Overview of Mark-recovery Studies on Adult and Juvenile Atlantic Menhaden, *Brevoortia tyrannus*, and Gulf Menhaden, *B. patronus*

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Introduction

Mark-recapture programs conducted by the Beaufort Laboratory of the NMFS Southeast Fisheries Science Center have played an important role in the determination of migratory habits, stock structure, and the estimation of mortality rates for Atlantic menhaden, *Brevoortia tyrannus*, and Gulf menhaden, *B. patronus*. Adult Atlantic menhaden were marked and released on the fishing grounds from 1966 through 1969 (Dryfoos et al., 1973), while adult Gulf menhaden were tagged and released from 1969 through 1971 (Pristas et al., 1976). Large numbers of juvenile (young-of-the-year) menhaden were captured, marked, and released in U.S. coastal estuaries on the Gulf of Mexico coast (Kroger and Pristas, 1975; Ahrenholz, 1981) and on the Atlantic coast (Kroger and Guthrie, 1973), with emphasis placed on determining recruitment patterns of menhaden on the basis of estuarine origin.

ABSTRACT—Extensive mark-recapture studies using internal ferromagnetic tags have been conducted on Atlantic menhaden, Brevoortia tyrannus, *and Gulf menhaden,* B. patronus. *From 1966 through 1969, 1,066,357 adult Atlantic menhaden were tagged; subsequently, from 1970 through 1987, 428,272 juveniles of this species were tagged. Similarly, from 1969 through 1971, 75,673 adult Gulf menhaden were tagged; concurrently from 1970 through 1985, 236,936 juveniles were tagged and released. This report provides an overview of the history of the tagging program, methodologies for both release and recovery activities, a summary of release areas and number of fish tagged within each area, and a review of assumptions necessary for the analysis of this type of mark-recovery data. The resulting data sets have proven to be highly useful for a variety of analyses ranging from determination of migratory patterns and population structure to estimating mortality rates. The relatively wide range of acceptance of tagging results by laymen, industry, and analysts alike have made these data extremely useful for management-oriented analyses.*

Internal, ferromagnetic, stainless steel tags were successfully used to tag both adult and juvenile menhaden. Mark-recapture studies using external marks requiring visual detection are considered impractical because commercial landings by an individual menhaden purse-seine vessel may range from 100,000 to 2,000,000 fish which are loaded and unloaded by fish pumps. Moreover, at least 95% of the menhaden landings on both the Atlantic and Gulf coasts are for reduction to fish meal, and estimates of numbers of fish landed range into the billions.

This paper provides an overview of the NMFS menhaden tagging program, summarizes when, where, and how many fish were released, and introduces analytical adjustments required for analysis of the internal, ferromagnetic mark-recovery data.

Brief History of the Tag

Development of an internal (body cavity) tag is credited to Robert A. Nesbit, who in 1931 internally marked weakfish, *Cynoscion regalis*, with a thin strip of colored celluloid (Rounsefell and Everhardt, 1966). In 1932, Rounsefell and Dahlgren (1933) developed internal magnetic tags to mark Pacific herring, *Clupea pallasii*. The early tags were pure nickel; later, nickel-plated steel was used. This modification greatly increased the recoverability of the tags on magnets (Dahlgren, 1936). In addition to herrings, these tags were also used in extensive marking programs on Pacific sardine, *Sardinops caerulea*, from 1935 through 1942 (Hart, 1943; Clark and Janssen, 1945). Experimental programs using internal tags to mark Norwegian spring spawning herring were conducted in Europe in 1948 (Dragesund and Jakobsson, 1963). Jakobsson (1970) appropriately commented regarding internal magnetic tags: "The development of this magnetic body cavity tag heralded a breakthrough in the tagging of herring and several other pelagic fish which are bulk-handled and sold for reduction in fish meal plants."

After a series of marking experiments in 1961 and 1962 which compared two sizes of nickel plated steel tags similar to those used in the Pacific sardine (Janssen and Alpin, 1945) and Pacific herring (Dahlgren, 1936) and stainless steel tags similar to those used for tagging Atlantic herring in Norway (Dragesund and Hognestad, 1960), Carlson and Reintjes (1972) concluded that the stainless steel tag was the most suitable for menhaden. Extensive testing (Carlson and Reintjes, 1972; Kroger and Dryfoos, 1972) indicated that smooth-edged stainless steel tags were preferable to rough-edged nickel-plated steel tags for menhaden. The NMFS menhaden tagging program adopted a large stainless steel tag ($14.0 \times 3.0 \times 0.5$ mm) for adult menhaden and a small stainless steel tag ($7.0 \times 2.5 \times 0.4$ mm) for juvenile menhaden (Dryfoos et al., 1973) (Fig. 1). After 1974, both large and small tags were used to tag juveniles. Each large tag is unique, identifiable with a prefixed letter and five digits. The small tags, however, are identifiable in lots of 100 with either three digits, a letter and two digits, or two letters and one digit.

