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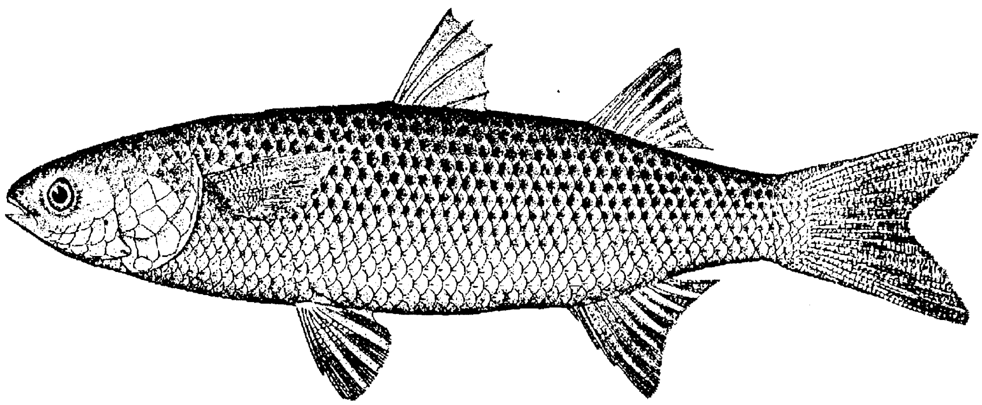

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A BIOLOGICAL AND FISHERIES PROFILE FOR STRIPED MULLET, *Mugil cephalus* IN LOUISIANA

by

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The drawing of striped mullet on the cover was downloaded from an internet copy of Massey and Harper (1993) who digitized the figure from Evermann (1899).

1.0 INTRODUCTION

This document presents the most recent available information regarding the biology of the striped mullet *Mugil cephalus*, a description of the Louisiana fishery, assessment of the current status of the stock in the State, management goals and specific management recommendations. The mullet fishery in Louisiana is still in a developmental stage commercially, and updates may be necessary to adequately document changes in fishing methodology, markets, or other factors.

Striped mullet were not targeted commercially in Louisiana until the mid 1970's. An abundance of more desirable species of fish in Louisiana waters has served to limit the expansion of the striped mullet food fishery. Recent creel surveys and historical information indicate that striped mullet are seldom used by the recreational fishery except as a bait species.

The average annual landings of mullet from 1978-1994 was 3,494,296 pounds (1,572,433 kg). This was a significant increase over landings prior to 1978 and was, in part, a response to an increased demand for mullet roe.

As commercial landings grew, concern was expressed by recreational fishers that the removal of large quantities of mullet would affect the populations of some recreationally targeted species. In its present state, the commercial mullet fishery is probably not affecting food supplies for the predatory fishes.

1.1 Status of the Fishery

There currently is little recreational fishery effort directed toward mullet in Louisiana. The commercial fishery has expanded in recent years and is currently capable of harvesting all mature year classes; however, due to the current market, roe mullet are mainly being targeted. The commercial mullet fishery has been impacted by House Bill 1316 passed during the 1995 Louisiana Legislative Session. The following is but a part of the legislation influencing mullet. The fishery is now open on the third Monday of October each year and closes on the third Monday in January that is the roe season for this species. No night fishing is allowed and no fishing from 5:00 a.m. Saturday through 6:00 p.m. Sunday. Mullet may not be taken outside this period.

A review of National Marine Fisheries Service (NMFS) records, indicate landings of striped mullet as early as 1930. Although there were significant landings in certain years from 1930 through 1976, yearly landings during this period were generally low (Figures 3.2 and 3.3). Following the development of the roe market in the mid 1970's, landings increased dramatically between 1977 and 1989 (Fig. 3.4).

The striped mullet fishery has seen tremendous growth in the early 1990's. Harvest figures for 1996 show a decline from the peak years of that period. Monitoring of harvest, recruitment, and relative stock size through the Marine Finfish Monitoring Program is intended to ensure that current and future harvest levels are sustainable.

1.2 Problems of the Fishery

The commercial striped mullet fishery has been undergoing a fairly rapid expansion since 1976. This expansion has been largely due to the increased demand for mullet roe. Since roe mullet are the primary target of commercial fishers, harvesting has been directed toward larger fish.

The fact that commercial fishers target roe mullet intensifies competition during spawning months. The spawning season in the northern Gulf of Mexico extends from October through March. During this period large schools of mullet are found throughout coastal Louisiana, both inshore and nearshore. Spawning habits of the striped mullet concentrates the fish, thus making the fishery highly visible during the peak months.

2.0 STRIPED MULLET BIOLOGY

The striped mullet belongs to the family Mugilidae. According to Randall (1968), mullet are thick-bodied, blunt-snouted fishes with two short-based dorsal fins. Mullet have a mouth shaped like an inverted V when viewed from the front. The teeth are minute. Most members of the family have a thick-walled gizzard-like stomach and a very long intestine.

2.1 Nomenclature and Taxonomy

Accepted classification of the mullet is that of Greenwood *et al.* (1966). Taxa higher than Class are not included here.

Class: Osteichthyes
 Superorder: Acanthopterygii
  Order: Perciformes
   Suborder: Mugiloidei
    Family: Mugilidae
     Genus: *Mugil*
      Species: *Mugil cephalus*

The valid name for the striped mullet is *Mugil cephalus* (Linnaeus 1758). The following synonymy is adapted from Jordan and Evermann (1896).

Mugil cephalus Linnaeus, 1758
Mugil alba Linnaeus, 1766
Mugil tang Bloch, 1794
Mugil plumieri Bloch, 1794
Mugil lineatus Mitchill, MS; Cuvier and Valenciennes, 1836
Mugil rammelsbergii Tschudi, 1845
Mugil berlandieri Girard, 1859
Mugil guntheri Gill, 1863
Mugil mexicanus Steindachner, 1875
Mugil albula Jordan and Gilbert, 1883
Mugil cephalus Jordan and Swain, 1884
Querimana gyrans Jordan and Gilbert, 1884

The striped mullet is the most abundant of the three members of the family Mugilidae found in waters of the northwestern Gulf of Mexico (Hoese and Moore 1977). The relationships within the family have been outlined by Ebeling (1957, 1961).

Striped mullet is the preferred common name recognized for *Mugil cephalus* by the American Fisheries Society (Robins *et al.* 1980). Other common names include common mullet, grey mullet, black mullet, jumping mullet, whirligig mullet, molly, callifavor, menille, mulle' (La. French, phonetic spelling), cefalo, macho, machuto, liza, lisa, and lisa cabezuda (Spanish of various regions) (Jordan and Evermann 1896, Gowanloch 1933, De Sylva *et al.* 1956, Hoese and Moore 1977, Collins 1985).

2.2 Distribution

Mugil cephalus is found in coastal waters, roughly between 42 degrees North and 42 degrees South. It is present in the western Atlantic from Brazil to Nova Scotia (Hoese and Moore 1977) but absent from the Bahamas and most of the West Indies and Caribbean (Robins *et al.*, 1986).

2.2.1 Louisiana Distribution

In Louisiana the striped mullet can be found in rivers, lakes, bays, bayous, and canals as well as along the coast in fresh, brackish and salt water. Generally, mature adults move offshore to spawn during the fall and winter months but later return.

Based on numerous otter trawl, gill, seine and trammel net samples taken across coastal Louisiana by the Dept. of Wildlife and Fisheries, the striped mullet was by far the most abundant mullet species caught. White mullet (*Mugil curema*) catch was very small (Judd Pollard, DWF, pers. comm.), and mountain mullet (*Agonostomus monticola*) has only rarely been taken in Louisiana waters (Suttkus 1956).

2.3 Stock Identification

Rivas (1980) reported that, based on tagging studies, striped mullet from the Gulf of Mexico are separated from those of the eastern coast of Florida and farther north. These findings were later confirmed by racial studies based on meristic and proportional characters. No data were found to show whether a break exists between the Gulf and the Caribbean Sea around the outer tip of the Yucatan Peninsula. There is basically one stock of striped mullet in the Gulf of Mexico with small variation at a few alleles (Lazuski *et al.* 1989). Campton and Mahmoudi (1991) stated that no protein electrophoretic evidence for genetic substructuring of striped mullet populations was found in allozyme polymorphisms between the east and west coasts of Florida based on spatial patterns of variation. In general, allele frequency variations among samples within locales were as great or greater than the variation among locales. Thompson *et al.* (1991) also found no differences in enzyme polymorphisms in striped mullet collected from various locations across Louisiana, or between those areas and mullet from Pascagoula River, Mississippi, Mobile Bay, Alabama, and Charleston Bay, South Carolina. They did note differences between S.E. U.S. mullet and specimens from Oahu and Hilo, Hawaii. Crosetti *et al.* (1994) did demonstrate significant differences between populations in worldwide sampling of mitochondrial DNA genotypes. They concluded that little or no genetic exchange occurs at the present time between widely scattered locales sampled on a global scale. They only examined striped mullet from North Carolina out of the Western Atlantic, so this data is of limited use in attempting to define sub-populations at a local level except through analogy. They found that different areas within major ocean basins were relatively similar, and that the major differences that they found were between populations in different basins.

Schooling behavior of mullet presents some interesting questions regarding the genetic relation among individuals within schools. A significant result at one locus ($P < 0.001$) regarding homogeneity of allele frequencies suggests some form of non-random demographic structuring may be associated with schools of mullet (Mahmoudi 1989).

2.4 Morphology

The following description is summarized from Martin and Drewry (1978), who compiled data from a wide variety of sources, with supplemental material from De Sylva *et al.* (1956) and Fahay (1983).

> D. IV-I,7-8; A. III,8; C. 7+7, procurrent rays 7-8+7-8; V. I,5; lateral line scales 37-43, vertebrae ll+13 or 12+12, first interneural bifurcate above seventh vertebra; gill rakers 24-36+50-76, numbers increasing with size; primary teeth uniserial, simple, 57-101 in upper jaw, 97-149 in lower jaw; secondary teeth in bands, bicuspid, numerous, number increasing with size; no teeth on vomer or palatines.
>
> Head 25.4-27.7; maxillary 7.0; interorbital width 9.3-10.4; body depth 25.4-26; first predorsal 50.8-57.1; second predorsal 74.6; preanal 73.0-73.5; prepelvic 39.4-39.5; first dorsal base 12.8-13.3; second dorsal base 10.6; second dorsal height 14.3-14.4; anal fin height 15.0-15.5; pectoral length 17.3-17.6; pelvic length 15.2-15.3; all being percent standard length (SL) means for 2 samples of 25 specimens (DeSylva *et al.* 1956)
>
> Body robust, moderately elongate, compressed; lower profile strongly curved from snout to caudal peduncle, upper profile less curved, but arched slightly from snout to first dorsal fin origin; body oval in cross section; caudal peduncle rather strongly compressed. Head massive, somewhat broader than deep; interorbital flat, short, and broad, its width more than twice eye diameter; snout shorter than eye, blunt or rounded anteriorly with a strong taper in dorsal view; some scales on top of head slightly enlarged; anterior and posterior nostrils widely separated. Mouth moderate, oblique, jaws weak; lower jaw included; maxillary hidden when jaws closed, its posterior end moving forward when mouth opened; lower lip with a thin edge directed horizontally forward or nearly so. Gape somewhat broader than deep. Gill openings

wide, gill membranes free of the isthmus; gill rakers numerous, long, slender, and close-set; pseudobranchiae large. A prominent adipose eyelid almost obscuring eye, covering preorbital anteriorly and extending almost twice as far posteriorly, leaving a narrow slit over pupil. Scales moderate, cylcoid or feebly ctenoid. Lateral line inconspicuous. Pectoral fins above midline, at level of eye, originating about length of head behind eye; tips pointed, not reaching first dorsal origin; a distinctly enlarged scale in pectoral axil; pelvic fins subabdominal; origin of first dorsal fin over pelvics; first dorsal spine longest, others graduated, last spine about half as long as first; origin of second dorsal fin slightly behind anal origin; upper margin concave, longest ray nearly same length as longest spine of first dorsal; anal fin about same size and shape as second dorsal but margin less concave; caudal deeply forked, longest rays nearly as long as head, shortest about half as long. Fine scales extending onto caudal fin and some on anterior rays of second dorsal and anal.

Pigmentation: Color varies with habitat and salinity, in fresh water very dark dorsally with overlay of dirty brown or bluish color, dull white ventrally; in marine waters dorsum olive green, sides silvery, venter off-white. In general, dorsum grayish olive, grayish blue, grayish brown, bluish brown or dark blue; shading to silvery white on sides and white or pale yellow ventrally; many brown spots on sides, organized into rows along scale centers on upper half, forming 5 to 10 dark longitudinal stripes on upper scale series down to about the tenth, lower band not extending beyond anal origin. Sometimes a terminal caudal bar in migrating adults. Fins dusky, minutely dotted with black, except pelvics, which are a pale yellowish color; pectoral black at base of upper rays and distally, with a narrow pale margin, inner surface almost black; margin and last few rays of anal fin pale. A dark blue streak or spot in the axil of pectoral. A golden ring around the iris.

2.4.1 Larvae and Juveniles

Development of the larval stage was described from hatching by Yashouv and Berner-Smsonov (1970) from Mediterranean specimens. Anderson (1958) described development from 4.0 millimeters (mm) larvae through the prejuvenile stage from material taken off the southeastern coast of the United States. Grant and Spain (1975) provided data on developmental morphology from the prejuvenile stage to adult. Ditty and Shaw (1996) provided characters for separating *Mugil cephalus* from *M. curema* and *Agonostomus monticola* larvae.

According to Thomson (1963), larval mullet average 2.4 mm total length (TL) at hatching. They lack a branchial skeleton, pectoral as well as pelvic fins, and even a mouth. Clearly noticeable jaws, organized internal organs, and developing fin buds can be seen in 5 day old specimens (approximately 2.8 mm in length). Meristic and morphological growth and development continue until the fish are approximately 16-20 mm SL. At this point they move to inshore waters and estuaries (Kilby 1949, Anderson 1958). The migrating *Mugil cephalus* have

2 spines and 9 rays in the anal fin (the "Querimana stage") until they grow to 35-45 mm SL. At this size, the first ray fuses into a third spine, the adipose eyelid becomes visible and the fish is considered a juvenile (Anderson 1958).

Ditty and Shaw (1996) noted that *Mugil cephalus* >6 mm SL (standard length) can be separated from *Mugil curema* and *Agonostomus monticola* by total number of anal fin elements. (*M. cephalus* has 11, *M. curema* and *A. monticola* have 12). *Mugil cephalus* and *M. curema* also lack pigment on the second dorsal fin until >25 mm SL.

