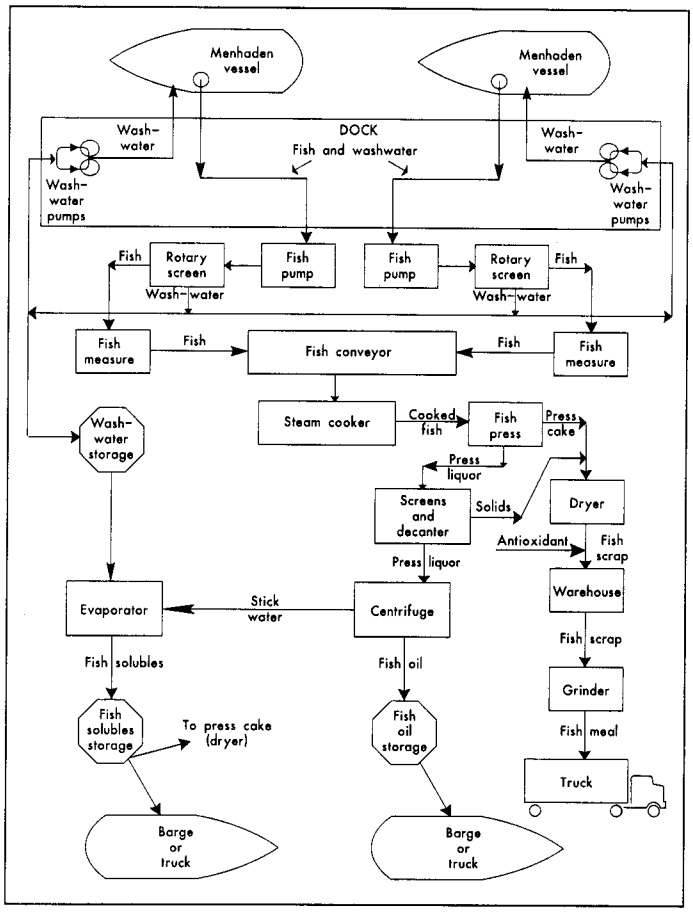


Figure 6.—Schematic diagram of a menhaden reduction plant (from ASMFC, 1981).

the fraction to a syrup-like consistency. The resulting condensed fish solubles (containing about 30% protein, 10% fat, and 10% minerals) are either stored in tanks or reincorporated into the press cake prior to the drying process. End product meal from this route is referred to as whole or full meal. Press cake is passed to rotary steam or direct heat dryers and dried to fish "scrap" with a minimum desired content of 60% protein, 10% fat, and about 20% minerals and 10% moisture. Dried fish scrap is transferred by overhead conveyors to large piles on the floor of the storage shed. At some point in this transfer, an antioxidant is added to the fish scrap to prevent caking and loss of product quality, and to promote cooling. Fish scrap is ground to fish meal by a hammermill prior to shipping via truck, railroad car, or barge. Fish oil is shipped in the same fashion.

Although in some years a small percentage is exported, most menhaden fish meal becomes a valuable ingredient in domestic animal feeds. The poultry industry, followed by the swine industry, utilizes a majority of the annual production of menhaden fish meal in feed formulas. Feed formulas vary by milling company and area, but up to 8% of broiler chicken ration may be menhaden fish meal. Other common constituents milled into feeds include corn, soy, meat, and bone meal. In recent years significant amounts of menhaden meal have been milled into aquaculture feeds for catfish, trout, salmon, and shrimp.

Inexplicably, during the 1940's, menhaden fish oil was omitted from legislation listing suitable oils permitted for human consumption in the United States.

Thus, most menhaden fish oil is exported to Europe and Canada where it has been used for decades as an edible oil. After deodorization, hydrogenation, and blending with other oils, it is marketed as a cooking oil or margarine. Domestically, small quantities of menhaden fish oil are refined and become valuable components of lubricants, plasticizers, resins, and paints. It also has use as a supplemental fat source in animal feeds.

Menhaden solubles are generally reintroduced to the press cake to make a "full" fishmeal. Solubles are also milled into various feeds to enhance their nutritional value, or mixed into liquid feed supplements.

In recent years (data available for 1980-85: AMAC, 1986) small but significant quantities of Atlantic menhaden (up to about 4,000 t/year) have been taken by purse seine and sold either fresh or frozen for crab bait. Purse seine landings of Atlantic menhaden for bait occur mainly in Massachusetts, New Jersey, Virginia, and North Carolina. A purse seine bait fishing operation targeting Gulf menhaden has also recently been established in Louisiana.

Beside these traditional uses of menhaden products, the industry has recently moved toward the development of new product lines (Hale et al., 1991). Increased demand for Japanese surimi-based seafood products has stimulated feasibility studies to determine the suitability of menhaden for surimi production (Lanier, 1985). Research into uses of menhaden oil for human food and medicinal markets is also underway (Hale et al., 1991).