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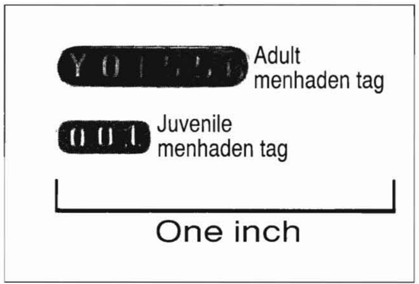

Figure 1.—Large (adult) and small (juvenile) ferromagnetic menhaden tags.

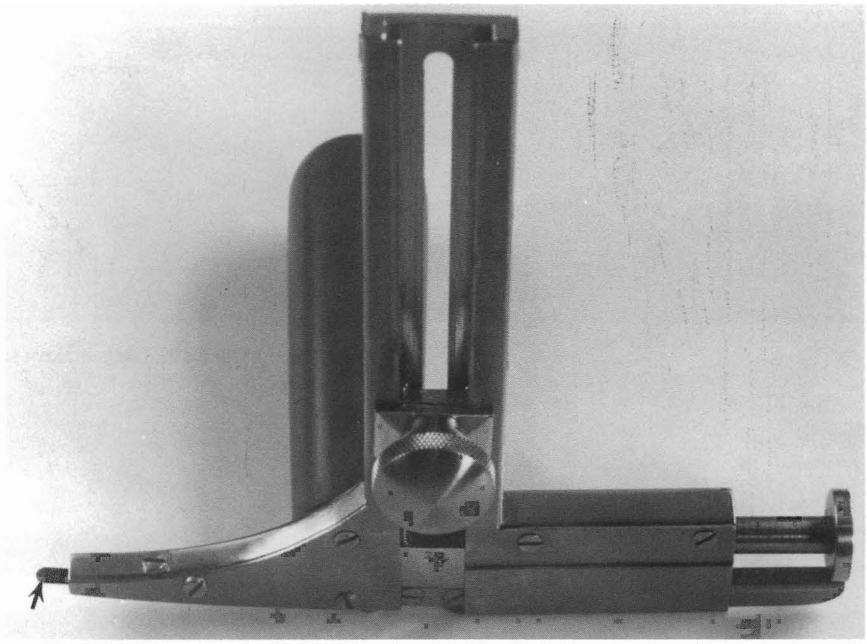

Figure 2.—Typical tagging gun used in menhaden mark-recovery studies. Note tag projecting from barrel to the left.

Tagging Procedures

Considerable experimentation was conducted on application methods (angle and area of injection into the body cavity), treatment of tags (antibiotics and disinfectants), and equipment used for the injection (scalpel-forceps or tagging gun). Kroger and Dryfoos (1972) concluded that a compromise between minimizing shedding and mortality was obtained by injecting the large tag through the body cavity wall in an anterior direction, at a site slightly posterior to the pelvic fin and up about one-third of the body depth (= regular method). The best results for the small tag were obtained by injecting the tag posteriorly from a site just below and behind the insertion of the pectoral fin (= pectoral method). Although subject to variation among individual taggers (Kroger et al., 1974b), the regular method has been used for tagging adult menhaden. The pectoral method was employed to tag juveniles (whether small or large tags were used), with the exception of a series of experimental releases in 1972 where tags were injected into the air bladders of juvenile Atlantic and Gulf menhaden (Kroger et al., 1974b).

With respect to treating tags with disinfectants and antibiotics, Kroger and Dryfoos (1972) reported that lower mortality rates of fish injected with treated tags were offset by higher shedding rates of treated tags. Hence, the use of untreated tags was recommended.

