APPENDIX B.—MARKING EXPERIMENTS

In this section the data on experiments in marking mackerel will be given and their results discussed with special reference to the technique of the method.

Field experiments, begun prior to the inception of the comprehensive mackerel investigations,[1] soon revealed the difficulties in marking a species so active and so delicate as the mackerel, and subsequent endeavors sought to discover methods of marking that would be suited to the species. For convenience in reference, the experiments will be serially numbered and taken in approximately chronological order.

FIELD EXPERIMENTS

Experiment No. 1

In the spring and late fall of 1925 in the vicinity of Woods Hole, Mass., 696 mackerel were marked. The fish were caught in commercially operated pound nets, transferred to a live car, marked and released at the place they were caught. The tag used was a celluloid band commonly used in marking poultry. It consisted of a flat strip of celluloid molded in the form of a flat spiral of two complete turns forming a ring that was unwound, placed around the caudal peduncle and when released, resumed its original ring-shape surrounding the peduncle. The mackerel were measured to the nearest half inch before release. Returns from this experiment are given in table 25. Since the subsequent returns from individuals below and above 15¼ inches of length differed significantly, these sizes have been separated in the table. The individuals released August 24 to September 1 were all between 11 and 14 inches in length.

[1] These marking experiments took place under the auspices of the North American Council of Fishery Investigations in the United States and Canada. In the United States they began in June 1925, under the general direction of Henry B. Bigelow and the immediate supervision of William C. Schroeder. Late in that season supervision was transferred to O. E. Sette.

Table 25.—*Returns from 696 mackerel released in Buzzards Bay and Vineyard Sound, near Woods Hole, Mass., in 1925*

(EXPERIMENT NO. 1)

Time of recapture	June 8–17, under 15½ inches long (142 released)	June 8–17, over 15¼ inches long (415 released)	Aug. 24–Sept. 1 (139 released)
Local (area XXII S):			
0–4 days after release	1	2	3
5–9 days after release	1	1	
10–14 days after release		1	
14–19 days after release			1
20–24 days after release	1	1	
25–29 days after release	1		
30–39 days after release		1	
Total	4	6	4
Massachusetts Bay (area XXII E):			
July 11–20, 1925		3	
Sept. 12, 1925	1		
Oct. 7, 1925	1		
Total	2	3	
Lightship Grounds (area XXII O):			
July 13–20. 1925		2	
Rhode Island Shore (area XXII S):			
June 21–23, 1925	2	1	
July 2, 1925	1		
June 19, 1926		1	1
Oct. 19, 1926			1
Total	3	2	2
Western Long Island (area XXIII B):			
July 7, 1925	1		
Central Nova Scotia (area XXI M)		1	
Grand total	10	14	6

Experiment No. 2

During the summer and fall of 1925, at pound nets and weirs in the vicinity of Provincetown, Mass., 3,939 mackerel were marked. Procedure was the same as in experiment No. 1 except that the mackerel were transferred to a pocket of netting instead of a live car. The tag was identical to that used in experiment No. 1. The returns are given in table 26. Since relatively few (4 percent) of the Provincetown mackerel were above 15¼ inches in length, the sizes have not been separated in the table. However, there was a significant difference in the

percentage returns of the various sizes in this experiment. (See p. 350.)

TABLE 26.—*Returns from 3,939 mackerel released at Provincetown, Mass., during the summer and autumn of 1925*

(EXPERIMENT NO. 2)

