has been criticized from a statistical point of view because c/f and f are obviously correlated. A measure of the magnitude of this correlation is clearly implied by (3) or (4).

Finally we should point out that our allusion to considering these indices as expressing relation among organisms was not careless because it seems to us that predator-prey relationships might be further elucidated through examination of concentration indices. For example, it would be interesting to relate the catch (in number of prey organisms) per predator stomach to the number of predator stomachs. This, however, is just a special case of the wealth of fishery-fish interaction models which could be applied to the prey-predator situation.

Acknowledgments

We would like to thank D. G. Chapman, Director, Center for Quantitative Science, University of Washington, for reading this note and J. Joseph of the Inter-American Tropical Tuna Commission for stimulating our writing this note.

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SUITABILITY OF INTERNAL TAGS FOR ATLANTIC MENHADEN

Investigations of the Atlantic menhaden resource depend primarily on sampling and analyses of the commercial landings and studies of menhaden biology and ecology. Results of these studies give a broad understanding of the resource but sometimes lack the reliability of more direct evidence. Tagging and recovery of menhaden help provide the reliable information on movements, population size, availability, mortality, and growth rates required to better understand the resource.

The methods by which menhaden are caught, handled, and processed determine some of the requirements for tagging. Menhaden are captured in purse seines and are transferred by suction pumps from the nets to the vessels and from the vessels to the reduction plants. In the plant, the fish are cooked, pressed, dried, and ground into meal. From the time the fish are caught until they are processed into oil and meal, there is little opportunity to handle or see an individual menhaden. Consequently tags or tagged fish must be recovered by mechanical or electronic means. Internal ferromagnetic tags that are mechanically or electronically recoverable have been developed for Atlantic and Pacific herring, Pacific sardine, and anchoveta.

We conducted a series of experiments at Beaufort, N.C., to find a mark suitable for Atlantic menhaden. In 1959 we tagged young menhaden with a nickel-plated, steel tag, (Type A in Figure 1). The tagged menhaden died within a week, terminating the experiment. During 1960 we attempted to mark menhaden with fluorescent pigments and to develop a photoelectric detector. The occurrence of natural fluorescence in menhaden and other marine organisms made discrimination of marked fish impractical (Reintjes, 1963). In 1961-62 we resumed tests with internal tags to select a type suitable for menhaden and to demonstrate its recovery with magnets in a menhaden reduction plant.

Tagging Experiments and Tag Selection

We selected four ferromagnetic tags (Table 1 and Figure 1) for insertion in young Atlantic

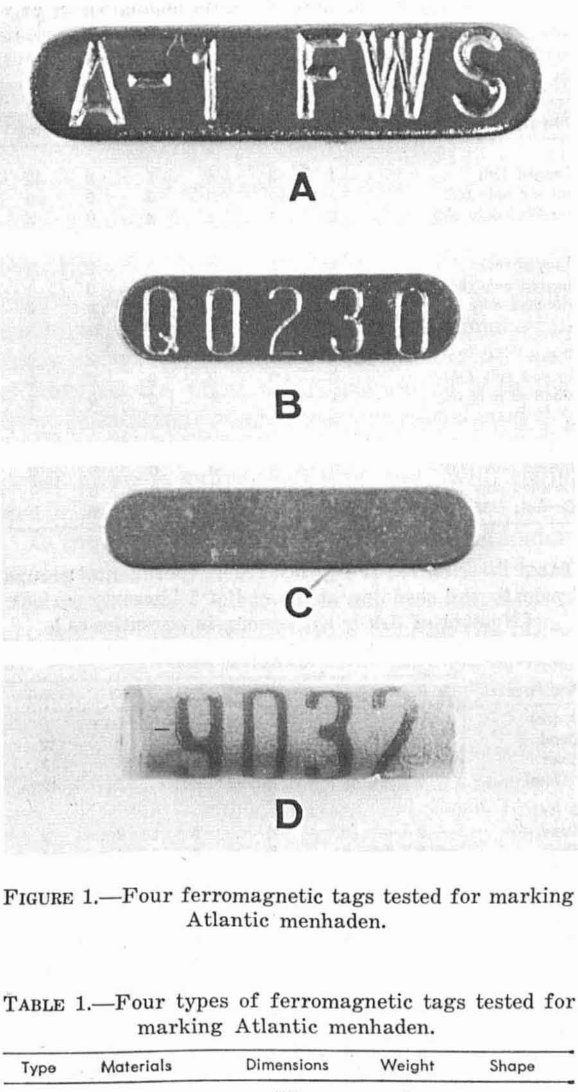

FIGURE 1.—Four ferromagnetic tags tested for marking Atlantic menhaden.