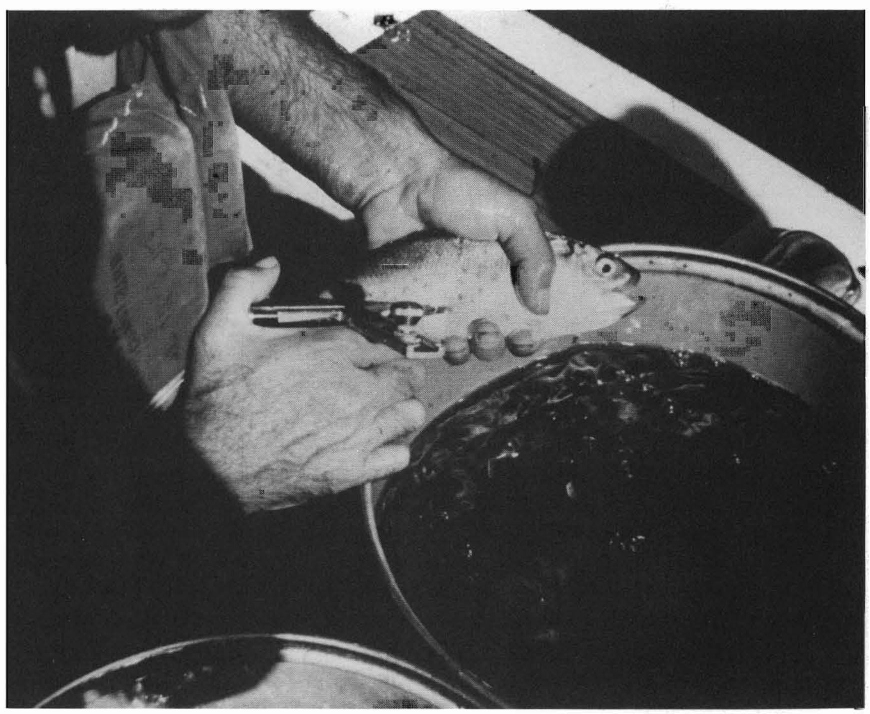

Figure 3.—A tag is injected into an adult menhaden.

When experimentally applying tags with the scalpel-forceps method, a small incision was made with the scalpel at the appropriate anatomical site, and the tag was inserted into the body cavity with the forceps. With the tagging guns (which hold about 100 tags), the tags extend slightly beyond the tip of the gun barrel and the projecting tag itself is used to make the incision (Fig. 2). The tag is then pushed into the body cavity by both the remaining tags in the barrel and the plunger (Fig. 3). The penetration depth

Figure 4.—NMFS purse-seine boats make a set.

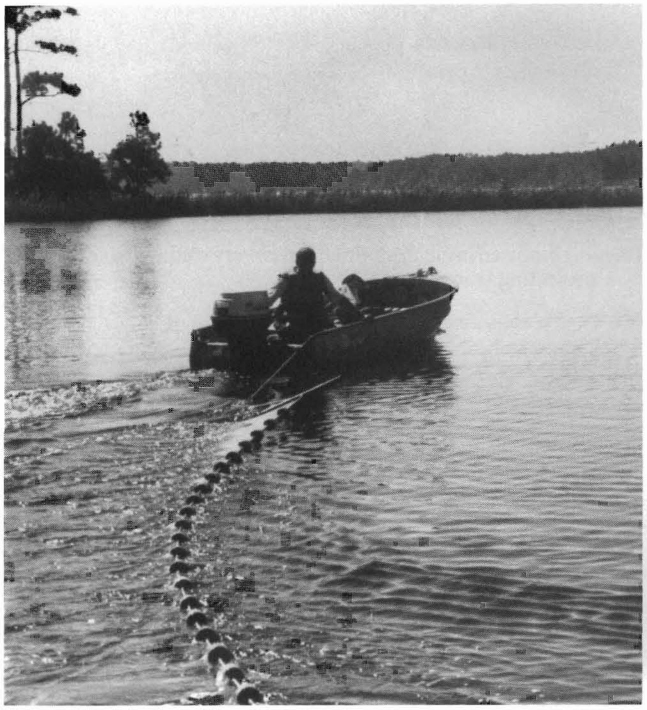

Figure 5.—Beginning a haul-seine sweep to capture juvenile menhaden.