Time and location of recapture	June 23–July 3 (949 released)	July 9–July 22 (1,294 released)	July 29–Aug. 5 (996 released)	Oct. 2–7 (700 released)	Total (3,939 released)
Southern Maine, area XXII D:					
Nov. 21, 1925	-------	1	-------	-------	1
Massachusetts Bay, area XXII E:					
0–4 days after release	28	57	55	29	169
5–9 days after release	16	4	3	-------	23
10–14 days after release	9	2	1	-------	12
15–19 days after release	2	1	-------	-------	3
20–24 days after release	2	-------	-------	-------	2
25–29 days after release	2	-------	-------	-------	2
30–59 days after release	3	-------	1	-------	4
60–89 days after release	2	1	-------	-------	3
90–120 days after release	2	-------	-------	-------	2
During first season, date uncertain	8	11	11	1	31
During second season—					
Aug. 2, 1926	-------	-------	1	-------	1
Aug. 28, 1926	-------	1	-------	-------	1
Sept. 8, 1926	-------	-------	-------	1	1
Total	74	77	72	31	254
Western side of South Channel, area XXII G: July 29 to Aug. 7, 1925	3	2	-------	-------	5
Southern Massachusetts, Area XXII R:					
June 8, 1925	1	-------	-------	-------	1
October 1926	1	-------	-------	-------	1
Total	2	-------	-------	-------	2
Rhode Island, Area XXII S:					
June 9, 1926	-------	-------	1	-------	1
Aug. 14, 1926	-------	1	1	-------	2
Total	-------	1	2	-------	3
Grand total	79	81	74	31	265

EXPERIMENT NO. 3

In Casco Bay, Maine, 930 individuals were tagged August 4 to 25, 1925. Of these, 249 were caught in floating traps, and the procedure was the same as in experiment No. 2. The remaining 35 were caught by purse seine, 10 miles southeast of Seguin Island, and presumably were tagged immediately upon being brailed to the deck of the vessel. Otherwise, procedure, as well as the tag used, was the same as in previous experiments. Only four returns resulted from the trap-caught mackerel: One was caught locally, August 6, 1925; another, 10 miles southeast of Block Island, October 19, 1925; the third, 3 miles southeast of Fire Island, N. Y., June 7, 1926; and the fourth, off Point Judith, Newport, R. I., August 6, 1926. Of the purse-seine-caught mackerel one was recaptured 15 miles southeast of Eastern Point Light, Gloucester, Mass., August 2, 1926.

EXPERIMENT NO. 4

To test the metal-strap tag of the type illustrated by Schroeder (1930, fig. 3), 90 individuals were tagged at Woods Hole, Mass. In this experiment the pound net was partially hauled to concentrate the mackerel which were dipped from the net, one at a time, tagged, and immediately returned to the water. The tag was the small size designated as No. 3 by its manufacturer, and it was attached at the base of the dorsal lobe of the caudal fin. Several tags were seen to have dropped off as the mackerel were returned to the water, and doubtless most of them did so later, for no returns resulted from this experiment, whereas other taggings of this size of mackerel at this season and at this place have yielded 13 percent returns. (If the stock at Woods Hole is such as to provide 13 percent returns with a suitable tag from a release of 90 individuals, there would be less than one chance in a thousand that no tags would be returned due to random causes alone.)

EXPERIMENT NO. 5

To see whether the mackerel approaching the coast in early spring in the southerly end of the range were on their way to more northerly waters, 400 were marked (with the same style of tag as used in experiment No. 1) in the offing of Delaware Bay (lat. 37°35′ W.; long. 74°35′–40′ N.) April 10, 11, and 15, 1926. The fish were caught by commercial purse-seine fishermen and were tagged immediately after the fish were brailed to the deck of the fishing vessel. Of course, only the liveliest of the mackerel were selected for tagging, but even with severe selection the fish suffered more injury from this method of fishing and handling than those that were caught in pound nets and handled differently. At least this appears to be the most reasonable explanation of the paucity of returns from this experiment from which only two were recovered. One was from the same grounds on the day following tagging, the other was taken off Chatham, Mass. (area XXII G) the following August.

EXPERIMENT NO. 6

To see whether better results might be obtained with an extremely light celluloid tag a special lot of tags was made of thin stock (0.025 inch thick) and with only one and a half turns. Thinking also that the bright cerise and yellow colors of the bands

previously used were likely to render their bearers more vulnerable to predators, the special bands were colored green. They were attached to 967 mackerel from pound nets in the vicinity of Woods Hole, Mass., July 15–27, 1927, using the procedure of experiment No. 2. A number of these mackerel were recaptured and released again shortly after the original tagging, so that the effective number released was 1,000. The releases and returns are given by sizes and by time-of-recapture groups in table 27. Returns from this experiment were so similar to those of experiment No. 2 that no substantial advantage of the modifications in the tag was indicated.