Biostatistical Monitoring

The Beaufort Laboratory of the Southeast Fisheries Science Center, National Marine Fisheries Service (Bureau of Commercial Fisheries prior to 1970), NOAA, began preliminary sampling of the Atlantic menhaden purse seine fishery in the Middle Atlantic and Chesapeake Bay areas between 1952 and 1954 (June and Reintjes, 1959), and expanded the sampling design to encompass the entire range of the Atlantic fishery in 1955. During the early 1960's, program managers were concerned that the Gulf menhaden resource might be overfished and extensive sampling of the Gulf menhaden purse seine fishery was instituted in 1964 (Chapoton, 1971). Sampling programs on both coasts have since continued uninterrupted. Early sampling strategies concluded that fish of similar size and age school together. It was estimated that a 20-fish sample was adequate to estimate the mean size of fish in a purse seine set (June and Reintjes, 1959). Seasonally hired port agents were instructed to sample a bucket of fish from the top of the fish hold (after discarding the top veneer of fish that may have desiccated). It was assumed that fish on the top of the hold represented the vessel's last set of the day (not necessarily the entire boatload). Location and date of the last set were ascertained from the captain or a crew member. One hundred fish were sequentially selected from the sampling bucket. Each fifth fish (20 fish per sample) was measured (fork length, mm), weighed (g), sexed, and scales removed for ageing (June and Roithmayr, 1960). By the late 1960's, menhaden program managers realized that age and size variability of specimens within vessels was less than that among vessels (Chester, 1984). Beginning in 1972 on both coasts, port agents were responsible for acquiring more samples per week (up to 20-25 per port), but sample size was cut to 10 fish and specimens were no longer sexed. The sampling program has remained relatively unchanged since the early 1970's, with only minor modifications. With the increased importance of Chesapeake Bay and North Carolina landings to the Atlantic fishery, and ranging of the fleet to adjacent fishing areas, sampling activity was increased in those areas during the 1980's during months of peak landings. In recent years (1983-88), the average number of 10-fish samples processed has been 875 samples (8,750 fish) per year for the Atlantic menhaden fishery and 1,492 samples (14,920 fish) per year for the Gulf menhaden fishery.

The menhaden companies on both coasts provide confidential daily landings and effort data, usually on a monthly basis. Daily vessel landings by plant are reported in values representing the number of "dumps" of the hopper per vessel offloading (1 dump = 304 kg or 670 pounds). The factor 0.3039 (670 pounds/2204.62 pounds), is multiplied by the number of dumps to get metric tons offloaded. Monthly landings by plant are added to get season totals.

Nominal or observed fishing effort is derived from daily plant records. The unit of nominal fishing effort for the Atlantic menhaden fishery is the "vessel week," that is, one vessel landing fish at least one day of a calendar week. Total nominal effort is the sum of the number of vessel weeks for all Atlantic vessels. The unit of nominal fishing effort for the Gulf menhaden fishery is the "vessel-ton week," that is, the product of a vessel's net registered tonnage multiplied by a vessel week. Total nominal effort for the fishery is the sum or vessel-ton weeks for all vessels in the fleet. Since, on average, large vessels in the Gulf menhaden fleet catch more fish than small vessels, the vessel-ton week explains some of the differences in efficiency within the Gulf menhaden fleet, more so than the vessel-week unit used for the Atlantic menhaden fleet (Schaaf et al., 1975).

Estimates of number of fish in the landings by coast are calculated by a computer program (Huntsman and Chapoton, 1973). Number of fish at each age caught each week at each plant (or combination of plants at the same port) are calculated on the basis of weight of the sampled fish, their ages, and the weekly vessel landings. Weekly numbers at age are added to get monthly and annual totals. Annual estimates of numbers of fish at age form the basis of menhaden stock assessments and population analyses (e.g., Ahrenholz et al., 1987; Vaughan, 1987).

Between 1955 and 1965, in an effort to better describe effort in the fishery and identify location of purse seine sets, logbooks were placed on Atlantic menhaden purse seine vessels at the beginning of each fishing season. Captains were requested to list number, location, and size of daily sets. Port agents were to pick up logbooks biweekly. In most years, over 60% of the fleet participated. Major results of this survey are reported in Nicholson (1971). A similar logbook survey was conducted on the Gulf coast

between 1964 and 1969. Locations of over 48,000 purse seine sets were recorded, the results of which are reported in Nicholson (1978).

Beginning in 1978 and continuing through the present, the menhaden industry and Federal and state agencies jointly devised a second logbook project called the Captain's Daily Fishing Report (CDFR's). Among other things, CDFR's request information on location of sets, start and stop time of individual sets, estimate of number of fish per set, and weather conditions. Since 1978, Atlantic menhaden vessels have logged over 39,000 CDFR's and Gulf menhaden vessels over 123,000 CDFR's. Key entry of CDFR data for several years has been completed with limited analyses conducted for selected data sets.