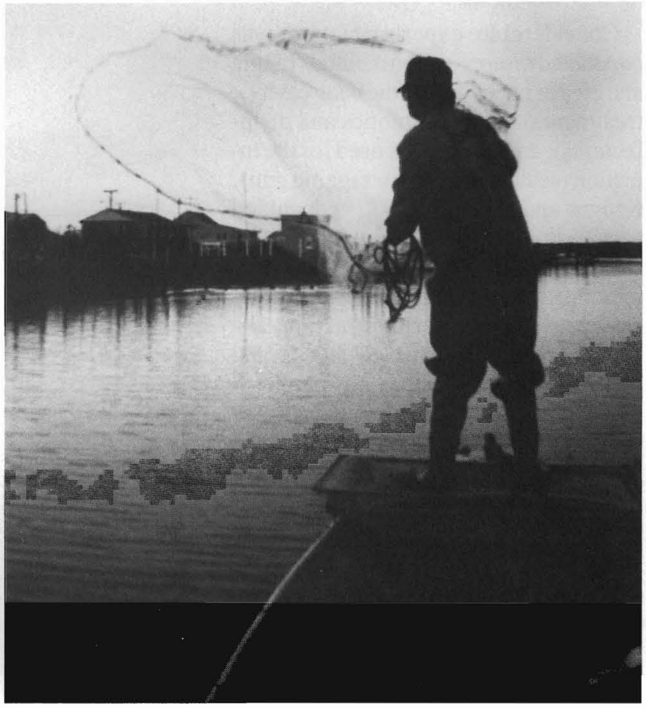

Figure 6.—Cast netting juvenile menhaden in an estuary.

is determined by the distance the tags projected from the barrel tip. The tagging guns were used because they were faster and safer than the scalpel and forceps for injecting tags. An early problem with high rates of tag shedding using the tagging guns was greatly reduced by employing guns with shorter barrels (hence greater projection of tags and deeper body penetration) (Kroger and Dryfoos, 1972).

Menhaden were obtained for field tagging by a variety of methods. Adult Atlantic menhaden were obtained from commercial purse-seine and pound-net catches, as well as off-season catches by NMFS haul seines, pound nets, and purse seines (Dryfoos et al., 1973; Pristas and Willis, 1973; Levi, 1981) (Fig. 4). Adult Gulf menhaden were obtained from commercial purse-seine catches (Pristas et al., 1976). During the earlier years of the tagging program, juvenile Atlantic menhaden were obtained by haul seining (Fig. 5), and juvenile Gulf menhaden by two-boat surface trawls (Ahrenholz et al., 1989). Since 1983, however, juveniles of both species have been captured with cast nets (Fig. 6).

Recovery Procedure

Tags that entered a menhaden reduction plant were recovered by powerful magnets installed at strategic points along the processing system. Some of the magnets had been installed earlier by the companies to remove stray pieces of metal from the fish scrap; additional magnets were provided by the NMFS and installed by plant personnel. Three types of industrial magnets were used: Plate, grate (or drawer) tubular, and rotating grate (Fig. 7). Magnets located adjacent the meal dryer and along the conveyor system to the scrap shed (primary magnets) normally recovered tags from fish within a few days of landing. Magnets located in the scrap storage shed and meal grinding area (secondary magnets) recovered tags from landings made weeks or months earlier (Fig. 8).

The magnets were cleaned at daily to several day intervals, depending on the processing activities within the plant (Fig. 9). Separation of tags from the material scraped from the magnets, a mixture of fish scrap and chunks of metal, required several steps. The collected mixture was spread over a flat surface and the metal concentrated and removed from the fish scrap with a magnetic sweeper (Fig. 10). The concentrated metal was further sorted with sieves. The reduced mixture containing the tags and minute metal particles was then sorted by hand over a contrasting background (Parker, 1973).

An electronic detector-recovery system was successfully developed and used during the summer of 1967 (Parker, 1972). This system provided for the recovery of whole tagged fish. These recoveries were used to validate annulus formation on scales for Atlantic menhaden, examine tagging wounds for rates of healing, and determine the best site on the body of the menhaden for tag incision. However, the system was too costly and time consuming for routine tag recovery operations.

Summary of Tag Releases

Initially, the goals of the tagging program focused on determining migratory habits, stock structure, and survival rates for the Atlantic menhaden population (Dryfoos et al., 1973). The U.S. Atlantic coast was divided into five tagging areas (Fig. 11). These areas were, for all practical purposes, the same (but not identical) as the currently recognized fishing areas (Ahrenholz et al., 1987), except the area south of the Virginia-North Carolina border was divided into two areas (Coston, 1971; Dryfoos et al., 1973). Tagging within each area was conducted during most of the seasonal periods when menhaden were present. From 1966 to 1969, more than 1 million