2.4.2 Adults

Distinctive characters stated by Fischer (1978) are as follows: "Body rather stout. Head broad, interorbital area flat; head length 27-29 percent of standard length; fatty (adipose) tissue covering most of eye; lips thin, terminal; lower lip with a high symphysial knob; hind end of upper jaw just reaching vertical from anterior rim of eye; teeth labial, fine, 1 to 6 rows in upper lip, 1 to 4 in lower, outer row unicuspid, inner rows usually bicuspid; preorbital slender, filling only half the space between lip and eye. Origin of first dorsal fin nearer to tip of snout than to caudal fin base; second dorsal fin origin on a vertical from between a quarter and a half along anal fin base; pectoral axillary scale 33 to 36 percent of pectoral fin length; pectoral fin 66 to 74 percent of head length; anal fin with 8 (very rarely 7) soft rays. Scales in lateral series 38 to 42; second dorsal and anal fins lightly scaled anteriorly and along base.

The color of the striped mullet is olive green on back, silvery on sides, shading to white below; 6 or 7 indistinct longitudinal brown bars on flanks; a dark purplish blotch at base of pectoral fin".

2.5 Reproduction

2.5.1 Age, Length, and Weight at First Spawn

It has been suggested that portions of some populations of *Mugil cephalus* can become mature by one (males) to two (females) years of age (Jhingran and Mishra 1962). Thompson *et al.* (1991) observed that male and female Louisiana striped mullet were generally mature at age two, although some females were not mature until age three. Collins (1985), using data from Broadhead (1953, 1958) and Rivas (1980), reported that mullet mature from 200-300 mm SL, with females maturing at a slightly larger size than males. Although some fish reach maturity in their second year, most mature in three. Broadhead (1953) showed a weight-length graph of spawning and non-spawning Florida mullet in 1951: the minimum length and weight for spawning females was 276 mm and about 305 grams; for males it was 286 mm and approximately 330 grams.

Thompson *et al.* (1990) used the criteria that maturity is reached when 50% of the individuals in a population develop functional gonads and stated Louisiana striped mullet males mature around 200 to 220 mm fork length (FL) and females around 220 to 230 mm FL. All their specimens less than 160 mm FL were immature and indistinguishable sexually while all males over 280 mm FL and all females larger than 290 mm FL were mature.

2.5.2 Fecundity

Futch (1966) stated that adult females produced from 1.2 to 2.7 million eggs in a single spawning, whereas Broadhead (1953) reported estimated fecundity between 0.5 to 2.0 million eggs, depending on the size of the female. Shehadeh *et al.* (1973) calculated a fecundity value of 648 plus or minus 62 eggs/g. of body weight.

Fecundity estimates for 67 Louisiana specimens ranged from 2.7×10^5 to 3.7×10^6 eggs per individual (Thompson *et al.* 1990). Thompson *et al.* (1991) stated fecundity increased proportionately to body size. Fecundity of an individual correlated well with standard length ($F = 5.6 \times 10^{-3} (SL)^{3.14}, r^2 = 0.85$) and fork length ($F = 5.6 \times 10^{3} (SL)^{3.14}, r^2 = 0.85$). Relative fecundity (expressed as the number of eggs per gram of eviscerated body weight) ranged from 798 to 2616 eggs/gram from fish 290 to 568 mm FL.

Ovaries from female Louisiana striped mullet sampled from February through August possessed only resting primary growth oocytes (Thompson *et al.* 1990). This agreed with Abraham *et al.* (1966) who also noticed a long resting non-reproductive period for striped mullet in Israel.

Mean girth of female Louisiana striped mullet increased 11% between September and November (Thompson *et al.* 1989). This increase in mean girth was strongly associated with ovary maturation and development. Thompson *et al.* (1990) stated gonadosomatic index values supported histological development data showing Louisiana's striped mullet reached maximum reproductive development during November and December.

Studies by Tamura *et al.* (1994) determined that brackish-water females produced the greatest number of fertilized eggs per spawn followed by females maturing in seawater, with the lowest number of fertilized eggs obtained from females maturing in freshwater. The rate of oocyte growth from females maturing in seawater and brackish water did not differ significantly, however, the rate of oocyte growth from females maturing in freshwater was found to be significantly slower than that of the other salinity groups.

2.5.3 Season and Duration of Spawn

The spawning season in the northern Gulf of Mexico generally extends from October through February or March (Anderson 1958, Hoese 1965, Ditty and Shaw 1996). Striped mullet in Louisiana were observed entering the spawning season in late September and October by Russell *et al.* (1986). They based their findings on the fact that red-yellow egg material in females and milky white spermatozoan material in males was discharged when pressure was applied near the urogenital opening. Maximum gonad maturation and development extended from late fall to mid winter, and was concentrated in Louisiana between early November and early January (Thompson *et al.* 1990, 1991; Render *et al.*, 1995). Ditty and Shaw (1996), based on the number and length of *M. cephalus* larvae in their collections, estimated that spawning is completed by late February.

Thomson (1955) reported that some females in Australia spawn only in alternate years. Shireman (1975) found evidence for this in Louisiana freshwater areas and implied this could also be the case for other mullet in U.S. waters. Render *et al.* (1995) described three conditions of anomalous ovarian development in Louisiana striped mullet, producing unusually low gonosomatic index (GSI) values. These anomalous conditions included (1) ovaries with arrested oocyte development at the cortical alveolar stage, (2) very small ovaries with low numbers of normal oocytes undergoing development, and (3) diseased ovaries, with atresia of advanced oocytes and a proliferation of red blood cells and intercellular material. Presence of these types of conditions could have led Thomson (1955) and Shireman (1975) to their conclusions regarding spawning in alternate years, since a portion of the population examined by those researchers would have appeared to not be developing ovaries for the incipient spawn. Shireman (1975) reported atretic oocytes in some ripe female mullet taken in freshwater areas in Louisiana, but did not mention the other characteristics described by Render *et al.* (1995).

Oocyte development patterns reported by Thompson *et al.* (1991) and Render *et al.* (1995) indicated that striped mullet are isochronal spawners that possess synchronous oocyte maturation. These researchers reported that in September, a small number of oocytes progressed to the cortical alveolar and early vitellogenic stages, while most oocytes remained in the primary stage. During October, ovaries contained a synchronous group of developing vitellogenic oocytes, while earlier stage oocytes disappeared, either through maturation or atresia. Ovaries in the vitellogenic stage were found from early November through early January. No hydrated oocytes nor ovaries with post-ovulatory follicles were found in Louisiana coastal estuarine waters (Render *et al.* 1995).

The duration of spawn seems to be short. Within a week after the spawning migration, fishermen observed spent male and female mullet in their catches. In addition, Leard (1995) mentioned an unpublished tagging study by the University of Miami that found two tagged mature mullet that were re-collected as spent fish within fourteen days of being tagged at the same location where they were set free. These findings suggest that the spawning process is not long, that the fish may not swim far, and that they may return to the same place.

Thompson *et al.* (1989) found that by February, primary stage oocytes in Louisiana striped mullet were dominant, indicating cessation of reproductive activity and a return to resting stage ovaries. Cessation of reproductive activity was further evidenced by an increased proportion of atretic mature oocytes during February.

Thompson *et al.* (1989) measured egg diameters of leading stage oocytes of Louisiana striped mullet through the reproductive season and found mean egg diameter increased from 0.21 mm in September to 0.56 mm in early November. They stated egg diameter from November to late December appeared to reach a plateau with diameters from 0.53 to 0.56 mm and then decreased towards February (0.19 mm). Terminal mean oocyte diameter was not reported since they did not observe oocytes in hydrated condition (Thompson *et al.* 1989). Oocyte diameter before spawning was reported by Pien and Liao (1975) as 0.60 to 0.70 mm, increasing to 0.90 to 0.95 mm during hydration.

2.5.4 Temperature, Photoperiod, and Habitat

There have been no reports of precise water temperatures or salinities associated with mullet spawning in the wild. However, Tung (1970) reported that the best temperatures from which to catch migrating spawners ranged from 21-25 degrees centigrade (°C). Kuo *et al.* (1974) discovered that the temperature most favoring the completion of oogenesis in captive *Mugil cephalus* was 21° C. Sylvester *et al.* (1975) were able to spawn striped mullet in the laboratory by hormone induction between 22.8-23.5° C. The egg survival was greatest at the highest salinity tested, 32 ppt (parts per thousand).

A study by Dindo *et al.* (1978) reported that when the natural photoperiod is shortening (less than 12 hours) and the temperature falls to approximately 20° C in September and October, there is a concurrent initiation of rapid gonadal growth and reproductive readiness.

The habitat in which mullet spawn has been researched by many investigators. Mullet have been reported to spawn inshore (Breder 1940), along beaches (Gunter 1945), 8 to 32 kilometers offshore (Broadhead 1953), and in water deeper than 40 meters (Anderson 1958). Arnold and Thompson (1958) documented mullet spawning 65 to 80 km offshore in the Gulf of Mexico in water 1000-1800 meters deep. Major (1978) reported that mullet mostly spawn in relatively deep, cool coastal waters. Fischer (1978) stated mullet form large aggregations during spawning, which takes place in the ocean, near the surface, over deep water toward the edge of the continental shelf. Collins (1985) declared that mullet spawn over a wide range of coastal waters but that most spawn offshore. Robins *et al.*, (1986), stated that all individuals spawn offshore. The current consensus is that most mullet spawn offshore. Earlier reports of inshore spawning may have been due to the speed of the offshore movement and spawn.

Thompson *et al.* (1990) indicated that the absence of post-vitellogenic oocytes in their samples supported the contention that striped mullet spawn offshore (Arnold and Thompson 1958, Greeley *et al.* 1987). Oocytes reach a terminal vitellogenic oocyte diameter and then arrest development until movement offshore occurs (Thompson *et al.* 1990). Further evidence of offshore spawning is reflected in the fact that no post-ovulatory follicles were observed histologically from striped mullet collected in inshore estuarine waters (Thompson *et al.* 1990). Post-ovulatory follicles can be seen historically for a relatively short time (Hunter and Goldberg

1980, Hunter and Macewicz 1985) after spawning and can be used to give direct evidence of spawning (Thompson *et al.* 1989).

2.5.5 Courtship and Spawning Behavior

According to Shireman (1975), mature mullet frequently form large schools and swim offshore to spawn in the fall and winter. Sexually mature fish that live in freshwater either resorb their gonads or move to the sea to spawn. Peterson (1976) observed that swimming speed during migration is much greater than that predicted to be energetically optimal, possibly because of the augmented hydromechanical efficiency provided by schooling and the selective force of heavy predation during spawning migrations.

According to Futch (1966) eggs are discharged into the water and nearby males fertilize them. Arnold and Thompson (1958) reported apparent spawning of striped mullet at night in the Gulf of Mexico from visual observation while drifting in 755 fathoms (1381 meters) of water as follows:

> "In a typical group, the males, noticeably smaller and more slender, maintained positions slightly behind what was ostensibly a female. Five or six times while they remained in view, one or more of the males would quickly move up beside or below the female, nudging and pressing against her abdomen with head and body. Often during this action the individuals thus engaged would quiver and cease swimming momentarily, sometimes rising to the surface. The unoccupied males swam rapidly back and forth in the immediate vicinity until they in turn behaved in a similar fashion."

Thompson *et al.* (1991) examined the first record of an hermaphroditic striped mullet in spawning condition taken in U. S. waters (near shore off Mississippi). That this mullet could act functionally as both female and male or have the ability of self-fertilization could not be completely discarded (Thompson *et al.* 1991).

2.5.6 Incubation

Thomson (1963) described *Mugil cephalus* eggs as buoyant, clear, straw-colored, non-adhesive, and spherical. They averaged 0.72 mm in diameter and hatched approximately 48 hours after being fertilized.

2.6 Age and Growth

According to Rivas (1980) mullet may live four or more years. Shireman (1964) reported mullet up to four years old from Maringouin Bayou, Louisiana in 1961-62. Thompson *et al.*

(1991) reported that Louisiana striped mullet have a maximum life span of approximately nine years but relatively few live longer than six years. Thomson (1963) stated the maximum age as 13 years. Bardach *et al.* (1972) stated that mullet reach lengths of 50-55 cm and weights of 1.2-2.0 kg. in 4 to 6 years, but it is unclear whether they are discussing growth in the wild, or in aquaculture situations. Thompson *et al.* (1989) reported that for striped mullet, variability in age at a given length indicated that length is a poor estimator of age. Age validation of striped mullet in Louisiana waters showed a single annulus being formed between April and August (Thompson *et al.* 1989).

Futch (1966) reported that larval mullet (approximately 2.5 mm long) grew into postlarvae in about 7 days. As they increase in size, they move inshore and when they reach a length of 20-30 mm move into the grassy parts of brackish water bays. Within 5 months they grew to 50 mm juveniles. When they were one year old they were about 185 mm. In their second year, at approximately 265 mm, they became available to the commercial fishery.

Fishery-independent seine samples taken by the Department of Wildlife and Fisheries indicate that striped mullet about 20 mm TL were found in November and December, but that more young-of-the-year (YOY) individuals were taken in the 20-50 mm range between January and April. During May and June, relatively few fish less than 30 mm TL were found, and by August, few juveniles remained less than 50 mm TL. The mode of the YOY length frequency was about 70 mm in June, 100 mm by September, and 120 mm by December. Growth rates over the first year of life are apparent in the graphed data (Figure 2.1). During the second spring of life, the fish are less effectively sampled by the seine gear and this, combined with variation in individual growth rates reduces the ease by which growth rates can be distinguished in this figure.

Thompson *et al.* (1990) suggested that Louisiana striped mullet complete much of their yearly otolith growth between July and November, before the reproductive season, and little additional otolith growth takes place during winter and early spring. Even though this is in contrast to suggestions presented by Cech and Wohlschlag (1975), it is consistent with the notion that mullet undergo somatic growth from July through October, then concentrate on oocyte (or testicular) maturation. Thompson *et al.* (1990) thought the growth stasis found between January and March could be a post-spawning recovery period.

Broadhead (1958) stated females were bigger and grew a little faster than males of identical age. Thompson *et al.* (1991) reported that growth models of Louisiana striped mullet showed significant differences between males and females in both length at age and weight at age. Futch (1966) found a rough correlation between average water temperature and size and age at maturity. Individuals from higher temperature areas matured faster than those from lower temperature areas. Rivas (1980) reported that growth of striped mullet during spring and summer is more than double the growth during fall and winter, and he believed the phenomenon to be related to temperature. He proposed that in the Gulf of Mexico, growth in length gradually slows as the fish become larger, and reaches an asymptote at an average length of 600 mm total length (TL), at probably 5-6 years of age.

Robins *et al.* (1986) reported *Mugil cephalus* to reach a maximum size of 910 mm but added that individuals found are usually less than 510 mm TL. However, a 914 mm TL specimen was found in India (Gopalakrishman 1971). A striped mullet caught from Florida's west coast was reported to have a fork length of 698 mm and a weight of 4.4 kg and unconfirmed records of 9.1 kg and 6.8 kg have been reported from Mexico and Hawaii, respectively (Topp and Beaumariage 1971). Thompson *et al.* (1991) obtained striped mullet from the U. S. Sabine National Wildlife Refuge (Louisiana) from 483 to 590 mm FL and weights to over 8 pounds (3.7 kg).