Recent Trends in Fisheries Statistics

Atlantic Menhaden Fishery

Temporally, the Atlantic menhaden fishery is usually partitioned by the industry into two distinct fisheries, the "summer" and "fall" fisheries. The summer fishery usually begins about April or May as surface schools appear off northern Florida and the Carolinas. By mid-to-late May, fishing in Chesapeake Bay commences, and by June schools migrate into New England waters. Peak coastwide landings occur from June to September. By early fall, schools begin to move south and fishing in New England waters usually ceases by late September. Early November signals the beginning of the fall fishery and large schools of all age and size classes concentrate as they round the North Carolina capes. The intensive fall fishery usually ends by mid-January as schools disappear south of Cape Lookout, N.C. Historically, most fall landings have been made at North Carolina ports, but in recent years vessels from Chesapeake Bay have exploited fall migratory fish as far south as Cape Hatteras.

Atlantic menhaden stratify during summer along the U.S. east coast by size and age, with older and larger fish moving farther north. Typical age composition of the landings in recent years by geographic area are:

Table 2.—Number of reduction plants, purse-seine vessels, and landings (1,000 t) for the Atlantic and Gulf menhaden fisheries, 1955-88.

	Atlantic menhaden[1]			Gulf menhaden[2]		
Year	Plants	Vessels	Landings	Plants	Vessels	Landings
1955	23	150	641.4	9	72	215.0
1956	24	149	712.1	10	81	244.8
1957	25	144	602.8	10	73	159.9
1958	22	130	510.0	10	77	201.5
1959	23	144	659.1	11	73	335.3
1960	20	115	529.8	10	75	380.7
1961	20	117	575.9	10	69	459.5
1962	19	112	537.7	12	74	480.7
1963	17	112	346.9	11	73	437.8
1964	18	111	269.2	11	76	409.4
1965	17	84	273.4	13	82	463.1
1966	20	76	219.6	13	80	359.1
1967	18	64	193.5	13	76	317.3
1968	17	59	234.8	14	69	373.5
1969	15	51	161.6	13	72	523.7
1970	15	54	259.4	13	73	548.1
1971	14	51	250.3	13	82	728.2
1972	11	51	365.9	11	75	501.7
1973	11	58	346.9	10	65	486.1
1974	10	63	292.2	10	71	587.4
1975[3]	12	61	250.2	11	78	542.6
1976	11	62	340.5	11	82	561.2
1977	12	64	341.1	11	80	447.1
1978	12	53	344.1	11	80	820.0
1979	12	54	375.7	11	78	777.9
1980	11	51	401.5	11	79	701.3
1981	11	57	381.3	11	80	552.6
1982	11	47	382.4	11	82	853.9
1983	10	41	418.6	11	81	923.5
1984	8	38	326.3	11	81	982.8
1985	6	24	306.7	7	73	881.1
1986	5	16	238.0	8	72	822.1
1987	6[4]	23	327.0	8	75	894.2
1988	6[4,5]	30	309.3	8	73	623.7

[1] Data for 1955-85 from Smith et al. (1987a).
[2] Data for 1955-84 from Smith et al. (1987b).
[3] For fishing years 1975-79, menhaden were landed at Pt. Judith, R.I., and trucked to South Portland, Me. Facility at Pt. Judith counted in Atlantic menhaden plant totals.
[4] Includes reduction plant in New Brunswick, Can.
[5] Includes Soviet factory ship, Maine-U.S.S.R. cooperative venture.

1) In the North Atlantic area (eastern Long Island through the Gulf of Maine), mostly age-3 fish with some older fish up to age-6;

2) In the Middle Atlantic area (western Long Island to Chincoteague, Va.), mostly age-2 and age-3 fish;

3) In the Chesapeake Bay area, age-1 and age-2 with some age-3;

4) In the South Atlantic area (Cape Hatteras to northern Florida), age-1 and age-2; and

5) In the North Carolina fall fishery, age-0 through age-8 may occur, although this segment of the fishery is highly weather dependent.

To understand recent trends in the Atlantic menhaden fishery, Ahrenholz et al. (1987) described stock status in terms of several temporal stanzas. The 1950's were described as years of stock expansion: The age structure broadened, and several dominant year classes entered the fishery. Landings surpassed 500,000 t in 1953 and peaked at 712,000 t in 1956, the record year for the Atlantic menhaden fishery (Table 2; Fig. 7). By 1962, dominant year classes of the previous decade disappeared from the fishery. The remainder of the 1960's was without a dominant year class; the stock's age structure began to contract and became severely truncated by 1967. Landings fell to 162,000 t by 1969. Improving recruitment during the 1970's gradually added significant numbers of older fish to the fishery. During the late 1970's landings rose to 378,000 t, and by the 1980's the stock showed signs of strengthening and significant expansion (1983 landings reached 419,000 t). Landings in 1986 fell to 238,000 t, but the decline was more indicative of prevailing economic conditions in the fishery, and a major plant in Virginia temporarily closed for the season. By 1987 the economic climate had improved, the closed plant reopened, and landings reached 327,000 t.

Estimated total numbers of Atlantic menhaden in the landings declined from a record 5.35 billion in 1959 to 0.87 billion in 1969 (Table 3). Landings gradually improved during the 1970's and by 1983, 3.94 billion fish were landed. The fishery has always relied heavily on prespawning fish (age 2 and younger), but despite the rebound in estimated numbers of fish landed, age composition of the landings changed considerably. Between 1955 and 1962, the annual percentage (by numbers) of prespawners in the landings averaged 83% (range: 51-96%), whereas between 1975 and 1987, the annual percentage of prespawners in the landings averaged 94% (range: 87-98%). Additionally, unprecedented numbers of age 0 menhaden or "peanuts" were taken in 1979, 1981, and 1984, mostly during the North Carolina fall fishery.