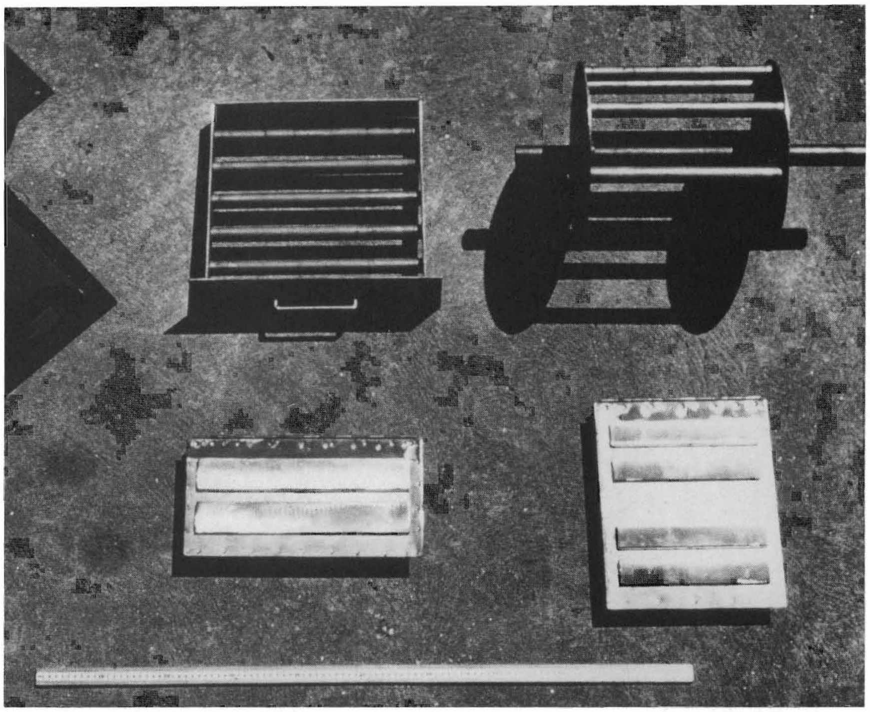

Figure 7.—Grate, rotating grate, and two kinds of plate magnets used to recover ferromagnetic fish tags from fish scrap.

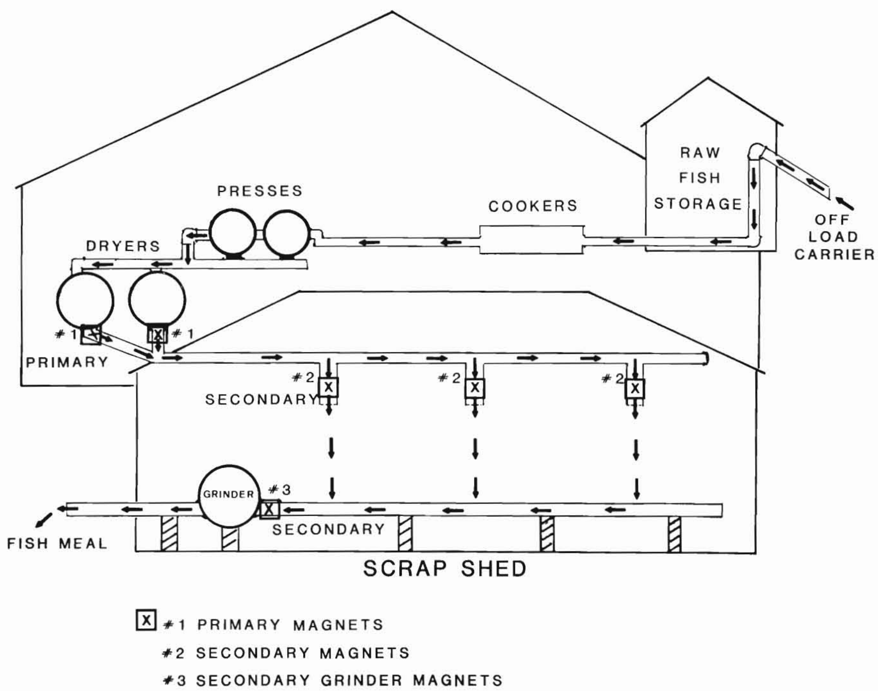

Figure 8.—Diagrammatic representation of a menhaden reduction plant showing magnet locations (X's) and type designation (see text).

Figure 9.—Plate magnet being cleaned.

Figure 10.—Sweeper magnet used to extract tags from magnet scrapings.

adult fish were marked and released (Table 1).

Tagging efforts were shifted to adult Gulf menhaden in 1969. Emphasis was placed on determining if any extensive eastern or western movement took place within or between fishing seasons (Pristas et al., 1976). Tagging was conducted in three tagging areas (Fig. 12). During this study over 75,000 adult Gulf menhaden were tagged (Table 2).