Louisiana striped mullet 4 and 5 years old averaged between 350 and 390 mm FL (Thompson *et al.* 1989). Thompson *et al.* (1990) found a near-linear growth rate to age 3 and a later typical asymptotic pattern with fork lengths leveling off at approximately 350 mm (Thompson *et al.* 1990). Thompson *et al.* (1991) reported von Bertalanffy growth models as follows for Louisiana striped mullet:

Female length:	$L_t = 471.70\ [1 - e^{-0.28(t-0.03)}]$
Female weight:	$W_t = 643.57\ [1 - e^{-0.88(t-1.16)}]^{2.93}$
Male length:	$L_t = 366.98\ [1 - e^{-0.36(t=0.15)}]$
Male weight:	$W_t = 545.37\ [1 - e^{-0.50(t-0.16)}]^{2.93}$

They also noted that fish collected East of the Mississippi River showed different growth parameters from those taken West of the River, but noted that collection methods were different for the fish taken from different parts of the state, which could have influenced the parameter estimates.

Thompson *et al.* (1991) stated that over the entire range of striped mullet examined, length-weight, girth-weight, and otolith-body weight relationships did not differ significantly between males and females. However, analysis of striped mullet (mostly females) obtained from the U. S. Sabine National Wildlife Refuge showed that their growth and reproductive parameters differed from mullet obtained from the Louisiana Department of Wildlife and Fisheries. The fork length/total weight relationship reported by Thompson *et al.* (1991) was:

$$TW = 2.1 \times 10^{-5}\ (FL)^{2.93}\ (r^2 - 0.99).$$

2.7 Other Life History Aspects

2.7.1 Food Habits

Mullet are primary consumers that feed mostly on relatively tiny living and dead vegetable matter (Collins 1985). According to De Silva (1980) most researchers now agree that larval mullet mainly eat microcrustaceans. Nash *et al.* (1974) grew larvae to 20 mm SL using animal matter as a food source and thus demonstrated the dependence of larvae and postlarvae on zooplankton. In Indian River Lagoon (Florida), stomach content analyses were performed on nearly 400 *Mugil cephalus* larvae up to 35 mm SL. Larvae up to 15 mm SL ate almost exclusively copepods (70%) and mosquito larvae (30%); those in the 15-25 mm SL range consumed copepods (50%), mosquito larvae (15%), and plant debris (35%); larvae 25-35 mm SL ingested mainly plant debris (80%) and copepods (10%) (Harrington and Harrington 1961). DeSilva and Wijeyaratne (1977) discovered that the proportion of sand and detritus in the gut of juveniles increases with length, indicating they tend to take more food from the bottom as they grow older. However, Odum (1968) found that mullet 35-80 mm in length fed on a bloom of the dinoflagellate *Kryptoperidinum* sp. and Futch (1976) stated that if non-toxic plankton blooms are available, mullet will feed almost entirely on plankton.

Mullet frequently feed by sucking up the uppermost layer of sediment, which is rich in detritus and microscopic algae, and by ingesting the epifauna and epiphytes on seagrasses and other substrates. They also eat surface scum when large amounts of microalgae can be found at the air-water interface (Odum 1970). Bishop and Miglarese (1978) reported that they also ingest polychaetes (*Nereis succinea*) in the water column. In some freshwater environments *Mugil cephalus* was found to eat mainly benthic filamentous green algae and epifauna and epiphytes on aquatic macrophytes (Collins 1981), but they also consume sediment for grinding.

The time of peak feeding activity varies with site. Odum (1970) found that in all the Florida habitats he studied, feeding varied with the height of the tide, whereas in the saltwater (Cedar Key, Florida) and freshwater (Crystal River, Florida) locations studied by Collins (1981) feeding was completely diurnal and had no relation to tidal stage. According to DeSilva and Wijeyaratne (1977), *Mugil cephalus* showed diurnal periodicity in feeding activity. Peaks of activity were observed at dawn and around midday and these were not related to tidal stage. Brusle (1970) also stated that striped mullet feed during the day, Tabb and Manning (1961) reported the species often feed on flats at night and returns to channels in the daytime.

2.7.2 General Behavior

Broadhead and Mefford (1956) found that *Mugil cephalus* tagged and released just before spawning have as high a recovery rate as individuals released at other times of the year. This contradicts the belief held by some fishermen that mullet do not return after spawning and are therefore lost to the fishery.

Russell *et al.* (1987) observed that few species were caught as bycatch in gill nets and haul seines targeting striped mullet. They believed this to be due to the tight schooling behavior of the mullet.

Mahmoudi (1989) stated that mullet form large schools during spawning months in inshore waters and may move offshore in large numbers during these months. After returning from spawning offshore, schools disperse and move to tributaries during spring and summer months. Thompson *et al.* (1990) reported that as striped mullet move seaward through the estuaries toward open marine waters, there appear to be "staging" areas where the schools temporarily delay migration as schools coalesce into larger, massive concentrations. In southeast Louisiana, these coalescing schools can be found in Lake Borgne and Breton Sound (Thompson *et al.* 1990).

Estuarine waters remaining warm late into the fall, and fall hurricanes may delay or disrupt these movements (Thompson *et al.* 1990). Thomson (1963) reported the timing of the offshore migration may vary as much as two months. Idyll and Sutton (1952) observed that migrations were not extensive in Florida, with 90% of their tagged mullet moving less than 32 km.

According to Hoese (1985) *Mugil cephalus* seems to have the same behavior as that described for *Rhinomugil corsula* by Hora (1938), as individuals of a school place much of the mouth, eye and the upper part of the opercle above the surface. This behavior, together with rolling and jumping, is thought to move air into the upper posterior portion of the pharynx where it is utilized for aerial respiration. The main evidence cited is that jumping frequencies are inversely correlated with dissolved oxygen concentrations, and that the pharyngobranchial organ has the ability to hold gas.

Hoese (1985) stated that escape jumps from predators or from fright are easily recognized because several disturbed fish jump together and they maintain an upright posture, entering the water cleanly. The normal jump is not as fast and not as long, and the mullet usually turns on its side or sometimes turns totally upside down before entering the water. Such easy jumps would not seem to be adequate in either dislodging parasites or fleeing, but would be one way to irrigate the pharyngeal chamber with air with a little expenditure of energy.

Juvenile *Mugil cephalus* 40-69 mm long can live in salinities ranging from 0-35 ppt. Mullet spend the remaining first year of their life in coastal waters, salt marshes and estuaries, and frequently swim to deeper water in the fall when the adults move offshore to spawn. However, many immature mullet overwinter in estuaries. Following their first year, striped mullet live in the ocean, saltmarshes, estuaries or freshwater rivers (Nordlie *et al.* 1982). It seems that on some occasions females are much more abundant than males in fresh and brackish water habitats (Shireman 1975, Collins 1981).

2.7.3 Pathology

Mullet are frequent hosts to parasitic infections and infestations. Collins (1958) found that in almost 300 adult mullet from saltwater and freshwater habitats on Florida's Gulf coast, all fish had parasites either on the body surface or gills.

Bacteria have attributed to individual *Mugil cephalus* mortalities. Lewis *et al.* (1970) documented deaths caused by a *Pasteurella*-like bacterium in Galveston Bay, Texas in November 1968. Substantial mucoid material covered the gill filaments and purulent material was found in abdominal cavities of sick fish. Plumb *et al.*,(1974) isolated a species of *Streptococcus* from mullet and other dying fishes from Florida to Alabama in August and September of 1972 and suggested that this bacterium was responsible. Cook and Lofton (1975) infected five species of fishes including *Mugil cephalus* with the bacterium and observed erratic swimming, external hemorrhagic lesions, peritoneal cavities, and intestines filled with a bloody fluid. Paperna and

Overstreet (1981) stated Donald H. Lewis of Texas A&M University found many mullet from near Galveston, Texas, with *Vibrio anguillarum* during early spring. These fish developed petechial hemorrhages in and at the base of the fins, in the oral cavity and around the vent while being transported to the lab. Lewis also saw loss of scales and large lesions on the abdominal wall of mullet; *Pseudomonas* sp. was most often present in the lesions, liver and frequently the blood.

Bacteria in or on mullet can also cause disease in man by touching or eating the fish (Paperna and Overstreet 1981). Janssen (1970) pointed out the need for further research in public health. Some of the bacteria taken from fishes are *Aeromonas hydrophilia*, *Mycobacterium marinum*, *M. fortuitum*, *Vibrio parahaemolyticus*, *Erysipelothrix rhusiopathiae* and *Leptospira icterohaemorhagiae*. All of the aforementioned can cause disease in man. Mullet can be vectors for cholera, salmonellosis, shigellosis, and probably other diseases besides those caused by the aforementioned bacteria. Most bacterial diseases that could be acquired from mullet can be prevented via cooking the fish (Paperna and Overstreet 1981).

Fungi which infect mullet, include the water-mould, *Saprolegnia* sp. (Sarig 1971). Mullet dying from this water-mould have been documented as well.

Flagellates also attack mullet. The parasitic dinoflagellate *Amyloodinium ocellatum* or a closely related species, sometimes infests striped mullet in Mississippi and can easily kill most pond fishes (Paperna and Overstreet 1981). *A. ocellatum* and related species become detrimental to confined fish because of their reproductive capabilities. Fresh-water baths were effective against *A. ocellatum* whereas most tested chemicals (Lawler, in preparation) seldom were. In Mississippi, *Trypanosoma mugicola* occurs in the blood of striped mullet but appears to have no effect.

Ciliates can also be found in striped mullet. Skinner (1974) pointed out an unidentified trichodinid on *Mugil cephalus* from Florida closely resembling *Trichodina halli*. What seems to be two species of trichodinids in the gill area and on the integument live on striped mullet and white mullet (*M. curema*) from at least Louisiana to Florida. One or both species were observed in *Mugil cephalus* being raised in ponds at Rockefeller Refuge, Grand Chenier, Louisiana, (Overstreet, unpublished data). Frequently *Scyphidia* sp. (another peritrich) also lived on the integument and gills. The ciliate known as 'ich' (*Ichthyophthirius multifiliis* is one of the most devastating parasitic diseases which attacks mullet and other fishes restricted to freshwater ponds or aquaria (Paperna and Overstreet 1981). Striped mullet fall prey to *Cryptocaryon irritans*, which is *I. multifiliis* salt water counterpart. Wilkie and Gordin (1969) found the fish vulnerable to this parasite when marine waters were warmer than 15^0 C.

Haemogregarina mugili is an Apicomplexa (taxonomic division which includes most taxa previously belonging to the Sporozoa) that infects only mullets. Saunders (1964) and Becker and Overstreet (1979) have observed it in striped mullet in Florida and Mississippi, respectively.

Mugil cephalus also hosts cysts of one or more species of *Kudoa* in Mississippi. These infections are found in the musculature and along the alimentary tract (Paperna and Overstreet 1981).

The parasite *Myxosoma cephalus* was found in *Mugil cephalus* from south Florida (Paperna and Overstreet 1981). It was discovered in the meninges, gill arches and filaments, buccal cavity, jawbone, crop, esophagus, intestine, liver and mesentery of the fish. This species was thought to have caused the heavy mortality of striped mullet in southern Florida in 1964 (Iversen, Chitty and Van Meter 1971). Material obtained from the brain-cavity and elsewhere pointed to this pathogen. More than one species of this complex can be found in mullet in America.

Parasitic copepods also infect striped mullet (Paperna and Overstreet 1981). The ergasilids *Ergasilus lizae*, *E. versicolor*, and two other forms parasitize *Mugil cephalus* in the United States (Johnson and Rogers 1973). Besides, several specimens of *E. funduli*, in areas heavy with cyprinodontid fishes frequently infest young or, sometimes, adult mullet. *E. longimanus* has been reported from Florida (Skinner 1974). Paperna and Overstreet (1981) stated that probably other ergasilid species parasitize mullet and pointed to ergasilids heavily infesting striped mullet in ponds at the Rockefeller Refuge near Grand Chenier, Louisiana. The fish however did not appear emaciated. The cyclopoid *Bomolochus concinnus*, plagues *Mugil cephalus* in the southeastern U. S. This parasite was observed in 20 of 83 fish with each fish having between 2-25 individuals in Biscayne Bay, Florida (Skinner 1974). *Bomolochus teres* and *B. exilipes* parasitized striped mullet in Texas (Pearse 1952, Causey 1953). *Naobranchia lizae*, a naobranchiid, has been found on the gills of striped mullet in the Gulf of Mexico (Paperna and Overstreet 1981). The lerneopodids *Clavellopsis robusta*, *Alella longimana* and *Clavella inversa* also plague *Mugil cephalus* from the Gulf of Mexico (Paperna and Overstreet 1981).

Argulus flavescens and *A. floridensis* (parasitic crustaceans that belong to the Branchiura) infest mullet throughout the Gulf Coast of the U. S. (Cressey 1972). A new species of *Argulus* was collected from *Mugil cephalus* in Mississippi (Overstreet 1974). There is definite evidence that species of *Argulus* have killed fishes in enclosed areas and therefore, they should be regarded as a threat to mullet in aquaculture (Paperna and Overstreet 1981).

Isopods also feed on striped mullet. The cymothoid *Merocila acuminata* (synonymous with a species closely related to *N. lanceolata*) parasitizes *Mugil cephalus* in Texas.

Monogeneans may be found on the gills and body of fishes. A new species of gyrodactylid plagues striped mullet in Florida (Skinner 1974). The dactylogyrid *Ancyrocephalus vanbenedenii* infests *Mugil cephalus* in the Gulf of Mexico.

Digenetic trematodes or flukes usually are the most abundant helminths in number of species and individuals (Paperna and Overstreet 1981). Table 2.1 from Paperna and Overstreet (1981), depicts adult digeneans observed in striped mullet in Louisiana and or neighboring states. Table 2.2 from the same source summarizes known zoogeographic information on digenean metacercariae. One major objection to *Mugil cephalus* as a food fish cited by Bardach *et al.* (1972) is that it carries a fluke *Heterophyes heterophyes* dangerous to man if the flesh is eaten raw or poorly cooked.

Phagicola longus causes few human infections in the southeastern U. S. because most fish is cooked, but eating raw, cold smoked, or salted mullet could easily modify the public health statistics (Paperna and Overstreet 1981). Courtney and Forrester (1974) found an average of 11,849 worms in each of 14 brown pelicans from Louisiana. Hamed and Elias (1970) observed live parasites in frozen fish at -10^0 or -20^0 C for 30 hours, but Paperna and Overstreet (1981) reported that deep freezing at -18^0 C for 24 hours killed all metacercariae. Hamed and Elias (1970) discovered live worms after 10 minutes at 100^0 C.