TABLE 27.—*Returns from mackerel tagged July 15–27, 1927, in the vicinity of Woods Hole, Mass.*

(EXPERIMENT No. 6)

Length when tagged, centimeters	Number tagged	Returns classified according to the number of days elapsed between release and recapture													
		0–4	5–9	10–14	15–19	20–24	25–29	30–34	55–59	60–69	70–79	80–89	90–99	Over 100	Sum
		Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
25.5	1														
26.5	3														
27.0	7														
27.5	6														
28.0	24	4													4
28.5	63	1	1		1								1		4
29.0	88	7	3	2		1									13
29.5	106	5	1	1								1			8
30.0	158	5	7	4		1				1			1	[1] 1	20
30.5	138	8	3	2	3	2	1		1	1	1				22
31.0	117	10	6	4	1							1			22
31.5	81	8	1	2										[2] 1	12
32.0	67	4	3						1						8
32.5	36	3	3		1										7
33.0	19	2													2
33.5	13		1					1							2
34.0	2														
34.5	1														
35.0	1		1												1
35.5	1														
36.0	7	2													2
36.5	8														
37.0	10														
37.5	12														
38.0	9														
38.5	2														
39.0	6	1													1
39.5	1														
40.0	3														
41.0	2														
44.5	1														
45.0	1														
45.5	1														
47.5	1														
49.5	2														
50.0	1														
Not measured	1				1										1
Total	1,000	60	30	15	7	4	1	1	2	2	1	2	2	2	129

[1] 101 days. [2] 359 days.

EXPERIMENT No. 7

Thinking that the attachment of tags to the rapidly moving caudal region of the mackerel was less desirable than to the less active forward parts, a modification of the strap tag was devised for attaching to the operculum. Higgins had found (unpublished notes) that No. 3 strap tags on the operculum of the mullet, *Mugil cephalus*, caused enlargement of the perforation made by the clinching point, presumably by rotation of the tag around its point of attachment. He suspected that the enlargement proceeded until it reached the margin of the operculum thus allowing the tag to drop off. This modified tag was three times as broad as the standard tag and had two clinching points to prevent rotation. In September 1926, tags of this type were attached to 396 individuals caught by purse seines with the same procedure as in experiment 5. No returns resulted and although this might have been owing to the rough treatment inevitable with purse-seine-caught mackerel, it is more likely that the lack of returns was due to loss of tags from the operculum, for 20 bull's-eye mackerel, *Pneumatophorus grex*, marked with this style of tag and held in a livecar at Woods Hole lost their tags within 14 days. The loss appeared due to necrosis of the tissue.

INFLUENCE OF TAGGING ON THE MORTALITY OF MACKEREL

The diminution in returns of the mackerel released in experiments 2 and 6 during the first month after release is of interest in providing field evidence on the merits of the methods used in tagging mackerel in 1925 and 1927. In experiment 2 (table 26) the returns from mackerel released during June 23 to July 3 diminished at an average rate of 54 percent per 5 days during the first three successive 5-day periods. The returns from those released during subsequent periods in the same experiment diminished at an even higher rate.[2] In experiment 6 (table 27) the returns declined at a nearly uniform rate of 50 percent in the first four successive 5-day periods. Such declines might be due to (1) the early loss of tags from the fish; (2) rapid dispersal of the fish from the point of release to areas in which less fishing was done; (3) early mortality of the fish tagged.