Tagging of prerecruit juvenile menhaden in estuarine systems began on the Atlantic and Gulf coasts in 1970, but was preceded by some feasibility tagging activity in the New England area in 1969 (Kroger et al., 1971). The objectives of the juvenile studies were to delineate movement and recruitment patterns on

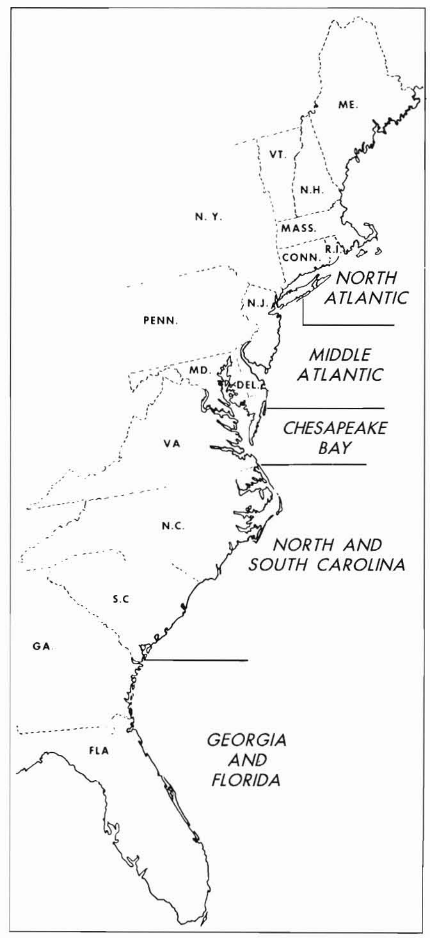

Figure 11.—Atlantic coast fishing areas and tag release areas for Atlantic menhaden.

Table 1.—Total releases of adult Atlantic menhaden marked with internal, ferromagnetic tags, by area and year, on the U.S. Atlantic coast (from Coston, 1971).

Year	Area					Totals
	North Atlantic	Middle Atlantic	Chesapeake Bay	N. and S. Carolina	Georgia and Florida	
1966	0	0	0	88,898	0	88,898
1967	2,093	13,660	100,128	159,077	95,832	370,790
1968	2,370	21,789	132,596	109,120	118,819	384,694
1969	8,468	700	75,581	29,076	108,150	221,975
Totals	12,931	36,149	308,305	386,171	322,801	1,066,357

Table 2.—Total releases of adult Gulf menhaden marked with internal ferromagnetic tags, by area and year, on the U.S. Gulf of Mexico coast (from Pristas et al., 1976).

Year	Area			Totals
	Western	Central	Eastern	
1969	11,198	5,799	18,101	35,098
1970	9,100	5,100	3,575	17,775
1971	7,400	5,200	10,200	22,800
Totals	27,698	16,099	31,876	75,673

Table 3.—Total releases of juvenile Atlantic menhaden marked with internal ferromagnetic tags, by state and year, on the U.S. Atlantic coast.

Year	State												Totals
	Mass.	R.I.	Conn.	N.Y	N.J.	Del.	Md.	Va.	N.C.	S.C.	Ga.	Fla.	
1970	2,600	1,200	48	2,261	347	900	1,351	3,300	5,142	1,400	1,400	1,200	21,149
1971	3,000	2,894	1,100	3,500	3,500	2,400	2,300	4,500	5,764	2,700	453	1,000	33,111
1972	1,000	1,000	3,000	4,500	975	0	1,000	3,000	4,075	185	0	0	18,735
1973	5,000	4,000	0	0	0	1,069	1,500	3,100	3,033	0	0	0	17,702
1974	1,000	0	0	2,000	3,599	4,994	6,198	7,893	9,900	0	0	200	35,784
1975	0	0	0	0	0	2,000	5,200	6,695	1,000	0	0	0	14,895
1976	0	0	0	3,882	1,799	3,099	4,000	3,987	9,182	1,000	0	0	26,949
1977	0	0	0	0	400	4,000	4,300	6,000	9,000	3,000	0	0	26,700
1978	3,700	0	0	1,600	0	3,000	4,400	6,000	3,800	300	0	500	23,300
1979	0	0	0	0	0	3,400	5,600	8,500	5,500	0	0	0	23,000
1980	2,000	0	0	0	0	4,600	4,200	2,000	6,000	0	0	700	19,500
1981	0	0	0	1,800	0	4,200	6,700	4,000	5,600	1,000	0	0	23,300
1982	2,000	0	0	2,000	1,997	4,000	2,000	5,999	4,000	2,000	1,264	0	25,260
1983	0	0	0	0	2,999	3,994	7,193	3,898	8,100	0	0	0	26,184
1984	898	0	0	1,199	2,789	2,365	5,572	6,592	7,612	3,238	2,000	2,799	35,064
1985	0	0	0	3,000	1,000	1,200	6,399	6,198	11,939	1,852	1,061	2,000	34,649
1986	0	0	0	0	0	0	0	5,398	6,592	0	0	0	11,990
1987	0	0	0	0	0	0	0	7,000	4,000	0	0	0	11,000
Totals	21,198	9,094	4,148	25,742	19,405	45,221	67,913	94,060	110,239	16,675	6,178	8,399	428,272