Cestodes are also commonly found in *Mugil cephalus*. At least two species under the group-name *Scolex polymorphus* have been found. One parasite was discovered in the cystic duct of striped mullet from Mississippi and Florida, the other was found in the intestine of young fish from Mississippi. A *Rhinebothrium* sp. has also been documented from the mesentery of *Mugil cephalus* in Mississippi (Paperna and Overstreet 1981).

Nematodes such as *Contracacecum robustum* larvae parasitizes *Mugil cephalus* from Louisiana, Mississippi, Alabama and Florida with heavy infections from near Grand Chenier, Louisiana, where the parasite may have affected the hosts' health (Paperna and Overstreet 1981). *Contracaecum robustum* lives in the liver, kidneys and adjacent tissues of striped mullet (Paperna and Overstreet 1981). *Hysterothlacium* type MB, recognized by Deardorff and Overstreet (1981) as a potential health hazard, has been found in *Mugil cephalus* in Gulf of Mexico waters. In addition, *H. reliquens* (Norris and Overstreet 1975) and *Hysterothlacium* type MD have been observed in Gulf of Mexico striped mullet (Deardorff and Overstreet 1981).

Larval ascaridoids are a potential human health hazard if infected fish are not well prepared. Symptoms comparable to those caused by cancer of the alimentary tract or an ulcer can be produced by some species (Paperna and Overstreet 1981).

Capillaria philippinensis was accused of human deaths in the Philippines. Most infected individuals had been consuming raw fish and shrimp (Paperna and Overstreet 1981). Rawson (1973) has documented small infections of *Capillaria* sp. from striped mullet in Georgia.

The acanthocephalan *Floridosentis elongatus*, may be found in the intestine of striped mullet from Florida to Texas. This species, in general, should not cause harm to *Mugil cephalus* in its natural environment (Paperna and Overstreet 1981).

The leech *Myzobdella lugubris*, can affect *Mugil cephalus* detrimentally if found in large numbers. It has been recorded from estuarine and fresh-water habitats in Mississippi (Sawyer, Lawler and Overstreet 1975). As discussed by Overstreet (1974), Sawyer *et al.* (1975) and others, leeches are probably vectors for the protozoan parasites living in the blood of mullet and other fishes.

Glochidia are the larval stages of the fresh-water bivalves of the Unionidae and striped mullet are potential hosts whenever they live in fresh-water (Paperna and Overstreet 1981).

Ciguatera poisoning can be acquired from eating *Mugil cephalus* either cooked or raw. Fortunately, Paperna and Overstreet (1981) stated that this type of poisoning is uncommon when you consider the quantity of mullet that is eaten throughout the world.

Hyuga fever which is synonymous with Kagami fever has *Richettsia sennetsu* as its aetiologic agent (Paperna and Overstreet 1981). Eating uncooked striped mullet may produce this disease in man (Kitao, Farrell and Fukuda 1973).

Paperna and Overstreet (1981) stated that in the United States only salt, glacial acetic acid and sulphamerazine can be used legally to treat mullet grown in aquaculture for consumption. For example, salt can be used to eliminate the disease caused by the phycomycete fungus *Saprolegnia* sp. on mullet. Paperna and Overstreet (1981) also declared that chemicals can harm mullet directly, they can harm people that consume or rear the fish and they can affect water quality. For example, malachite green may cause cancer, and if potassium permanganate is used in dust form, a cotton mask, safety glasses and gloves should be worn by the handler.

Overstreet (1990) declared that numerous health problems in aquaculture facilities, particularly those concerning marine stocks, can be eliminated, controlled or reduced by drying out ponds periodically. He added that getting rid of accumulated waste and employing lime or some other agent on the cleaned bottom will be appropriate in some cases while in others letting the sun bake the sediment for a few days might be enough.

Paperna and Overstreet (1981) stated that mullet have fed on sewage and on matter saturated with petroleum products. They presume pathogenic bacteria, toxic organic substances and heavy metals acquired by the fish are accumulative and can all be transmitted to man when he eats the mullet.

2.7.4 Trophic Position in the Community

Adult striped mullet have been classified as detritivorous, herbivorous, and interface feeders. The diet and feeding behavior of the fish can vary by site, but their predominant food is either epiphytic and benthic microalgae, macrophyte detritus or inorganic sediment (Odum 1970). Collins (1985) stated that even though the diet of mullet overlaps that of a variety of aquatic species, inter-specific competition has not been reported. Cordona *et al.* (1996) stated the presence of striped mullet increases the global efficiency of resource exploitation, not only of detritus but also of small zooplankton.

Thomson (1963) observed that the main predators of juvenile and adult mullets are fishes and birds. Breuer (1957) reported that spotted seatrout (*Cynoscion nebulosus*) eat mullet up to 35 cm in length, and in Florida sharks occasionally feed heavily on large mullet. In Louisiana waters, juvenile and adult mullet have been found in stomachs of red drum (*Sciaenops ocellatus*) and spotted seatrout (LDWF data, H. Blanchet, pers. comm.).

2.7.5 Habitat Requirements by Various Life History Stages

Mullet live in many habitats and depths and spawn predominantly in relatively deep, cool coastal waters. Larval fish move inshore to shallow waters along beaches and enter salt marshes (Collins 1985). Thompson *et al.* (1990) reported postlarval and juvenile striped mullet showed a strong movement toward lower salinity estuarine waters and became common in estuarine habitats by mid to late winter. Seasonality data reported by Ditty and Shaw (1996) showed that most young *M. cephalus* leave offshore waters by April. Smaller juveniles in their first year in the estuaries showed strong preference for shallow protected shoreline and marsh habitats. With growth, the young-of-the year formed larger schools and became oriented more towards open water. Striped mullet of all size and age classes were found in Louisiana estuarine waters (Thompson *et al.* 1990). Major (1978) observed in Hawaii, in spite of near-lethal temperatures, schools of mullet less than 50 mm SL were invariably found in very shallow waters, including the swash zone and tide pools. Juveniles larger than 50 mm SL favor the slightly deeper waters beyond the swash zone, although, they may swim into shallow waters that smaller mullet have left unoccupied during flood tides. The very shallow water favored by fish smaller than 50 mm SL may help them elude the majority of their predators and to feed without significant competition. Perret *et al.* (1971) reported striped mullet in Louisiana were more abundant in shallow waters near the shore. Seine collections produced fish during all months; the highest catches were made in January (Perret *et al.* 1971).

Larvae - Ditty and Shaw (1996) described the distribution of larval striped mullet in the offshore northern Gulf of Mexico. They found most larvae at stations with surface water temperatures $\leq$24.7° C (range 16.7-27.0° C, mean 23.4° C) and salinities $\geq$34.0 ppt (range 23.5-36.8, mean 34.4 ppt). Their largest tow came from 185 km ($\approx$115 miles) south of the mouth of the Mermentau River in western Louisiana, in water 103 m ($\approx$ 338 feet) deep. They caught striped mullet at stations with water depths between 7 and 2,837 m (23 to 9,308 ft.), with the highest relative frequency of stations containing larvae between 41 and 180 m (135 to 591 ft.).

Temperature - An analysis of the worldwide distribution of striped mullet indicates mullet are temporary residents in regions where waters do not reach 18° C (Collins 1985). Young striped mullet living in salt marsh pools on Florida's Gulf coast at temperatures ranging from 13-34.5° C were reported by Kilby (1949). Water temperatures presumably regulate the amount of time that young individuals stay in estuaries. For example, mullet less than 50 mm SL favor temperatures between 30.0-32.5° C and fish from 50 to 130 mm SL prefer temperatures in the 19.5-20.0° C range. For all sizes of mullet, the temperature chosen tends to decrease as salinity increases. The minimum water temperature reported for the species was 4.5° C (Moore 1976) and one adult was caught at 36° C (Moore 1974). Perret *et al.* (1971) stated that 1,146 striped mullet were taken by trawl and 1,280 were caught by seine in Louisiana. All fish were caught from water temperature intervals 5.0-9.9° C up to and including water temperatures of 30.0-34.9° C.

Salinity - Live mullet of undetermined size were reported in waters with a salinity of 84-86 ppt, as were deaths and emigration above 75 ppt (Wallace 1975). Adult mullet have been documented from salinities ranging from 0 ppt (Collins 1981) to 75 ppt (Simmons 1957). Perret *et al.* (1971) reported striped mullet in Louisiana to range in size from 15 to 465 mm and to occur from fresh water to salinities over 30 ppt. The largest catches were made at 5.0 to 19.9 ppt. Sylvester *et al.* (1975) induced fish to spawn in the laboratory and found that egg survival was greatest at the highest salinity tested, 32 ppt. Survival of larvae was greatest at 26 ppt in tests from 24-36 ppt. Nordlie et al (1982) stated that when mullet are 40-70 mm SL they achieve a definitive state of osmoregulatory capability and can live in fresh water to full strength sea water.

Dissolved Oxygen - Sylvester *et al.* (1975) observed that mullet eggs and larvae apparently cannot live below a dissolved oxygen (DO) level of 4 ppm. Over a range of 1.0-8.0 ppm DO, eggs incubated in the laboratory for two days had a survival rate of 0%-3% at levels 4.5 ppm and below. The survival rate was 85-90% for 5.0 ppm and above. Larvae were kept in DO concentrations of 4.0-7.9 ppm from 1-4 days. The larvae held for 96 hours had a mean survival of 0-8% at 4.0-5.4 ppm, 21% at 6.4 ppm, and 84% at 7.9 ppm. Even though 7.9 ppm was 146% saturation under the conditions tested, there was no sign of gas bubble disease. Collins (1985) reported no specific data on oxygen requirements for adult mullet from the literature. However, initial experiments with fish in cages reported by Collins (1985) revealed their tolerance to a DO level of 4.4 ppm at 29° C and a salinity of 28 ppt.

2.7.6. Environmental Tolerances

Diet deficiencies, environment, including pollution, and genetic problems can cause atypically shaped mullet (Paperna and Overstreet 1981). Tumors have been observed in striped mullet from the northern Gulf of Mexico and Biscayne Bay, Florida (Sindermann 1972, Lightner 1974, Edwards and Overstreet 1976). Increased pollution was suggested by Edwards and Overstreet (1976) as the cause of these tumors.

"Red tide" caused by dinoflagellates or dinoflagellates and bacteria have killed fishes along the Gulf of Mexico apparently by lowering the dissolved oxygen level when these organisms decompose. In addition, according to Ray and Wilson (1957), and Gates and Wilson (1960) single alga and bacteria-free cultures of *Gymnodinium breve*, and cultures of *Gonyaulax monilata* with bacteria, each produced one or more substances which were deadly to striped mullet in relatively low concentrations.

Paperna and Overstreet (1981) stated quick changes in water temperature, sometimes associated with salinity levels, probably are responsible for most naturally occurring fish kills. A massive kill almost completely of striped mullet was documented by Overstreet (1974) in tidally influenced bayous of the Mississippi after a period of freezing temperatures. Where salinity was greater than 6 ppt, other individuals of *Mugil cephalus* did not die.

Paperna and Overstreet (1981) reported that most major kills in estuaries are due to either oxygen-depletion or a combination of the aforementioned with some other factor. According to Christmas (1973) striped mullet and menhaden are the most impacted species in most kills of unknown cause in Mississippi.

Good water quality is not only essential for mullet and other fishes but also, for the people who eat them. Pesticides concentrate in mullet tissues, especially those containing lipids (Paperna and Overstreet 1981). The authors also reported humans can concentrate pesticides in their tissues by eating the mullet and that mullet can die from rapid release of high levels of pesticides stored in its fat into the blood during starvation.

TABLE 2.1. Adult digeneneans in *Mugil cephalus*, site and locality (from Paperna and Overstreet 1981)

PARASITE	SITE	LOCALITY
Hysterolecitha elongata Manter 1931	stomach, intestine	Mississippi
Lecithaster helodes Overstreet 1973	intestine, pyloric, caeca	Mississippi and Florida
Epithelionematobothrium sp. Skinner 1974	body cavity	Florida
Haplosplanchnus mugilis Nahhas and Cable 1964	intestine	Florida
Hymenocotta manteri Overstreet 1969	intestine	Georgia to Louisiana
Schikhobalotrema elongatum Nahhas and Cable 1964	intestine, pyloric caeca	Florida
Schikhobalotrema sp. Skinner 1974	intestine	Florida
Schikhobalotrema sp. Nahhas and Short 1965	intestine	Florida
Chalcinotrema mugilicola (Shireman 1964) Overstreet 1971	intestine	Louisiana
Dicrogaster fastigata Thatcher and Sparks 1958	intestine, pyloric caeca	Georgia to Louisiana
Saccocoelioides beauforti (Hunter and Thomas 1961)	intestine, pyloric caeca	North Carolina to Louisiana
Lasiotocus glebulentus Overstreet 1971	intestine	Mississippi to Florida
Lasiotocus mugilis Overstreet 1969	intestine	Florida and Georgia

TABLE 2.2. Digenean metacercarie in *Mugil cephalus* (from Paperna and Overstreet 1981).