After the Atlantic menhaden stock declined precipitously in the early 1960's and fish became scarce in the northern half of their range, many plants north of the Chesapeake Bay closed (Nicholson, 1975). During the 1970's significant numbers of fish again appeared in

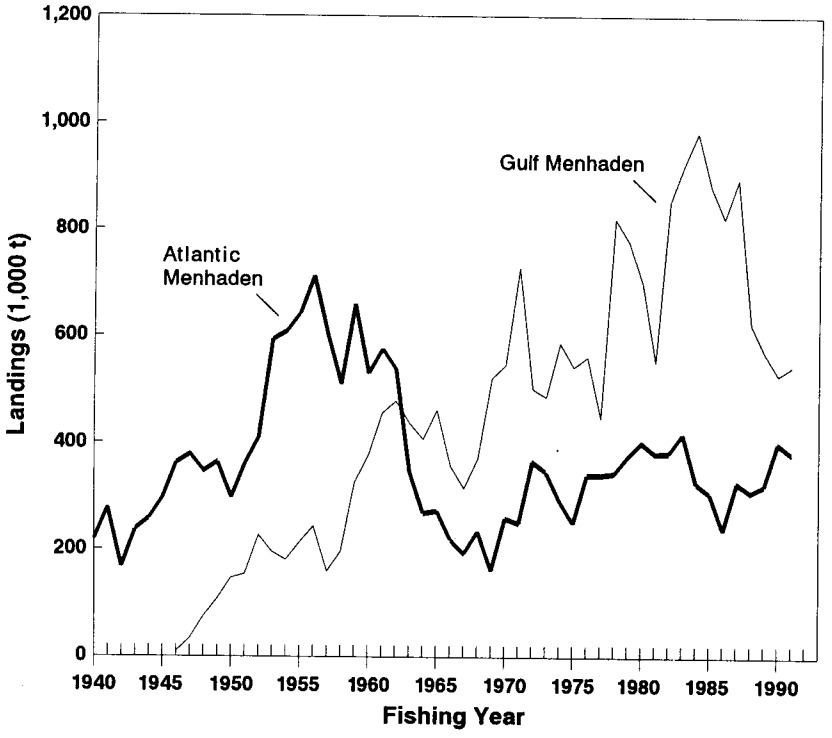


Figure 7.—Historical landings of Atlantic (1940-91) and Gulf menhaden (1945-91) by purse seine for reduction.

Table 3.—Estimated numbers (millions) of Atlantic menhaden by age landed by purse-seine vessels, 1955-88.

Year	Number by age									Total no. (millions)
	0	1	2	3	4	5	6	7	8-10	
1955	761.01	674.15	1,057,68	267.31	307.21	38.07	10.53	1.84	0.64	3,118.44
1956	36.37	2,073.26	902.72	319.60	44.78	150.68	28.70	6.72	1.99	3,564.82
1957	299.58	1,599.98	1,361.77	96.73	70.80	40.52	36.93	4.26	1.10	3,511.67
1958	106.06	858.16	1,635.35	72.05	17.25	15.94	9.09	4.88	0.43	2,719.21
1959	11.40	4,038.72	851.29	388.27	33.41	11.87	12.36	4.55	1.77	5,353.64
1960	71.17	281.01	1,208,63	76.37	102.20	23.77	7.95	2.36	0.65	2,775.11
1961	0.25	832.42	503.60	1,209.57	19.18	29.38	2.86	0.81	0.24	2,598.31
1962	51.58	514.11	834.52	217.25	423.37	30.75	24.60	2.98	0.70	2,099.86
1963	96.89	724.23	709.20	122.53	44.97	52.38	10.42	3.33	0.56	1,764.51
1964	302.59	703.95	604.98	83.50	17.94	7.85	6.62	1.31	0.32	1,729.06
1965	249.12	745.21	421.40	77.76	12.19	1.81	1.22	0.75	0.06	1,509.50
1966	349.45	550.99	404.22	31.70	3.85	0.36	0.19	0.11	0.04	1,340.83
1967	6.95	678.29	266.97	72.87	5.09	0.48	0.01	0.00	0.00	1,030.67
1968	173.75	309.72	466.22	65.24	10.67	0.98	0.06	0.00	0.00	1,026.65
1969	158.13	377.33	284.31	47.81	5.44	0.15	0.01	0.00	0.00	873.18
1970	21.42	870.85	473.92	32.63	4.02	0.11	0.00	0.00	0.00	1,402.96
1971	72.85	263.29	524.32	88.29	17.84	2.51	0.00	0.00	0.00	969.96
1972	50.16	981.27	488.47	173.06	19.12	1.86	0.00	0.00	0.00	1,713.95
1973	55.98	588.47	1,152.94	38.63	7.00	0.34	0.00	0.00	0.00	1,843.36
1974	315.55	636.68	985.97	48.59	2.49	1.35	0.00	0.00	0.00	1,990.63
1975	298.64	719.96	1,086.53	50.24	6.63	0.20	0.10	0.00	0.00	2,162.30
1976	274.23	1,611.96	1,341.09	47.97	7.95	0.28	0.00	0.00	0.00	3,283.47
1977	484.62	1,004.54	2,081.77	83.46	17.80	1.41	0.11	0.00	0.00	3,673.71
1978	457.41	664.09	1,670.91	258.12	31.19	3.48	0.00	0.00	0.00	3,085.20
1979	1,492.46	623.14	1,603.29	127.93	21.76	1.47	0.09	0.00	0.00	3,870.13
1980	88.29	1,478.06	1,458.23	222.71	69.23	14.36	1.44	0.00	0.00	3,332.32
1981	1,187.57	698.66	1,811.46	222.20	47.47	15.37	1.27	0.00	0.00	3,984.02
1982	114.11	919.44	1,739.55	379.67	16.33	5.78	0.53	0.32	0.00	3,175.72
1983	964.41	517.22	2,293.06	114.35	47.37	5.01	0.23	0.00	0.46	3,942.11
1984	1,294.22	1,024.17	892.09	271.50	50.34	15.21	0.51	0.00	0.00	3,548.04
1985	637.19	1,075.85	1,224.62	44.06	35.63	6.25	1.68	0.00	0.00	3,025.29
1986	100.28	224.99	1,527.45	48.72	10.18	6.38	1.15	0.00	0.00	1,919.16
1987	44.93	541.78	1,652.04	143.87	25.47	2.23	0.75	0.00	0.00	2,411.08
1988	429.16	314.09	1,180.64	309.28	70.74	6.77	0.52	0.23	0.00	2,311.43