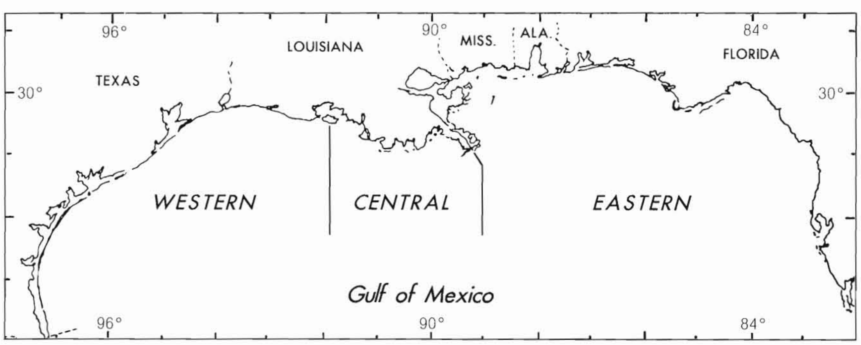

Figure 12.—Gulf of Mexico coast fishing areas and tag release areas for Gulf menhaden.

the basis of estuarine origin (Kroger and Guthrie, 1973). It was believed that with an improved knowledge of area specific recruitment rates coupled with area specific juvenile abundance estimates from another study (Ahrenholz et al., 1989), estimates of area-specific contributions to total recruitment could be obtained. Hence, the necessary parameters to estimate subsequent fishery recruitment and yield would be available (Kroger and Pristas, 1975). The number of tagged fish released are summarized by state for each coast (Tables 3, 4).

Refining the Mark-Recovery Data

Mark-recovery data in general require one or more types of quantitative adjustments to satisfy assumptions necessary for some analytical procedures, especially those that estimate population mortality rates or abundance. The internal ferromagnetic mark-recapture data share many analytical problems with external, visually detected, and voluntarily reported data, and have some more or less unique characteristics as well. The nature of the errors that can occur in parameter estimation when assumptions are not met are discussed in depth by Ricker (1975). Some of the errors are discussed with respect to mortality estimation for Gulf menhaden in Ahrenholz (1981).

Adjustments to Numbers Released

Tagging Mortality-Tag Shedding (Short Term)

Soon after tagging, some fish may die as a result of handling or tagging, or may simply shed their tag through the unhealed incision. Errors may result in some population parameter estimates derived from the recovery data if the number released is not reduced with an accurate estimate of tagging mortality. The NMFS conducted a series of marking-survival experiments (Kroger and Dryfoos, 1972), from which several applicable estimates of tagging loss (dead fish and shed tags) were obtained for juvenile and adult Atlantic menhaden. Estimates of loss for adult fish tagged with the large tag were 10 and 24% (experiments 3 and 4). Estimates of losses of 37% were obtained for juveniles (mean FL = 83 mm) tagged with the small tag and 54% for those tagged with the large

Table 4.—Total releases of juvenile Gulf menhaden marked with internal ferromagnetic tags, by state and year, on the U.S. Gulf coast.