PARASITE	LOCALITY
Cyathocotylidae Poche 1926 *Mesostephanus appendiculatoides* (Price 1934) Lutz 1935	Florida
Bucephalidae Poche 1907 *Rhipidoctyle lepisostei* Hopkins 1954	Louisiana
Didymozoidae Poche 1907 *Didymozoid* larva	Mississippi
Acanthocolpidae Luhe 1909 *Stephanochasmus* sp.	Florida
Heterophyidae (Leiper 1909) Odhner 1914 *Phagicola longus* (Ransom 1920) Price 1932	Southeastern United States

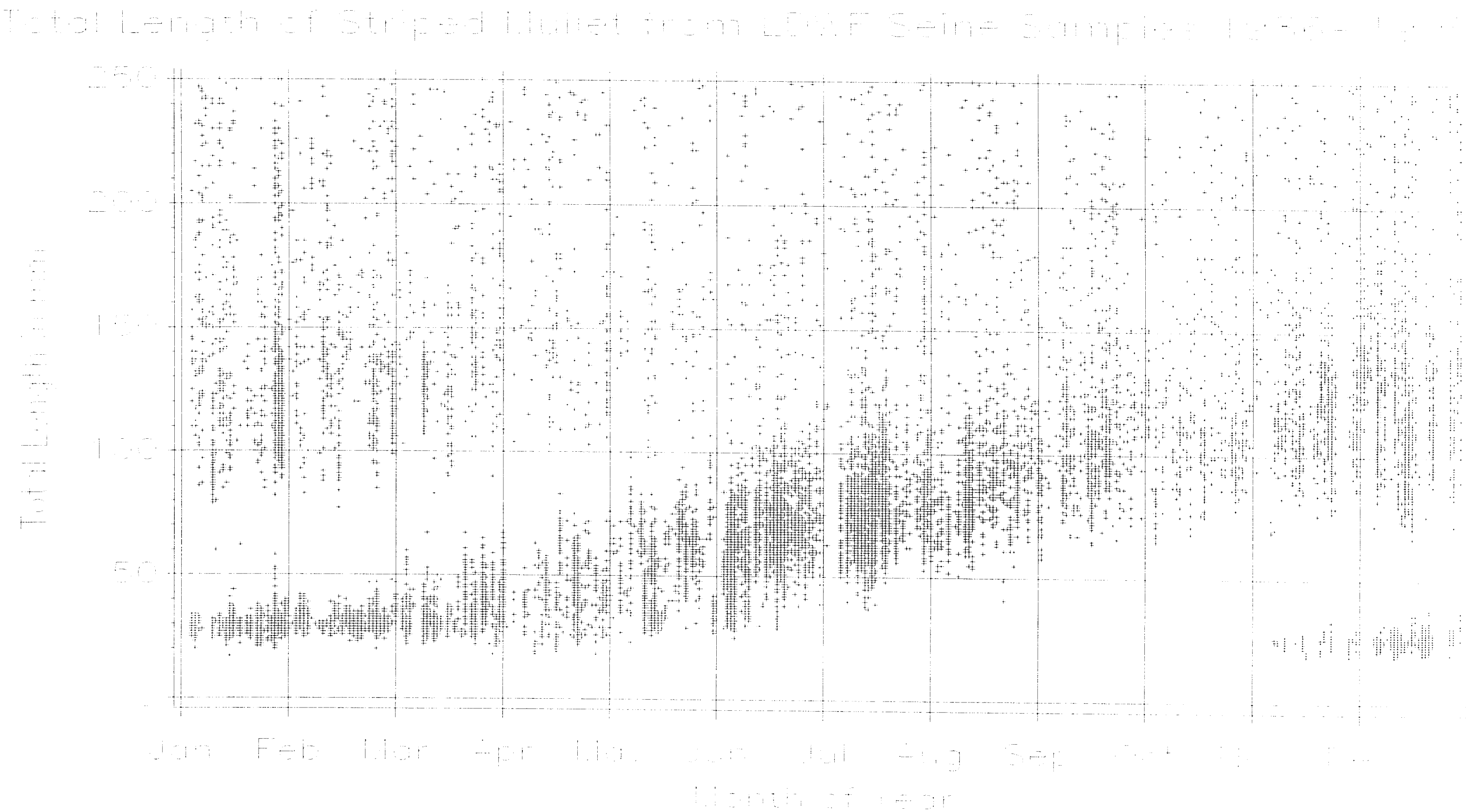


Figure 2.1. Total length of striped mullet taken in LDWF fishery-independent seine samples, 1986-1995. Fish over 250 mm TL excluded. Graph is intended to show the time of recruitment to the seine gear, and growth over the first year of life.

3.0 DESCRIPTION OF THE FISHERY

3.1 History of Exploitation

Due to the variety and abundance of more desirable species of fish in Louisiana waters, striped mullet were not a significantly targeted species until recently. Consequently, there is little documentation of the historic fishery. National Marine Fisheries Service (NMFS) records for striped mullet catch and landings in Louisiana are as early as 1930, although the commercial industry did not develop significantly until the 1970's. Commercial catches in those early years were probably limited to food or bait.

Recent creel surveys and historical information (or a lack thereof) suggest that striped mullet are not a targeted recreational fish in Louisiana (Adkins *et al.* 1990, Guillory and Hutton 1990).

In all probability, the first mullet catches taken from Louisiana waters were taken by native Indians from tidal impoundments. Block off methods, primitive traps, baskets and nets were probably used by the natives to extract mullet from coastal estuaries in the past. European explorers and settlers may have expanded the removal of mullet from Louisiana waters during exploration and settlement by use of better boats, nets and fishing methods.

3.2 Commercial Fishery

The commercial striped mullet fishery in Louisiana consists of inshore and nearshore components. Boat size, type and size of fishing gear and fishery regulations are important in the divisional structure of the commercial fishermen and the area of fishing preference. The inshore fishery is composed mainly of smaller vessels, using hand-hauled gear. The nearshore fishery is composed of larger vessels, often with power reels for gear retrieval.

The striped mullet fishery is concentrated east of the Mississippi River with effort and catch per trip increasing during the spawning months in response to the availability of large fish aggregations and market demand for roe (Mahmoudi 1989).

From 1958 through 1990, Florida produced 80-90% of the United States mullet catch from the Gulf of Mexico (Collins 1985, Leard 1995). Louisiana's fishery has relatively recently expanded, mainly targeting roe mullet, and is presently comparable to Florida's recent annual landings.

3.2.1 Description of Commercial Fishing Activities

The present commercial fishery is limited by statute to a season between the third Monday in October to the third Monday of the following January, using strike gill nets. Harvest is not allowed on weekends or at night. The present season structure essentially limits the harvest to the "roe" season. The following description of fishing activities is intended as a historical characterization of the fishery as it has developed.

Louisiana fishermen have utilized a variety of methods to capture striped mullet for commercial exploitation: mono- and multifilament gill nets, seines, trammel nets and purse seines. Special interest was placed on some gear types as a result of experimental permits issued from 1980 through 1986.

Gill nets were usually deployed by one of two methods: **A.** As a set net located in an area of dense mullet concentrations or in a location that has a channeling effect; or, **B.** as a strike net deployed in a circling manner to surround the school. Recent legislation only allows strike netting. Schooling mullet were often located for strike net fishermen by spotter planes until this practice was outlawed in 1990.

"Florida skiffs" are the dominant type vessel used in the striped mullet gill net fishery. Skiffs from 22 to 28 feet in length are used which often have specialized gear such as a small flying bridge (for spotting), lights for night fishing (pre 1995 legislation) and power rollers for net retrieval (Russell *et al.* 1986).

The maximum legal length of saltwater gill nets used in the Louisiana mullet fishery is 1200 feet; they are constructed of 3.5 to 4.5 inch stretched multifilament mesh. The most common mesh size used is four-inch stretched, and the set time averages ten minutes (Russell *et al.* 1986).

Marais (1985) conducted a gill net study in an Eastern Cape estuary using multifilament polyester gill nets (0.5 mm thick). Each net consisted of five sections with stretched mesh openings of 55, 70, 85, 110 and 145 mm. Nets were set for 12 hour periods from dusk to dawn. Mullet catches indicated that 34% were caught around the head, 45% were caught around the widest part of the body, and 21% were gill-entangled.

Few incidental species are caught in gill net and haul seines used to harvest mullet due to the schooling behavior of mullet. Species which are occasionally caught in small numbers during mullet sets are sheepshead, black drum, red drum and Spanish mackerel (Russell *et al.* 1987).

In Louisiana, the gill net fishery for mullet is concentrated in the area of Lake Borgne, Mississippi River Gulf Outlet, Breton Sound and Breton Bay (Bane *et al.* 1985). Since this time, landings data indicate the fishery has expanded westward of the Mississippi River.

Trammel nets are a gear consisting of at least three panels or walls grouped together in a sandwich-like fashion. The inner panel being smaller, the outer panels are large enough to allow the inner panel to be pushed through them, causing a pocketing effect that entangles individual fish (Everhart and Youngs 1981).

Fishermen using trammel nets in the mullet fishery probably changed to a method consuming less time to retrieve a net set, or remove the catch, or left the mullet fishery in favor of other fisheries.

Permits for seine use to harvest mullet were requested in 1980, the first year of the experimental fishery permitting system. Seines, most commonly used in conjunction with spotter planes (no longer permitted), are very efficient gear for catching large numbers of mullet, as they do not require the time consuming process of removing fish.

A study by researchers at LSU (Russell *et al.* 1987) showed that seines catch a higher percentage of males than gill nets, causing the price per pound from a seine set to be lower than the price per pound from a gill net set. They found the following sex ratios from samples taken East of the Mississippi River in Louisiana waters:

Gill Nets		Haul Seine	
Male	Female	Male	Female
15%	85%	53%	47%

Purse seines were a popular gear type utilized to harvest mullet prior to 1984, when this gear was prohibited by legislation. Purse seines have a purse line at the bottom of the net which is tightened in a draw string manner giving the net a bowl shape from which captured mullet can be scooped out with large dip nets (Everhart and Youngs 1981). Purse seines have the capability, depending on net size, of capturing over 100,000 pounds (45,000 kg) of mullet per set. Vessels which used purse seines were typically 50-80 feet (approx. 15-24 m) in length, with holding capacities of up to 200,000 pounds (9,000 kg) (Russell *et al.* 1986).

Prior to 1984, purse seine vessels operated primarily in Breton Sound and offshore waters due to permit restrictions banning them from most inshore waters. Most purse seine operators transported their catches directly to processors out of state, usually in Alabama or Florida (Bane *et al.* 1985). Regulatory changes have eliminated its use since 1986 (La. Administrative Code, Title 76, Part VII, Chapter 7).

3.2.2 Trends in Commercial Effort and Harvest

Recent increases in effort in the Louisiana striped mullet fisheries were initiated mainly by the demand of Florida and Alabama processors and the influx of out-of-state fishermen exploiting the mullet fishery. In 1976 a market developed in Florida for mullet roe (Mahmoudi 1989), greatly increasing the demand for mullet. The fishery expanded to Louisiana in light of the high quality of roe mullet extracted from Louisiana waters (Russell *et al.* 1987).

As in all fisheries, supply and demand are reflected by trends in harvest and prices. This scenario is greatly magnified during the spawning (roe) season and is quite obvious in monthly harvest records (Fig. 3.2). Since roe is the most valuable of the four marketed mullet products, the greatest harvest of mullet takes place from October through January. The other mullet products are testes (white roe), stomachs (gizzards), and fillets (Bane *et al.* 1985).

The Hopedale-Yscloskey area in St. Bernard Parish has been the center for mullet roe production in Louisiana. In 1986, over 70 boats from Louisiana, Alabama, Florida and Mississippi, worked in St. Bernard Parish and the surrounding waters. Out-of-state fishermen were more experienced at netting mullet than most Louisiana fishermen, but more local fishermen are developing an interest in the fishery due to its obvious profit potential (Russell *et al.* 1987). Since the period from 1986 the fishery has expanded westward of the Mississippi River. The 1995 legislation eliminating those fishermen from states with net bans from purchasing the necessary licenses, has effectively reduced the numbers of fishermen in the mullet industry at present.

The history of the commercial striped mullet fishery in Louisiana can be divided into two periods of exploitation: pre-roe and roe market periods, the latter of which was initiated by Florida processors during 1976.

National Marine Fisheries Service (NMFS) records show Louisiana average landings of 87,729 pounds (39,478 kg) of mullet for the five year period 1972 through 1976. Average landings of 3,494,296 pounds (1,572,433 kg) of mullet for the twelve year period (1977-1994) followed the development of the mullet roe market (Fig. 3.1).

Prior to 1977, landings of striped mullet from Louisiana never exceeded a quarter of a million pounds with the exception of 1949 when 572,000 pounds (247,400 kg) were taken (Figs. 3.3 - 3.4, NMFS 1962-1994 Annual Louisiana Landings). For the period 1972 through 1976, landing records show a range of 15,845 (7,130 kg) to 213,000 pounds (95,850 kg) (Fig. 3.1). The twelve years following 1976 show an increase in striped mullet landings with only three years (1977, 1980 and 1985), falling below the one million pounds (Fig. 3.1). Records indicate that there was a significant harvest between June and October of 1980, 1981 and 1988 (Fig. 3.1). A late hurricane (Juan) followed by inclement weather during the spawning season of 1985 was responsible for the second lowest landing since 1976 i.e. 579,297 pounds (260,684 kg). Respective high (3,157,207 pounds (1,420,743 kg) in 1989) and low (204,310 pounds (91,940 kg) in 1980) landings of striped mullet occurred during the period 1977 through 1989. Record catches have occurred during the 1990's with landings data from 1994 being the highest recorded.

With demand for mullet roe continuing and with a corresponding price increase, the Louisiana mullet fishery has evolved from an underutilized species fishery to a viable fishery today.

3.2.3 Aquaculture

Mullet does not seem to be a desirable species for aquaculture in Louisiana at this time due to its abundance in the wild, market competition with more desirable food fishes, and returns versus costs in aqua farming. However, the holding of juveniles and subadults for harvest as roe mullet may be possible and economically feasible if legal and technical issues with this could be resolved.

Futch (1966) recommended the aquaculture of mullet because they are one of the major species reared in the Orient and because brackish ponds closely approximate the natural habitat. However, Futch points out two major economic factors to be considered in mullet aquaculture: the abundance of fish for stocking ponds and the high cost of pond development and maintenance.

Experiments with mullet aquaculture have been carried out in the following countries: Italy, Taiwan, Israel, India, Pakistan, Burma, Cyprus, Yugoslavia, Greece, Tunisia, United Arab Republic, Egypt, France, Indonesia, Philippines, Republic of China, Hong Kong, Japan, the United Kingdom and the United States.

Bardach *et al.* (1972) stated if researchers could succeed in unlocking the secrets of spawning and rearing *Mugil spp.* on a large scale, mullet could well become the most important human food product of the estuarine environment.

A brief summary of the major contributions to the propagation of mullet by artificial means as reported by Bardach *et al.* (1972) follows:

1. Artificial propagation of mullet was first achieved in Italy in 1930 by a method similar to "stripping" trout in hatcheries.

2. Induced ovulation and successful spawning of striped mullet by injecting ripening fish with striped mullet pituitary extract and the synthetic hormone Synahorin occurred in Taiwan in 1964.

3. In 1968, researchers in Israel spawned striped mullet using three time-lapsed injections of common carp pituitary.

Mullet are not normally regarded as a food fish in the United States, except for Hawaii, Florida, Georgia and, to some extent South Carolina, Alabama and Mississippi. Therefore, they have received a limited amount of research from United States aquaculturists. Bardach *et al.* (1972) summarized the following experiments regarding mullet aquaculture in the United States:

1. At Bears Bluff, South Carolina, a 0.6 hectare brackish water pond, 1 to 2 meters deep, stocked by natural processes and virtually unmanaged, yielded 85 to 227 kg/ha of fish, of which 47.5 to 74.2% were striped mullet, during five 6 to 13 month growing seasons.

2. Similar yields from fertilized ponds used for experimental monoculture were obtained at the Marineland Laboratory, Orlando, Florida.

3. A 5.6 hectare brackish water pond, 1.7 meters in depth, intended for pompano culture at the Florida Board of Conservation laboratory in St. Petersburg, Florida, produced a high yield of extraneous fish. Striped mullet and white mullet constituted the majority of the fish population and yielded 767 kg/ha over a two year growing period.

In Louisiana, Perry (1972) and Perry and Avault (1975) conducted monoculture and polyculture studies with striped mullet from 1966-1973 at the Rockefeller Wildlife Refuge, Grand Chenier. In 1969, a monoculture pond was stocked with 2,519 mullet/ha to determine survival and growth during the winter. The mullet experienced water temperatures of 11^0 C with a survival rate of 87% and a production rate of 352.8 kg/ha. The pond was harvested after 317 days.