New England waters and as many as four plants were active in the North Atlantic area (plants in this area primarily process fish offal from the New England trawl fisheries, but also process menhaden during summer). By winter 1988, however, plants at Pt. Judith, R.I., Gloucester, Mass., South Portland, Maine, and Rockland, Maine, had closed, not because of a scarcity of fish, but due to social problems of fish factory operation in densely populated urban areas. Beginning in 1987, a plant in New Brunswick, Can., began receiving menhaden for reduction, and by 1989 it was the only shoreside plant processing menhaden from the Gulf of Maine (Fig. 8). During 1988 and 1989, a cooperative venture between a company in Maine and the Soviet Union allowed processing of menhaden for reduction onboard a Soviet factory ship anchored off Maine. Actual fishing operations, however, were performed by up to twelve U.S. vessels.

The recent closure of reduction plants along the New England coast, and to some extent the Middle Atlantic coast, appears symptomatic of a trend referred to as "waterway gentrification"[1]. Revitalization of urban harbor areas along the U.S. "northeast corridor" has led to increasing demands for waterfront space and properties; nontraditional waterfront users, such as restaurants, shopping malls, and condominium/marina complexes now compete with traditional user groups such as commercial fishing enterprises, and in general are capable of paying the most for waterfront space (Houlahan, 1987). Menhaden reduction factories with their associated (but not insurmountable) air and water effluent controversies are often deemed less than desirable when adjacent to trendy waterfront developments. Thus, local governments have moved to restrict odor emissions from plants and, in some instances, forced plant closures. In New England a recent solution to the enigma of an abundance of menhaden in coastal waters without shoreside processing facilities has been the advent of a near-

[1]Lippson, R. 1987. Natl. Mar. Fish. Serv., NOAA, Oxford Lab., Oxford, Md. Presentation entitled, "Waterway gentrification" given at annu. meet. Tidewater Chapt., Am. Fish. Soc., Nov. 15-17, Atl. Beach, N.C.