TABLE 1.—Four types of ferromagnetic tags tested for marking Atlantic menhaden.

Type	Materials	Dimensions	Weight	Shape
		mm	*g*	
A	Nickel-plated steel	19 × 4 × 1.5	0.89	rectangular
B	Nickel-plated steel	12.5 × 3 × 0.6	0.19	rectangular
C	Stainless steel	14 × 2.5 × 0.3	0.15	rectangular
D	Plastic capsule	12 × 3	0.63	cylindrical

menhaden. Type A tags were similar to tags used for Pacific herring (Rounsefell and Dahlgren, 1933) except were twice as thick and had sharp edges. Type B tags, also with sharp edges, were similar to tags used for California sardine (Janssen and Aplin, 1945), anchoveta (Bayliff and Klima, 1962) and anchovy (Vrooman, Paloma, and Jordán, 1966; Haugen, Messersmith, and Wickwire, 1969; Wood and Collins, 1969). Type C tags were similar to tags used for small Atlantic herring in Norway (Dragesund and Hognestad, 1960) and had smooth edges. Type D tags, used for Pacific herring (Wilimovsky, 1963), were dummy radioactive tags that consisted of a gold-plated iron core encased in plastic.

Young menhaden, 115-168 mm fork length, were caught nearby and held in concrete tanks at the laboratory for several weeks prior to the tagging trials. They were fed a homogenized slurry of fish meal and raw hard clams throughout confinement. Test lots of menhaden for each tag type consisted of equal numbers of tagged, incised but not tagged, and handled but not incised or tagged. A fifth lot of fish, not handled, was used as controls.

At tagging, menhaden were transferred to a tank of seawater containing 50 ppm tricaine methanesulfonate (MS-222) until they lost equilibrium. With a scalpel a technician made a small incision on the right side below the midline of the body about midway between the tip of the pectoral fin and the insertion of the pelvic fins to minimize disturbance of viscera. He inserted metal tag Type A, B, or C, into the body with forceps (Figure 2) and Type D through a hollow needle.

The tags and instruments were dipped in a mixture of penicillin G and liquid terramycin. These antibiotics were also added to the anesthetizing tank. All fish were hand-held for 20 sec whether they were tagged, incised, or only handled.

Dead fish and shed tags were removed daily. The dead were measured, weighed, and examined for abnormalities by X-ray and by dissection. The study was concluded in January 1962 when the temperature in the tanks dropped overnight from 3.0° to 0.4°C and most of the fish died. During the preceding 10 weeks the water had cooled gradually from 22°C without killing the fish. Salinity, during this period, ranged from 27 to 32‰.

The Norwegian herring tag, Type C, was the most suitable of the four tested. Tag D was not considered further for it cost ten times more than the metal tags, and we were not planning to use its radioactive capability.

The numbers of menhaden that died in each tagging experiment are shown in Table 2. Tag Type A caused the most deaths. The combined loss from dying and shedding are shown in Table 3. More menhaden tagged with Types A and B died or shed their tags than did those with Type C. From these trials, Type C was selected for menhaden tagging studies.

Menhaden that died during the experiment and those that survived until the end of the 10-week period were examined for an apparent cause of death. At the end of the 10-week period, all survivors had healed incisions that were faintly visible as slight depressions without scales. Recipients of Type A tags dying during the study had enlarged open wounds and some tags protruded. Types A and B tags found in dead fish or loose on the bottom of the tanks were corroded. The peritoneum did not heal in any incised fish. Muscles were discolored near Types A, B, and D tags, and the tags were imbedded in the mesenteries near the cardiac and pyloric stomachs. Types A and B tags usually were enveloped with tissue. Types C and D tags were better for they apparently caused less irritation.

We were unsuccessful in our attempts to tag smaller menhaden, 75 to 90 mm fork length, in