A polyculture pond of Atlantic croaker (*Micropogonias undulatus*)and striped mullet, into which supplemental feed was not added, was stocked the same year. Atlantic croaker survival was 10% and contributed 63 kg/ha. At the end of the study, mullet weighed 77 grams more on average in the polyculture pond than those cultured alone at the same density. However, survival of mullet was 18% greater in the monoculture pond.

In 1970, eight ponds were stocked with mullet at the following rates: 1) Two ponds at 247 fish/ha, 8 grams/fish; 2) three ponds at 4,940 fish/ha, 6 grams/fish, and 3) three ponds at 4,940 fish/ha, 33 grams/fish. Supplemental feed was not added. Mullet were harvested after 181 days with production of 1) 60 kg/ha, 2) 191 kg/ha and 3) 454 kg/ha respectively. Ponds stocked at 247 fish/ha were the only ones producing fish of harvestable size, averaging 380 grams (330mm). Approximately 65% of the fish harvested exceeded 340 grams.

During 1971, production of 1,602 kg/ha was obtained from a polyculture experiment with mullet and channel catfish (*Ictalurus punctatus*).

A polyculture experiment was conducted in 1972, stocking 4,940 channel catfish and 14,820 mullet per hectare. A monoculture control of 4,940 channel catfish supplementally fed was also conducted. Catfish in the polyculture pond produced 2,353 kg/ha and had a survival rate of 85%. Mullet survival was 51% and averaged 59 grams. Production of catfish in the monoculture pond was 2,323 kg/ha with a survival rate of 91%.

In 1973, experiments were conducted with Atlantic croaker and mullet in polyculture using a croaker monoculture as a control. The ponds were stocked with 4,940 croaker and 247 mullet/ha. Polyculture survival was 90% for mullet and 35% for croakers with mullet accounting for 136 kg/ha of the 315kg/ha of fish produced. Croaker survival and production from the monoculture pond was 35% and 123 kg/ha, respectively.

The Rockefeller experiments indicated mullet culture to be quite promising, though techniques must be improved and marketing, especially local, needs to be developed.

Mullet culture has not been developed in the western hemisphere other than the United States, although its potential for alleviating the serious protein problem of Latin America is obvious. It could also prove useful in reducing the protein supply problem in tropical Africa (Bardach *et al.* 1972).

3.2.4 Economics of the Commercial Striped Mullet Fishery

The commercial striped mullet fishery is divided into three markets, and the dockside price of each product may be different. Mullet are harvested for three general uses: as bait for fishing operations, as food fish for human consumption, and as a source of fish roe. Mullet sold for bait typically bring the lowest dockside price, while mullet sold for roe bring the highest.

Each market supplies a different geographic region. The bait market is essentially a local market, providing bait to crab and trotline fishermen in coastal Louisiana. Mullet as food fish is mainly marketed out of state, though a small local market exists in Louisiana. Most of these fish are exported to Georgia, Florida, and Alabama. Roe mullet is either processed within the state or shipped out of state for processing. The final product is intended for export to foreign countries, especially in Asia.

The effect of the roe market on prices may be seen in the dockside price paid on a monthly basis. Figure 3.7 shows the monthly harvest and dockside prices of mullet from 1978 to 1992. Those months of roe harvest (October to January) have higher prices than other months. Harvest is lower in October and January than in November and December. Prices will vary by month due to the quality of roe, availability from other areas, and availability of alternative species.

Figure 3.1 presents annual harvest and prices from 1978 to 1994 in Louisiana. This data for mullet harvest and associated price are unusual for commercial fisheries, where higher prices are typically associated with times of lower harvest. This may be due to the fact that Louisiana has been a small supplier and that Louisiana prices followed prices set in the Florida fishery. Further, the demand for roe increases demand and price for the fish during the roe season.

Only the female mullet has value for the production of roe, and the presence of significant numbers of males in the harvest can affect the price of this commodity. Males harvested in the roe fishery may be sold separately at a much lower price or may be included in the sale of females with the reduction of price absorbed by the entire catch. During the roe season, the harvest rate substantially exceeds the harvest rate at other times of the year. Therefore, there is relatively little directed harvest for food or bait at that time. However, the bait fishery has a ready supply of carcasses available from roe processors, and there is no need for quality control for mullet carcasses used as bait.

The price structure for mullet sold at the dock is variable and has become more complex over the past few years. Russell *et al.* (1986) described a simple price structure, with females receiving a higher flat rate dockside than males. More recently, common practices involve some method of variable pricing depending on the size (weight) of the individual roe, the percentage of roe by weight in the female, and the percent of females in the harvest (Table 3.1).

Prices per pound for mullet as food or bait are lower than the price for roe mullet (Figure 3.1). Since 1990, the market for mullet as a food fish has complicated the non-roe price structure. Sales are unclear as to destination, and the prices collected monthly by NMFS may use an average price for bait and meat. However, prices adjusted for inflation have shown an upward trend.

The typical relationship between price and harvest for most fisheries is not evident for Louisiana mullet. In most fisheries, landings for a species or group are inversely correlated with dockside price. For instance, if landings increase, prices tend to decline. When price is plotted against monthly landings, this produces a negative slope for the regression line. This is not the case for Louisiana mullet. Slope of the regression line between seasonal (roe or non-roe) harvest and price is not significant, and very near zero (Table 3.2), or is positive. This is perhaps not unexpected when the Louisiana fishery is considered as a relatively small part of the regional fishery, which has been dominated by Florida harvest. It does have implications, though, that at least at harvest levels seen in recent years, the market is fully capable of utilizing the harvest. It also implies that at least modest increases in landings would result in minimal declines in price per pound.

An economic analysis of a commercial fishery will involve dockside values. However, using only dockside prices will not measure the total benefit of the fishery to society. Commercial fishermen may accept lower financial returns and more uncertain benefits to remain within their occupation. There may be other non-monetary values the fisherman receives, such as more freedom, the aesthetic setting, wildlife seen while fishing, etc. Dockside value will not completely capture this value.

The total benefit to consumers of mullet is greater than a dockside price. Total benefits include the dockside price, any value added, and the willingness of some consumers to pay more than the market price. Value added is any processing or preparation of the fish for consumption as bait, food, or roe. Some consumers would be willing to pay more for mullet than the market price because they derive more satisfaction from its consumption. The total benefits to the Louisiana economy would include all these items.

3.3 Recreational Fishery

3.3.1 Description of Recreational Activities

Striped mullet are not a highly targeted species for sports fishermen because there is an abundance of more desirable sport fish in Louisiana's coastal waters and mullet are not a species which can be readily taken by hook due to their feeding habits. As documented by the 1984 Louisiana Department of Wildlife and Fisheries creel census (Adkins *et al.* 1990) only a limited number of mullet were taken, and then only incidentally. Striped mullet during the 1984 creel survey amounted to less than 1% of the total catch (Adkins *et al.* 1990).

Striped mullet are often caught by coastal inhabitants, usually by cast net, the preferred method of capture by recreational fishermen. These fish are taken to provide live, especially juveniles, or cut bait to fish for a variety of species in near shore and offshore waters; whereas larger fish may be consumed as fillets or smoked. Mullet are also taken to provide bait for recreational crab traps. Another method of capture is to throw a treble hook into a school of mullet in hopes of snagging a fish when the hook is retrieved. Many local youngsters historically fished for mullet from docks, piers, or roadside. They were successful in catching mullet by using a long-shanked small hook onto which was pressed a piece of bread, not unlike a dough-ball. Many hours of entertainment was provided by this "fishery".

3.3.2 Trends in Recreational Effort and Harvest

Data on striped mullet recreational effort and harvest at this time are not adequate to establish trends. However, it would seem logical that the majority of mullet taken recreationally as a target species are caught during the spawning season, October-February, when mullet are aggregated. Harvest of young-of-the-year "finger" mullet are probably distributed over the last half of the year, when mullet are available in sizes appropriate for use as bait. Saltwater recreational fishing effort is also higher at this time of the year than during January through April, so that harvest of larger mullet for bait may also increase with overall fishing effort.

3.3.3 Economics of the Recreational Striped Mullet Fishery

Recreational fishing is a highly diverse activity and has economic value. Participants are seeking a recreational experience and are willing to pay more for this activity than it actually costs. Households actually "produce" recreational trips by allocating their time, buying market services, and combining these with publicly provided natural resources (McConnell and Strand, 1994). The value of recreational fishing is variable across individuals and trips. It will depend on many conditions--the quality of fishing, the weather, the skill of the angler, etc.

There are two kinds of economic value for recreational fishing. One is the access value to a resource. Access pertains both to the overall opportunity for fishing and to the opportunity for fishing in specific locations. The value of access is what anglers would pay rather than do without or the amount they would accept in compensation for their loss of access. The second kind of economic value is the value of catching an additional fish. This is the amount an angler is willing to pay to catch more fish, larger fish, or more desirable fish. This amount will depend on many things, such as the species sought, the time when fishing takes place, the mode of fishing, the weather, environment, etc.

The estimation of the value of a recreational fishery such as striped mullet will involve the measure of species specific effort and the expenses incurred. There have been several studies made to collect total numbers of recreational fishermen, percentage of fishermen targeting various species, average number of fishing trips per year, and expenditures per trip. Data from these studies have been highly variable among studies, even over the same time period. Conclusions drawn from these studies should therefore be viewed with caution.

Recreational fishing effort depends primarily upon the number of fishermen and number of trips per fisherman. Individual fishing effort is largely a function of the expenses incurred in the activity and the perceived benefits received from the activity. As costs rise and benefits remain the same, effort tends to decrease. Costs can increase through increased spending, in relation to other leisure activities, or as a fraction of disposable income. Anglers can receive both tangible and intangible benefits from fishing activities. Tangible benefits include the number or quality of fish caught. Intangible benefits can be enjoyment of the outdoors, change in routine, companionship, etc.

Fishing effort will continue as long as the economic costs are not greater than the angling satisfaction (or what economists call utility). Fishing net benefits (satisfaction minus costs) may decline due to satiation, declining catch per angler, congestion at favored locations, degradation of aesthetic value of trips, or from increased fishing costs.

Direct expenditures per trip for marine recreational anglers in Louisiana were estimated at \$53 (Kelso *et al.* 1992), \$64 (Bertrand 1984), \$75 (Kelso *et al.* 1991), and \$133 (Titre *et al.* 1988). Direct expenditures include spending for automotive and boat fuel, lodging, food and drinks, ice, boat launch fee, bait, and other expenses directly related to the trip. In addition to trip expenditures, anglers purchase equipment (boats, motors, trailers, vehicles) and speciality gear. This equipment is used for more than one trip and even over several years. Their cost needs to be allocated over time. Published annual estimates of these expenses vary widely depending on what is included: \$800 (U. S. Fish and Wildlife Service 1997), \$698 (U.S. Fish and Wildlife Service 1993), \$824 (Kelso *et al.* 1991), and \$1108 (Kelso *et al.* 1992).

Bertrand (1984) estimated total annual expenditures by saltwater anglers in Louisiana as 180.6 million dollars. Estimates can also be calculated from other surveys. From a 1985 survey, the U.S. Fish and Wildlife Service (1988) estimated that state residents spent a total of \$197 million dollars on saltwater fishing expenses, including equipment and trip-related expenses.

Nonresident anglers spent an estimated $37.6 million in trip-related expenses in Louisiana. From the next survey in 1991, the U.S. Fish and Wildlife Service (1993) estimated expenditures of 158.8 million dollars by state residents on saltwater angling. As in the 1985 U.S. Fish and Wildlife survey, expenditures of nonresident anglers were not broken out by fresh and saltwater expenditures. However, from the 1991 survey data, the Sport fishing Institute estimated that expenditures of saltwater anglers in Louisiana total $183.3 million (Fedler et al. 1993). The 1996 U.S. Fish and Wildlife survey reported total (fresh and saltwater) angler trip and equipment expenditures in Louisiana to be $824.3 million, 9.2% from non-resident anglers. From the 1996 survey data, the American Sportfishing Association (Maharaj and Carpenter 1998) estimated that expenditures of saltwater anglers in Louisiana totaled $205.4 million.

Direct expenditures for the fishing trip may be less than the angler would be willing to pay for the whole experience. The difference between the costs of the trip and what the angler is willing to pay is called consumer's surplus. This is the difference between the maximum amount an angler would be willing to pay and what he/she actually paid fro the activity. Titre et al. (1988) found that the average recreational user would be willing to pay approximately $193 to $394 annually for the right to recreate in Louisiana wetlands under certain conditions of harvest, catch, and amenity situations.

Mullet are seldom targeted by Louisiana recreational anglers as a food or sport fish. Estimates of mullet harvest by anglers in the state are highly variable, and the size frequency of the harvest indicates that at least some of the harvest is intended as bait. Though there is little directed recreational fishery, striped mullet do have value to recreational fishermen as bait for a wide range of species which are targeted by these fishermen.

Mullet are a relatively hardy species, easy to maintain in a live condition on board a vessel, so are often used as live bait. Many recreational fishermen capture mullet, rather than purchasing them from retail tackle and bait shops. An estimate of the value of mullet to these fishermen can be estimated by the cost of alternative baits, such as live shrimp or Gulf killifish ("cocahoe minnow"). The price of bait in a live condition on the Louisiana coast presently is approximately $2.00 per dozen.

Mullet are also sold as gutted or cut frozen fish for use as cut bait or whole bait for crab traps, or as chum for some types of angling. In this condition, sale price to the fishermen typically is in the $2.00 to $6.00 per dozen range. No data on statewide sales are available for this resource, but it probably is only a small fraction of the statewide total harvest. At least some of the mullet utilized in this market are imported from other states and do not come from the Louisiana fishery.

Data on retail bait mullet sales are not available. Estimates of numbers of mullet harvested by recreational fishermen are available from the Marine Recreational Fishery Statistics Survey (MRFSS), but disposition of these fish, whether they are used as bait or directly consumed, is not determined. Without these values, complete estimation of the value of the species to the recreational fisher is presently indeterminate.

Table 3.1. Example price matrix for Louisiana roe mullet, based on roe percentage of body weight and whole fish weight. In this case, the percentage of roe and count are based on sampling procedure below; count is the number of whole fish in a 100 pound sample. For instance, "50 ct." fish are 50 fish per 100 pound box, or two pounds each on the average. If "50 ct." fish yield 16% roe from the procedure below, the price would be $1.30 per pound for the whole (round) fish.