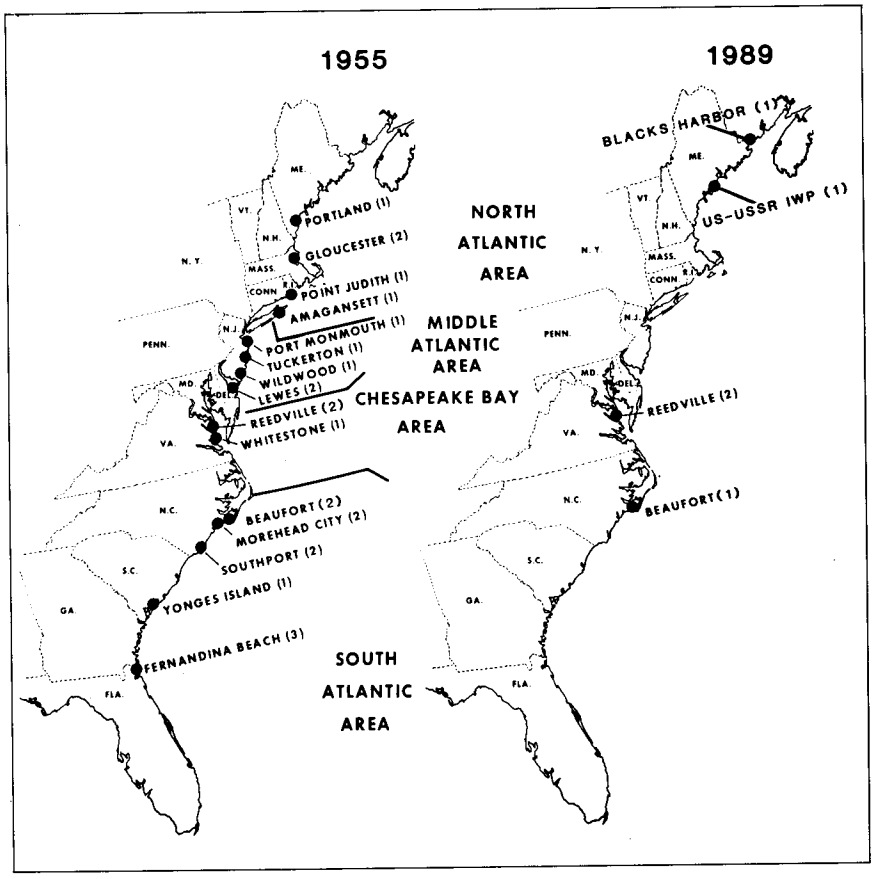


Figure 8.—Location of reduction factories for Atlantic menhaden, 1955 vs. 1989.

shore factory ship operated by a Maine-U.S.S.R. cooperative venture.

In the Middle Atlantic area as many as five plants were active during the early 1960's, but through the 1970's only one plant at Port Monmouth, N.J., operated; it closed after the 1981 season. During 1973-85, two plants in the Chesapeake Bay area were active, both in Reedville, Va.; one temporarily closed in 1986, but reopened in 1987. In the South Atlantic area and during the North Carolina fall fishery, three plants in Beaufort, N.C., were active during 1973-84, but one plant only operated intermittently during summer and a second closed after the 1986 season. A plant in Southport, N.C., was active during 1972-83 and also participated intermittently in the North Carolina fall fishery before closing in 1983. A small plant at Fernandina Beach, Fla., was active through 1986 before it closed in July 1987.

Total number of vessels in the Atlantic menhaden fleet fell from 150 in 1955 to 51 in 1971. The number of vessels then increased slightly to 64 in 1977, but declined further to 38 vessels in 1984. During 1987, 24 vessels were active in the Atlantic menhaden fleet. Declines in number of vessels in the fleet in recent years reflect: 1) Closure of several plants in the North and South Atlantic areas and 2) decisions by major companies to retire older and inefficient wooden-hulled vessels.

Gulf Menhaden Fishery

Gulf menhaden exhibit an inshore-offshore migratory pattern with surface schools appearing in nearshore coastal waters as early as March and remaining into November before moving to deeper offshore waters to winter. Historically, a few landings have occurred in March and November. However, in 1977 four of the five Gulf states voted in favor of a cooperative regional management plan (GSMFC, 1983) that limited the fishing season to a 26-week period, beginning in mid-April and ending by mid-October. Peak landings occur between May and August.

Prior to World War II, purse seine landings of Gulf menhaden were few and sporadic, annually ranging from 2,000 to 12,000 t between 1918 and 1944 and were landed in Florida, Mississippi, and Texas (Nicholson, 1978). During the late 1940's, new reduction plants were built in Mississippi, Louisiana, and Texas and landings increased to 103,000 t by 1948. As larger, more efficient vessels entered the fishery and fishing technologies improved, landings steadily increased, reaching 481,000 t by 1962. By 1963 annual Gulf menhaden landings exceeded Atlantic menhaden landings, a trend which continues through the present (Fig. 7). Between 1963 and 1981, Gulf menhaden landings ranged from 316,000 to 820,000 t (Table 2). Beginning in 1982 and for 6 consecutive years, landings exceeded 800,000 t, with record landings for Gulf menhaden of 983,000 t in 1984.

Between 1964 and 1987, annual estimates of the number of Gulf menhaden landed ranged from 4.24 billion fish in 1966 to 11.15 billion fish in 1985 (Table 4). The fishery harvests almost exclusively age 1 and age 2 Gulf menhaden, and over the sampling period the combined age classes annually averaged 96% of the fish landed by number. Age 1 fish annually contributed an average of 63% (range: 45-76%), and age 2 fish contributed an average of 33% (range: 19-45%). Age 0, age 3, and age 4+ usually comprise less than 5% of the landings.

Through the 1950's, between 9 and 11 menhaden plants operated in Florida, Mississippi, Louisiana, and Texas (Table 2). During the 1960's, 10-14 plants were active, but after 1971 menhaden reduction plants were located exclusively in Mississippi and Louisiana. Between 1972 and 1983, the number of plants stabilized at 10-11. In 1984 one of the largest menhaden processors acquired its closest competitor, thus gaining ownership of 7 of the 11 active plants

in the Gulf of Mexico. Consolidation followed in 1984-85, with plants closing in Moss Point, Miss., Morgan City, La., and Cameron, La. Also in 1985, economic conditions forced the temporary closing of a plant at Empire, La., reducing active plants to 7. During 1986-88, four companies operated 8 plants in Mississippi (2) and Louisiana (6). In 1989, a ninth plant opened in Morgan City, La. (Fig. 9).