Year	State					Totals
	Tex.	La.	Miss.	Ala.	Fla.	
1970	4,090	3,400	622	1,199	1,147	10,458
1971	4,463	5,749	1,099	2,500	1,600	15,411
1972	4,939	5,040	1,100	0	2,500	13,579
1973	0	0	0	0	4,400	4,400
1974	3,200	4,200	1,700	0	1,861	10,961
1975	0	0	0	0	0	0
1976	3,000	9,000	2,000	2,000	3,600	19,600
1977	7,000	6,900	0	0	9,600	23,500
1978	6,000	5,600	2,000	1,400	4,000	19,000
1979	4,000	0	0	0	0	4,000
1980	7,790	4,200	4,500	0	0	16,490
1981	4,978	4,000	2,000	2,000	4,800	17,778
1982	8,000	6,000	2,300	2,500	2,400	21,200
1983	7,579	1,792	2,986	1,000	2,000	15,357
1984	10,287	5,914	1,400	2,099	2,000	21,700
1985	10,471	6,000	2,000	2,000	3,031	23,502
Totals	85,797	67,795	23,707	16,698	42,939	236,936

tag (experiment 12). In a study conducted by the Louisiana Wildlife and Fisheries Commission (Byars, 1981) to estimate tagging loss among juvenile Gulf menhaden, an estimate of 30% loss was obtained for fish tagged with the small tag, and 35% for those (>90 mm fork length) tagged with the large tag. No studies of tagging mortality have been conducted with adult Gulf menhaden, but results should be similar to those obtained for the Atlantic menhaden.

Differential Mortality-Tag Shedding (Long Term)

Errors may also result when tags are shed at a more or less continuous rate over the lifespan of the fish, or if there is a differentially greater long-term mortality for tagged fish than for untagged fish. Studies to evaluate this type of potential error have not been conducted for either Atlantic or Gulf menhaden. However, losses from shedding should be minimal after the incision has healed (a few weeks as reported by Kroger and Dryfoos, 1972).

Differential Tagger Induced Mortality

Different taggers may induce a differential rate of short-term tagging mortality. Since there have been extensive field tagging programs with two or more taggers working side-by-side, this additional potential source of error can easily be evaluated. Although the short-term loss rate is assumed to be constant among taggers, occasionally differences are great enough to require special treatment. Adjustments for differential tagging mortality among taggers were made to some of the adult Gulf menhaden releases (Ahrenholz, 1981).

Adjustments to Numbers Recovered

Not all of the tags that enter a plant are recovered by the series of magnets. To estimate the tag recovery efficiency for a plant, test batches of 100 tagged dead fish were added to the plant landings at regular intervals during the fishing season. The number of test tag batches released at a given plant ranged from 1 to 30 during a fishing season, depending on the length of time the plant operated. Recovery efficiencies (number recovered divided by the number placed into the system) have been calculated for primary, or both primary and secondary magnets, depending on the intended analytical application. Estimates of the actual numbers of field-released tags which entered a plant are obtained by multiplying the number actually recovered by the inverse of the recovery efficiency.

Occasionally tags became lodged in the plant machinery and were recovered one or more seasons after the tags entered the plant. This source of error results in overestimates of total numbers of tags recovered for subsequent years. This type of recovery, although not uncommon, occurred at low enough rates that adjustments were not required for the earlier Gulf menhaden mark-recovery mortality analyses (Ahrenholz, 1981). Adjustments for lodged tags can, however, be made where necessary.

Behavioral Limitations

The determination of migratory patterns does not require data refinement. Unadjusted, primary recoveries are adequate for examining most migratory hypotheses considered. Migratory patterns that could be influenced by the fish's body size should still be reflective of the population as a whole, as the presence of the internal tag does not appear to affect growth rate (Kroger et al., 1974a). The two types of tagging studies (adults tagged on the fishing grounds and juveniles tagged in estuarine nursery areas) have proved to be complementary when examining for adherence to assumptions required for analytical procedures to estimate mortalities and abundances.

Program Accomplishments

The menhaden tagging programs and their resultant data sets have made major contributions to our knowledge of the biology and population dynamics of both the Atlantic and Gulf menhaden. Initially, returns from the adult program provided documentation for hypotheses of stock structure and migratory patterns (Ahrenholz, 1991). Estimates of *M* were subsequently obtained for each species from their mark-recapture data (Dryfoos et al., 1973; Ahrenholz, 1981; Reish et al., 1985). Data from the juvenile tagging programs permitted the determination of general recruitment patterns from estuarine nursery areas to the fishery. These collective results provided information necessary to construct and support stock assessment analyses for each species (Nelson and Ahrenholz, 1986; Ahrenholz et al., 1987).

The mark-recapture program has provided direct, highly visible answers to stock structure and recruitment questions that have been understandable and acceptable to many laymen and industry members. The characteristically high information content of tagging data have made these results desireable for use by analysts as well. Because of this high level of credibility and information, these data are extremely useful for supporting management-oriented analyses.

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