Sample Roe Mullet Price Chart
(All fish yielding 2-4 ounce red roe)

Pct\count	50 ct	60 ct	70 ct	80 ct	90 ct	100 ct	>100 ct
12%	$1.10	$0.95	$0.80	$0.65	$0.50	$0.35	*
13%	$1.15	$1.00	$0.85	$0.70	$0.55	$0.40	*
14%	$1.20	$1.05	$0.90	$0.75	$0.60	$0.45	*
15%	$1.25	$1.10	$0.95	$0.80	$0.65	$0.50	*
16%	$1.30	$1.15	$1.00	$0.85	$0.70	$0.55	*
17%	$1.35	$1.20	$1.05	$0.90	$0.75	$0.60	*
18%	$1.40	$1.25	$1.10	$0.95	$0.80	$0.65	*
19%	$1.45	$1.30	$1.15	$1.00	$0.85	$0.70	*
20%	$1.50	$1.35	$1.20	$1.05	$0.90	$0.75	*

* No market price for fish this small

Sampling Procedure for Estimating Percent Roe:

1) From a 100 pound sample of fish, count and record the number of fish in the sample.
2) Remove all "red roe" and "white roe" from the fish. Sort the carcasses by sex.
3) Weigh male fish and gonads together.
4) Select female fish, as nearly as possible the same size and number as the removed males, from fish <u>not</u> included in the original sample.
5) Remove the roe from these fish, and add the roe and carcasses to the original female sample.
6) Weigh all of the female roe in the adjusted sample.

The resulting weight equals the percentage of "red roe" found in all of the female fish in the full lot being sold.

If purchased, male fish are typically purchased at a greatly reduced price, based on the percentages obtained in step 3 above. Otherwise, the price is adjusted by the percentage of males, with no value being given these fish.

Table 3.2. Relationships between price and landings for Louisiana mullet. Prices are deflated to 1994 dollars. Landings by gear and season (roe and non-roe), and monthly total landings are regressed against dockside price. Estimation function is:

Price (in 1994 dollars) = Intercept + Slope * Landings.

Landings Type	Intercept ($/lb)	Intercept St. Err. ($/lb)	Slope ($/lb*$10^6$)	Adjusted r^2
	Regression for 1986-94			
Total landings	0.2969	0.017	+0.112**	0.13
	Regression for 1986-89			
Gill Net	0.2361	0.031	+0.561**	0.55
Haul/Purse seine	0.2005	0.064	+0.508 (n.s.)	0.04
Trammel	0.2644	0.128	+41.767 (n.s.)	0.15
Trawl	0.3049	0.041	+9.105 (n.s.)	0.00
Roe Season	0.5578	0.050	+0.243*	0.16
Non-roe	0.1781	0.011	-0.284 (n.s.)	0.02
	Regression for 1990-94			
Roe Season	0.6661	0.074	+0.034 (n.s.)	0.02
Non-roe	0.3439	0.028	-0.156 (n.s.)	0.02

*slope significant at p=0.05 level
**slope significant at p=0.01 level

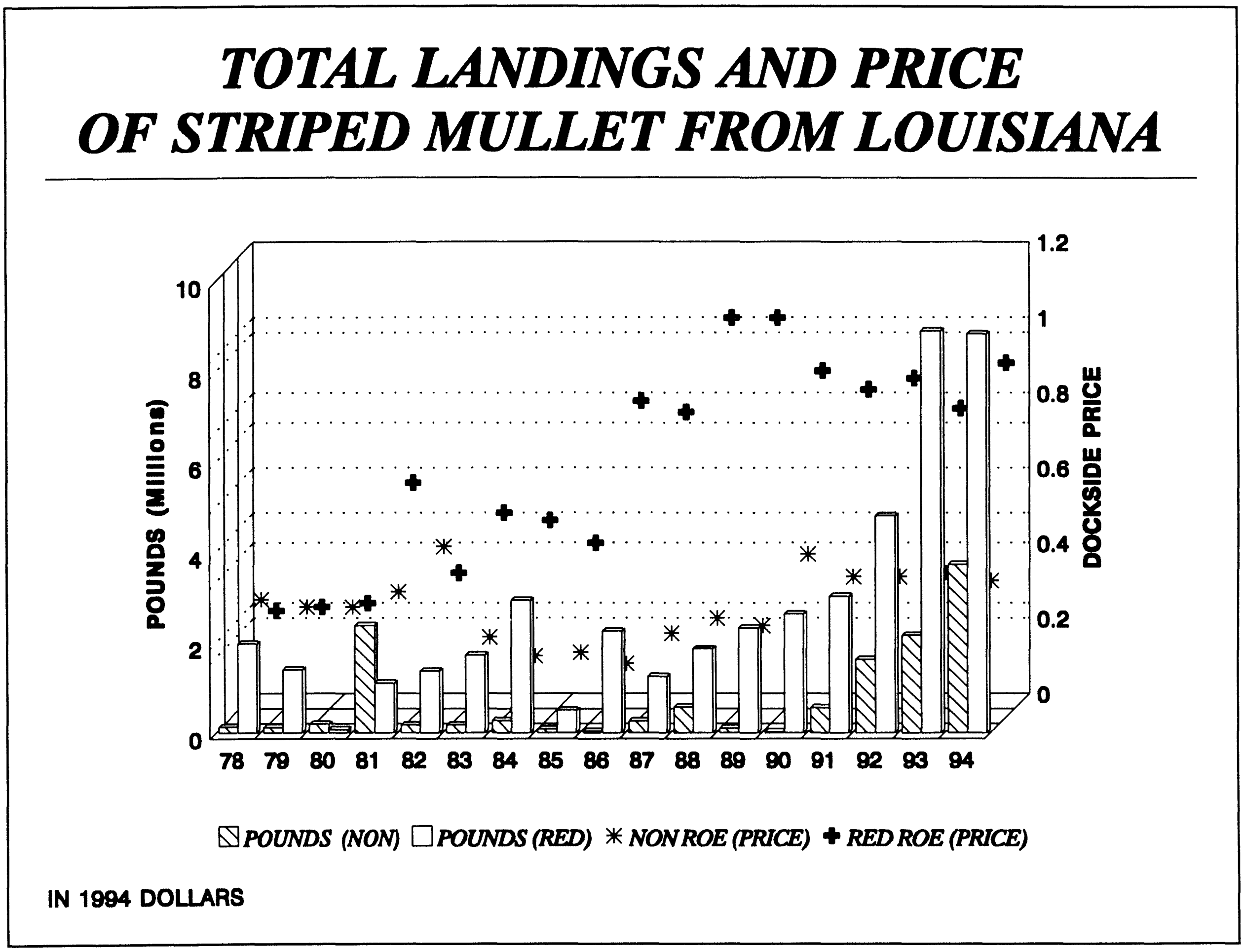


Figure 3.1. Seasonal harvest and prices for striped mullet landed in Louisiana. "Roe" season landings are from October through December, "non-roe includes January through September.

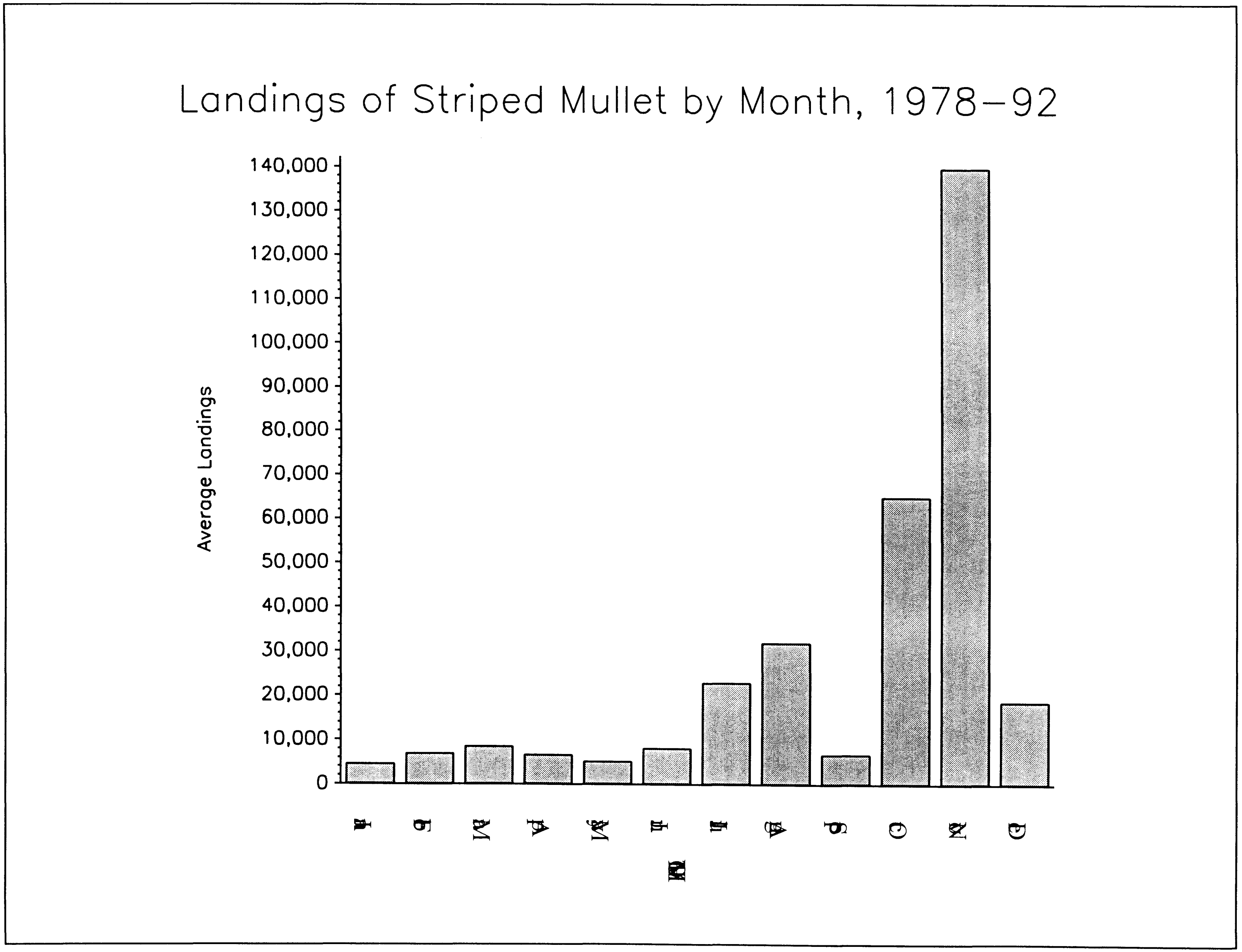


Figure 3.2 Relative monthly landings of striped mullet in Louisiana, based on 1978-1992 monthly landings.

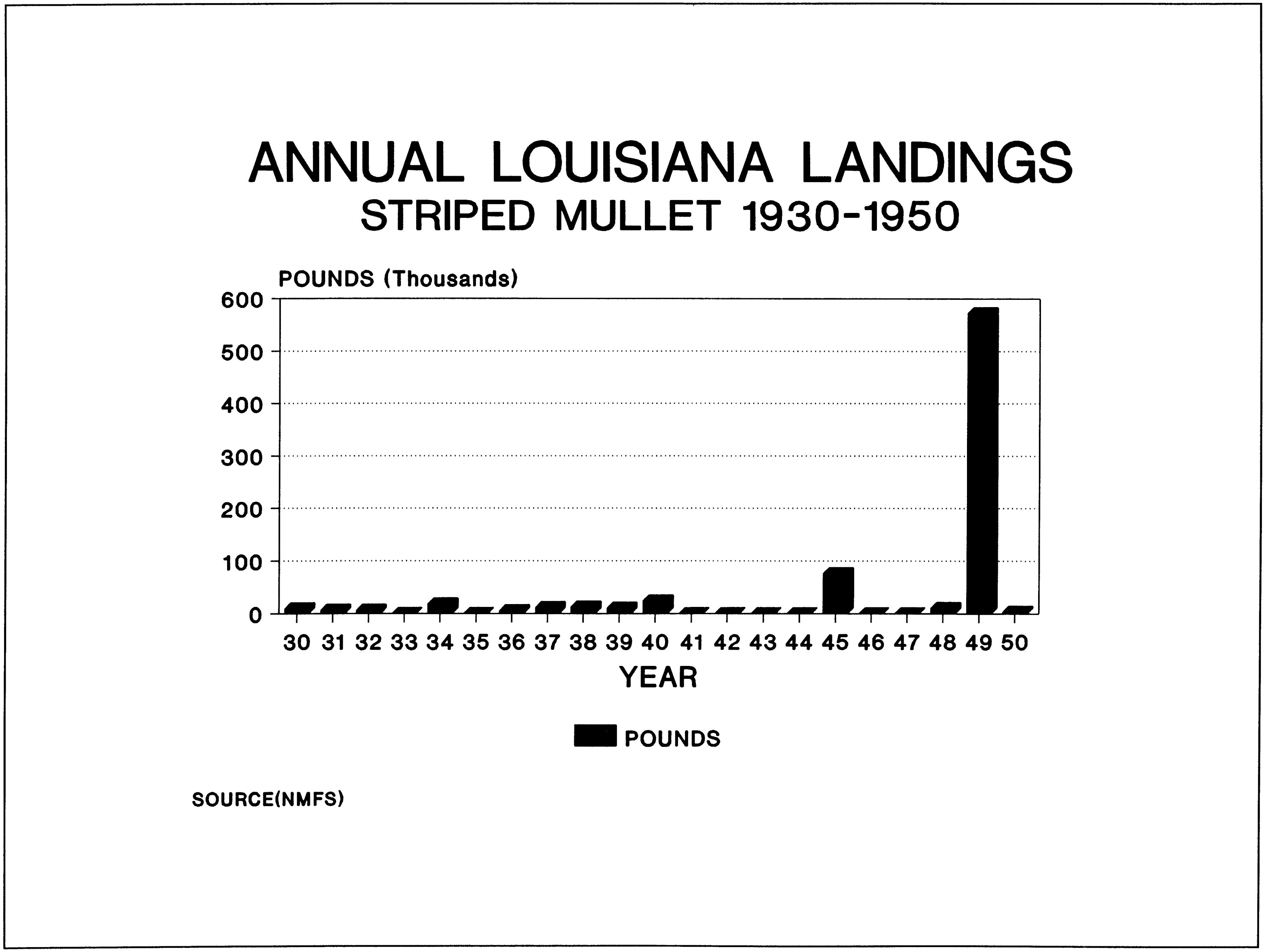


Figure 3.3. Annual landings of striped mullet in Louisiana, 1930-1950. Source: NMFS annual landings statistics summary.