During the late 1940's, the Gulf menhaden fleet increased rapidly from 10 to 53 vessels. The fleet increased slowly through the 1950's to a peak of 82 vessels in 1965. Between 1966 and 1984, fleet size varied from 65 to 82 vessels. After the corporate consolidation in 1984, the fleet declined to 73-75 vessels in 1985-88.

The unit of nominal or observed fishing effort in the Gulf menhaden fishery is the vessel-ton week. As the fleet grew in numbers and size, nominal effort gradually increased and by 1969 reached the 400,000 vessel-ton-week level. By 1975 nominal effort for the fishery climbed above 500,000 vessel-ton weeks, and peaked in 1983 at 655,800 vessel-ton weeks.

Forecasting

In 1972 the Beaufort Laboratory was asked by the menhaden industry to provide annual forecasts for upcoming Atlantic and Gulf menhaden fishing seasons because, with a forecast, the industry could better plan its next year's operations. Program biologists decided upon a multiple linear regression approach to forecasting menhaden catches as a function of effort anticipated in the fishery and catch and effort in previous years. Development and description of the model are recounted in Schaaf et al. (1975). Initially, the model was used to estimate catches for past years (pre-1973) on the Atlantic coast and was deemed satisfactory in estimating or "hindcasting" historic catches (coefficient of determination, $r^2 = 0.85$). Application to upcoming fishing seasons began in 1973 for both coasts and

Table 4.—Estimated numbers (millions) of Gulf menhaden by age landed by purse-seine vessels 1964-88.

Year	Number by age 0	1	2	3	4+	Total no. (millions)
1964	2.76	3,329.28	1,495.15	118.07	4.35	4,949.61
1965	43.43	5,031.39	1,076.63	80.27	0.70	6,232.41
1966	30.45	3,314.42	865.16	33.76	0.26	4,244.05
1967	22.44	4,267.65	337.66	13.00	0.00	4,640.74
1968	65.06	3,475.23	1,001.30	37.45	0.50	4,579.55
1969	20.80	6,075.00	1,286.34	31.66	0.00	7,413.81
1970	50.19	3,279.85	2,279.98	36.08	0.00	5,646.10
1971	21.59	5,761.13	1,955.45	181.84	4.12	7,924.12
1972	19.11	3,047.74	1,733.53	88.54	4.03	4,892.95
1973	49.90	3,033.00	1,106.98	99.62	1.27	4,290.77
1974	1.41	3,846.75	1,471.65	59.08	0.00	5,378.89
1975	108.77	2,440.51	1,499.21	461.83	0.19	4,510.51
1976	0.00	4,591.39	1,373.94	203.92	0.00	6,169.25
1977	0.00	4,659.95	1,331.72	110.37	5.63	6,107.66
1978	0.00	6,787.44	2,742.01	52.67	5.24	9,587.37
1979	0.00	4,701.22	2,877.16	337.20	6.81	7,922.39
1980	65.86	3,409.41	3,261.11	436.15	47.86	7,220.39
1981	0.00	5,750.53	1,424.94	329.40	34.22	7,539.08
1982	0.00	5,146.74	3,301.96	503.54	62.26	9,014.50
1983	0.00	4,685.73	3,809.23	382.61	25.10	8,902.67
1984	0.00	7,749.55	2,881.49	438.36	49.75	11,119.14
1985	0.00	8,127.64	2,723.64	283.04	20.58	11,154.90
1986	0.00	4,266.16	5,022.44	186.36	25.17	9,500.13
1987	0.00	5,936.61	4,528.74	396.13	12.36	10,873.84
1988	0.00	5,568.62	2,799.45	164.68	13.20	8,545.95