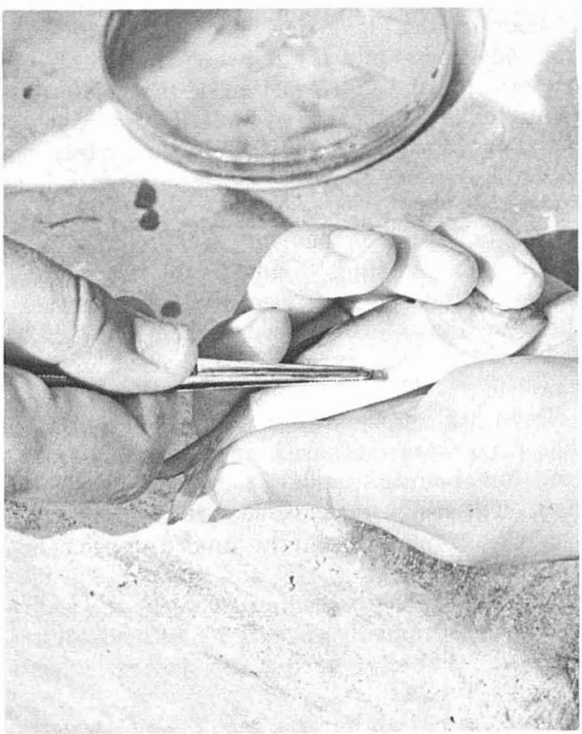

FIGURE 2.—Inserting a metal tag into the body cavity of young Atlantic menhaden.

TABLE 2.—Number of dead Atlantic menhaden in each tagging experiment at the end of 5 biweekly periods. [Number of fish in each lot in parentheses.]

Tag type	Number of weeks 2	4	6	8	10	Total
A						
Tagged (86)	1	3	6	2	0	12
Incised only (86)	1	1	0	0	0	2
Handled only (86)	0	1	1	0	0	2
B						
Tagged (86)	2	0	0	0	0	2
Incised only (86)	0	1	0	0	0	1
Handled only (86)	1	2	1	0	0	4
C						
Tagged (86)	1	1	0	0	0	2
Incised only (86)	0	0	0	0	0	0
Handled only (86)	1	1	0	0	0	2
D						
Tagged (33)	0	0	1	0	0	1
Incised only (33)	0	0	0	0	0	0
Handled only (83)	0	1	0	0	0	1
Controls (135)	2	1	0	0	0	3

TABLE 3.—Number of tags lost from experimental groups by death and shedding at the end of 5 biweekly periods. [Number of fish in each group in parentheses.]

Tag type	Number of weeks 2	4	6	8	10	Total
A (86)						
Dead	1	3	6	2	0	12
Shed	1	2	2	1	1	7
Total	2	5	8	3	1	19
B (86)						
Dead	2	0	0	0	0	2
Shed	8	2	0	2	2	14
Total	10	2	0	2	2	16
C (86)						
Dead	1	1	0	0	0	2
Shed	0	0	0	0	0	0
Total	1	1	0	0	0	2
D (33)						
Dead	0	0	1	0	0	1
Shed	0	0	0	1	1	2
Total	0	0	1	1	1	3

August 1962. We used Type C tags but nearly all fish died within 5 days irrespective of treatment. Water temperatures over 30°C were partly responsible for the deaths. No more small menhaden were tagged.

Tag Recovery Trials

We tested the effectiveness of magnets to collect Type C tags in the menhaden reduction plants. Magnets usually are installed in plant conveyor systems to protect the hammermills from stray ferrous metal that breaks off machinery in the plant or is brought in with the fish. Menhaden are cooked and pressed, and the presscake is dried in rotary driers. Most of the dried scrap is pulverized into meal with hammermills.

In the first trial we tagged 102 dead menhaden in the storage or raw box and recovered 60 tags. Nine tags were retrieved from the magnet located after the drier within 8 hr, and the other 51 were collected on a second magnet several days later when the dried scrap was ground into meal (Table 4).

TABLE 4.—Recoveries of 340 tags released in a menhaden reduction plant.

Location and method of release	Number released	Number recovered	Recovery location		
			Magnet after drier	Magnet before hammer-mill	Total
			%	%	%
Raw box, in fish	102	60	9	50	59
Raw box, in fish	38	26	5	63	68
Cooker input, loose	40	26	12	53	65
Press input, loose	40	35	10	78	88
Press output, loose	40	33	17	65	82
Drier output, loose	40	34	18	67	85
Shed floor, loose	40	34	0	85	85

In the second trial, 238 tags were placed in different locations throughout the plant. Thirty-eight were placed in dead fish in the raw box, and five lots of 40 tags each were scattered loosely in (1) cooker, (2) press input, (3) press output, (4) drier output, and (5) storage shed floor. The recoveries ranged from 65 to 88%. These results showed that recovery of tags was practical with magnets already installed in menhaden plants. We believe the recovery efficiency could be improved by installing additional magnets in the processing system.

We concluded from these preliminary experiments that Atlantic menhaden longer than 115 mm fork length could be tagged internally with a smooth piece of stainless steel and that the tags could be recovered on magnets in the reduction plants.

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