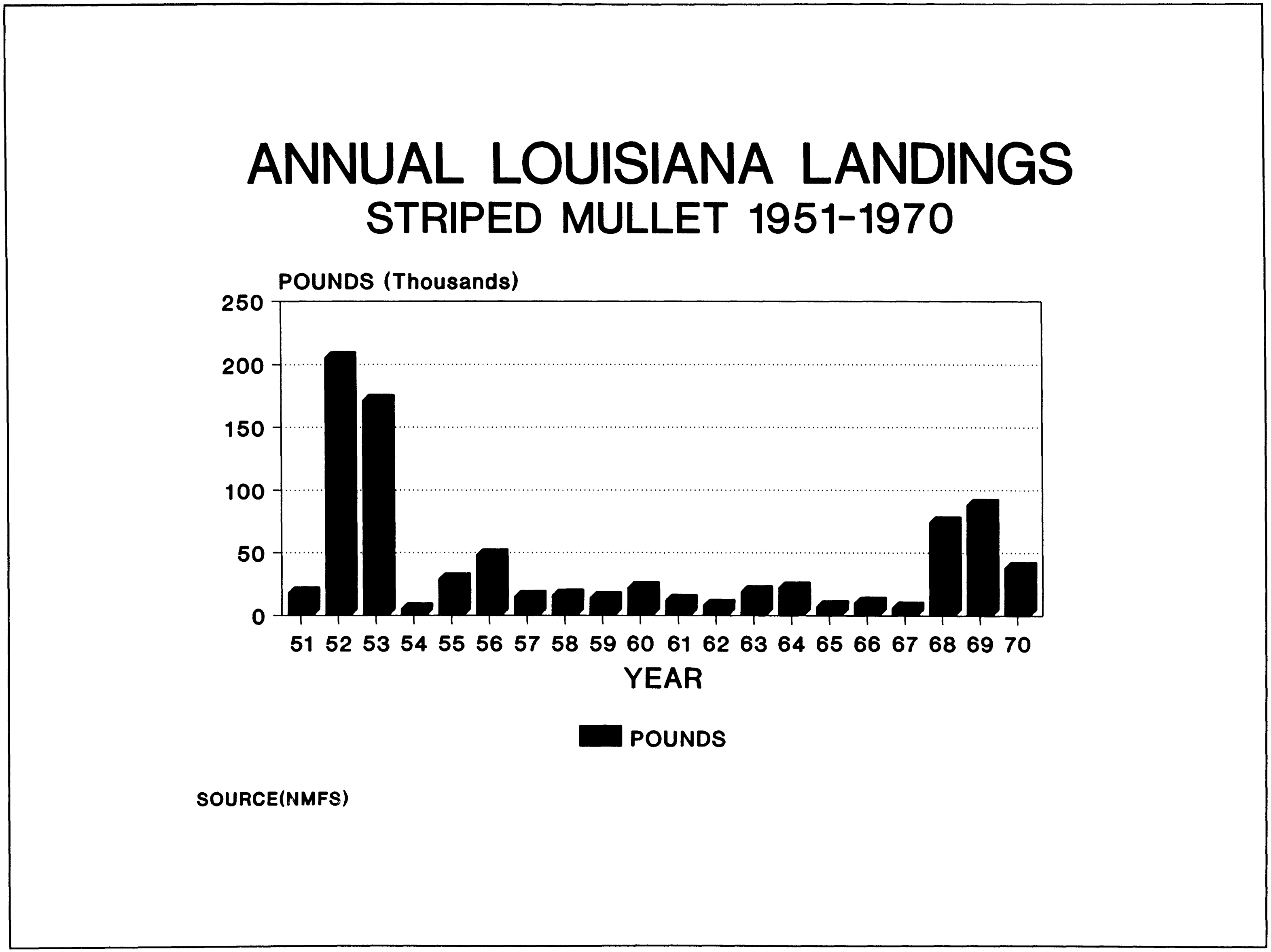


Figure 3.4. Annual landings of striped mullet in Louisiana, 1951-1970. Source: NMFS annual landings statistics summary.

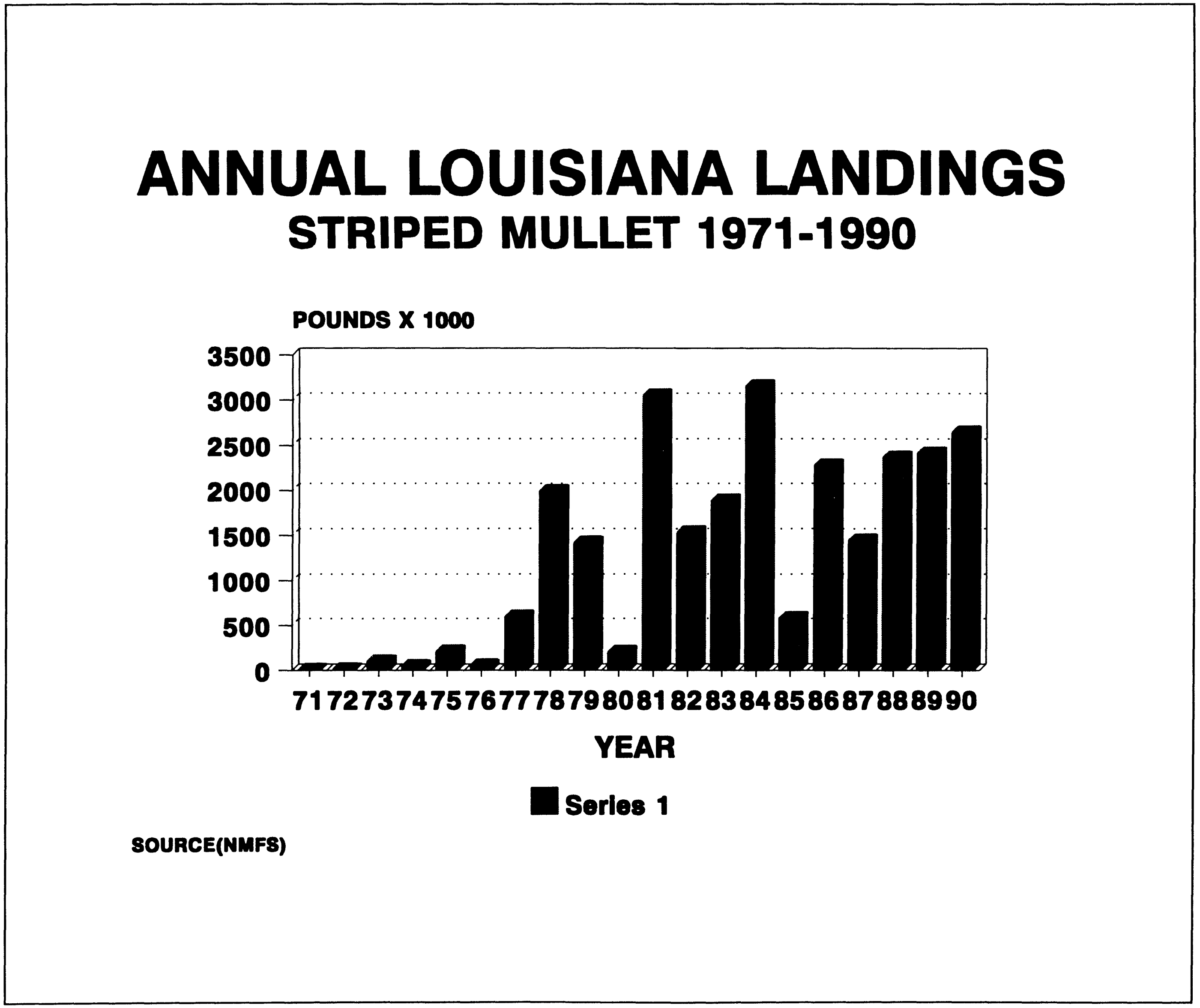
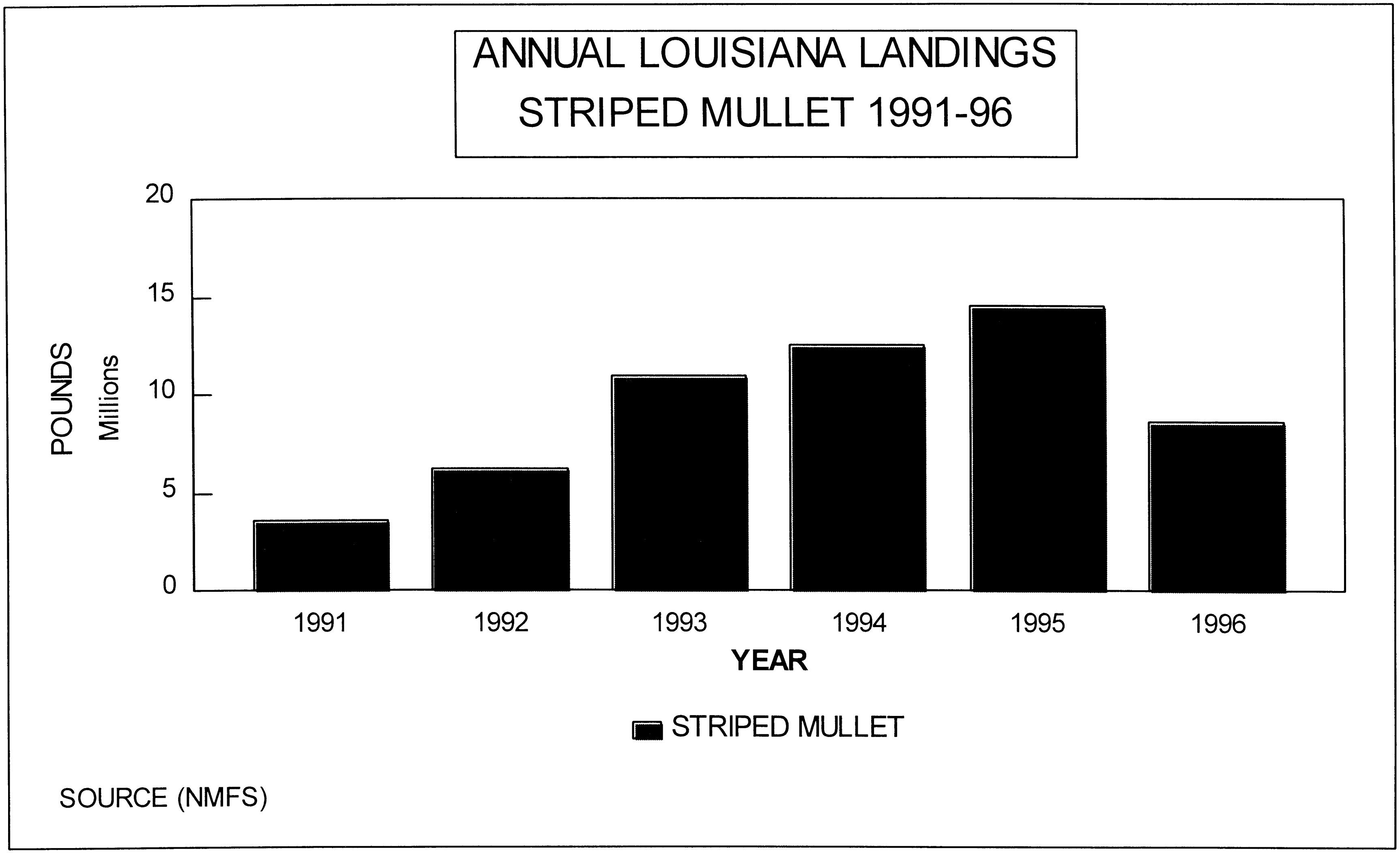


Figure 3.5. Annual landings of striped mullet in Louisiana, 1971-1990. Source: NMFS annual landings statistics summary.



. **Figure 3.6.** Annual landings of striped mullet from Louisiana water, 1991-96.Source: NMFS annual landings statistics summary

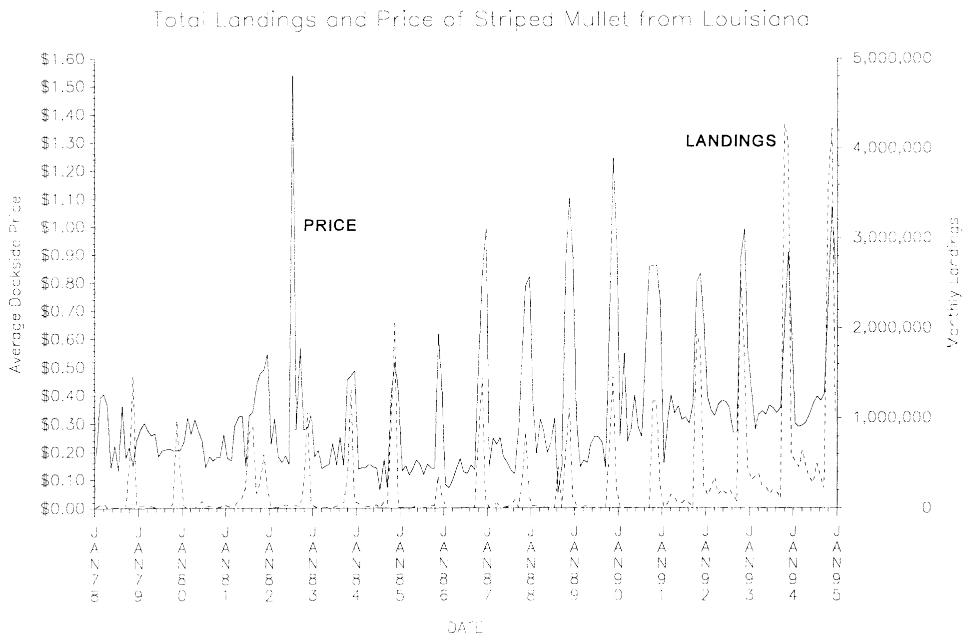


Figure 3.7. Landings (dashed line) and average monthly price per pound (solid line). Prices adjusted to value in 1994 dollars using CPI index.

4.0 RESEARCH NEEDS

4.1 Fishery-independent Data

There is some information to suggest that growth rates and sizes of mullet available to the fishery differ in various parts of the State. Identification of these variations could allow establishment of local regulations which could increase yield in the fishery and help distribute output from the fishery geographically. In other areas of the Gulf Coast, harvest of mullet outside of the roe season has utilized significantly smaller mesh nets. Since the species is abundant throughout the Gulf, if significant movement of juvenile and adult mullet is present, these fisheries could affect the availability of striped mullet to Louisiana fishermen.

Estimation of migration rates of juveniles and adults through tagging or other means would assist in estimating the independence of yield between fisheries with differing regulations. Theoretical or field studies analyzing larval drift could help to delineate regional recruitment effects for the species.

4.2 Fishery-dependent Data

4.2.1 Biological

The existing Louisiana fishery is predominantly a fishery for roe mullet during the fall of the year. This fishery predominantly uses a gill net of 3¾ - 4 inch mesh. The mullet at this time of year has a larger girth than at other times of the year. There is an increasing fishery using 3½ to 3¾ inch mesh gill nets outside the roe season. The ages harvested by this fishery are not known at this time. Evaluation of the age distribution of this fishery will be necessary before the impact of this fishery on the roe season fishery could be quantified. A consistent fishery-dependent monitoring program collecting information on gears, ages, and sexes harvested would allow much more quantitative information on allowable harvest.

4.2.2. Social and Economic

Social and economic information is needed on participants of the mullet fishery. Information on other fisheries that these mullet fishers participate in, processing and marketing costs, investment, operating, and harvesting costs, could help identify the health of the industry and impacts of regulatory changes on participants in the mullet fisheries.

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