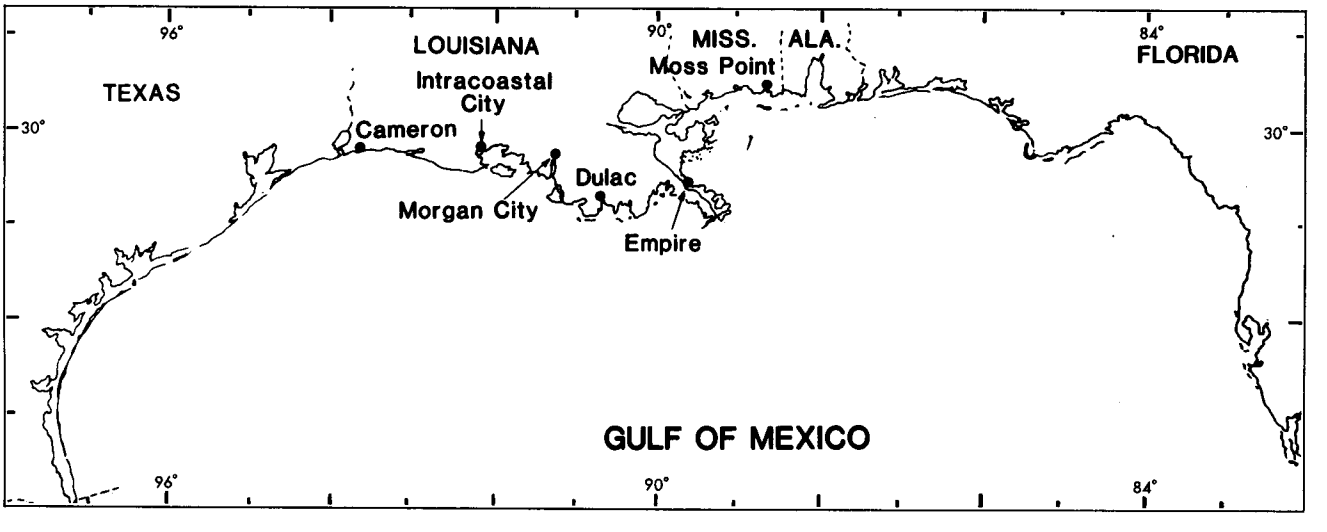


Figure 9.—Location of reduction factories for Gulf menhaden, 1989.

1989 marked the seventeenth consecutive year of forecasts. Written forecasts take two forms:

1) In late November a preliminary forecast is released for the next year's fishing season based on estimates of catch and effort for the just-completed Gulf menhaden season and the ongoing Atlantic menhaden season; and

2) In mid-April a formal forecast is released based on finalized catch and effort values from the previous season's activities on both coasts and expected effort in the upcoming season.

Forecasts of landings for the upcoming fishing year are conditioned on estimates of expected effort which are primarily derived from 1) industry input (i.e., the number of vessels that companies expect to be active during the forthcoming year) and 2) historical performance (effort) of the vessels expected in the fishery. Through the period 1973-88, our preseason estimates of fishing effort have differed from actual year's-end effort values an average of 8.4% for the Atlantic menhaden fishery and 4.1% for the Gulf menhaden fishery. To measure the accuracy of our forecast equation, we generate a hindcast at season's end, using the actual fishing effort for the season and then compare the hindcast to actual landings. For the Atlantic menhaden fishery using observed effort, actual purse-seine landings have differed an average of 10.8% from those forecast for the sixteen-year period 1973-1988 ($r^2 = 0.84$); similarly, landings for the Gulf menhaden fishery have differed from those forecast by an average of 15.8% for the same period ($r^2 = 0.88$).

As noted by Schaaf et al. (1975), our statistical model performs satisfactorily on average for forecasting menhaden landings. It will not predict sudden and large changes in catch, and offers no explanation for such. Recent studies by Jensen (1976, 1985) and Schaaf and Chester[2] strive to improve the predictability of menhaden forecasts using autoregressive models.

[2]Schaaf, W. E., and A. J. Chester. Forecast strategies for Atlantic menhaden catch. Unpubl. manuscr. on file at Beaufort Lab., SEFSC, Natl. Mar. Fish. Serv., NOAA, Beaufort, NC 28516-9722.

Summary

The menhaden purse-seine fishery, with its origins in New England during the mid-1800's, is one of the oldest and largest commercial fisheries in the United States. By the early 1900's, the fishery for Atlantic menhaden was established as far south as the Carolinas and northern Florida. The post-World War II years mark the inception of the Gulf menhaden fishery, and with it the modernization of the fisheries on both coasts. Technological advances in fishing gear and vessel design and construction have steadily increased the speed, range and efficiency of menhaden carrier vessels. Modern design changes within menhaden reduction plants increased efficiency and capacity. Menhaden meal, menhaden oil, and solubles continue to be the industry's chief products. Most meal and solubles are sold and incorporated into animal feeds, primarily poultry feed. Most menhaden oil continues to be exported to Europe and Canada where it is refined into margarine or cooking oil. Development of new menhaden products, such as surimi for analog foods and refined oils for human consumption and medicinal markets, hold promise for future diversification of the menhaden industry.

NMFS menhaden biostatistical sampling programs have been conducted for over three decades on the Atlantic coast and over two decades on the Gulf coast. Research has determined that during the 1970's and 1980's stock size and recruitment of Atlantic menhaden increased and age composition broadened, reversing trends witnessed during the fishery decline in the 1960's. Landings steadily improved through the 1970's, and by 1983 coastwide landings reached 418,000 t. Through the 1970's and 1980's, the Chesapeake Bay fleet has dominated the fishery in landings and fishing effort. Economic problems plagued the fishery in the mid-1980's and several plants closed temporarily. Numerous plant closures in New England and the Middle Atlantic area epitomize the modern fishery's dilemma regarding coastal development.

The Gulf menhaden fishery through the late 1970's and early 1980's has remained relatively stable with 11 reduction plants and about 80 carrier vessels. After 1984 a major corporate acquisition reduced the number of plants to 8 and the number of vessels to about 73. Beginning in 1982 and for six consecutive years total Gulf menhaden landings have exceeded 800,000 t, and in 1984 record landings for the fishery were produced, 982,800 t. Exceptional landings through 1987 are related to increased stock size due to large year classes entering the fishery in the late 1970's and 1980's.

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