That some tags were lost from the mackerel is probable. In tables 28 and 29 are given the returns of fish by size groups, demonstrating that the maximum returns of the mackerel tagged in 1925 were of the 14- to 15-inch size groups, and of those tagged in 1927, the best returns were of the 30.5 to 32.0 centimeters (12 to 12½ inches). In each case the tags were chosen of a size to fit the prevailing size of mackerel and it is seen that the maximum returns in each case were close to modal length of the mackerel released. Below these sizes the returns were appreciably poorer, and we consider it probable that a portion of the tags placed on the smaller mackerel slipped off over the caudal fin. If the percentage returns from the groups of maximum return are indicative of the returns to be expected when there is no loss of tags, the loss of tags from mackerel 8 to 12 inches may be estimated at 60 percent, and the loss from mackerel 12½ to 13½ inches, at 36 percent in

[2] This higher rate may reflect the care with which the mackerel were handled. Those tagged during June 23 to July 3 were under the immediate supervision of a trained biologist. Subsequent to that date the tagging was done by an untrained crew, without immediate supervision.

TABLE 28.—*Relation between size of mackerel tagged and percentage of returns in 3 groups of mackerel tagged at Provincetown, Mass., 1925*

Length, inches [1]	June 23–July 3			July 9–22 [2]			July 29–Aug. 5			Total		
	Released	Recaptured		Released	Recaptured		Released	Recaptured		Released	Recaptured	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
8	1									1		
8½				1						1		
9	4			4						8		
9½	5			22			1			28		
10	4			108	3		12			124	3	
10½	3			114	5		37	3		154	8	
11	4			112	6		45	1		161	7	
11½	14	1		40	2		51	2		105	5	
12	21	1		35	4		37	2		93	7	
Total	56	2	3.6	436	20	4.6	183	8	4.4	675	30	4.4
12½	15			39			47	4		101	4	
13	56	2		49	5		67	4		172	11	
13½	197	15		96	11		175	9		468	35	
Total	268	17	6.4	184	16	8.7	289	17	5.9	741	50	6.7
14	378	31	8.2	199	24	12.1	303	24	7.9	880	79	9.0
14½	138	21		98	10		186	21		422	52	
15	39	6		49	3		24	3		112	12	
Total	177	27	15.2	147	13	8.8	210	24	11.4	534	64	12.0
15½	8			19	2		6	1		33	3	
16	14			23	3		3			40	3	
16½	11			2			1			14		
17	8			11	2					19	2	
17½	8	2		1			1			10	2	
18	8			6						14		
18½	3			3						6		
19	5			3						8		
19½	3									3		
20	1			2						3		
21	1									1		
Total	70	2	2.9	70	7	10.0	11	1	9.1	151	10	6.6
Grand total	949	79	8.3	1,036	80	7.7	996	74	7.4	2,981	233	7.8

[1] Measurements were made to the nearest quarter-inch, but there was such marked bias in favor of the whole-inch and half-inch intervals that the quarter-inch measurements were grouped with the preceding whole-inch group and the three-quarter-inch mark with the preceding half-inch group, so that the mid points of the class intervals in this column are 8⅛, 8⅝, 9⅛, 9⅝, etc.

[2] Exclusive of the last 258 mackerel tagged on July 22, omitted because suspected of being in exceedingly poor condition when released.

TABLE 29.—*Relation between size and percentage of returns from 1,000 mackerel tagged and released at Woods Hole, July 15–27, 1927*

(EXPERIMENT NO. 6)

Length, centimeters	Number tagged	Number returned	Percent
25.5–28.5	104	8	7.7
29.0–29.5	194	21	10.8
30.0	158	20	12.7
30.5	138	22	15.9
31.0	117	22	18.8
31.5–32.0	148	20	13.5
32.5–34.5	72	11	15.3
35.0–50.0	69	4	5.8
Total	1,000	128	12.8

experiment 2. Similarly, in experiment 7, the loss of tags from the group 25.5 to 28.5 centimeters long, may be estimated at 51 percent and the loss from the group 29.0 to 30.0 centimeters at 27 percent. If only the size groups of maximum return be considered, the rate of diminution in both the 1925 and 1927 experiments is still about 50 percent per 5-day period during the first 15 or 20 days, indicating that the loss of tags, although affecting total returns of small mackerel, was distributed uniformly during the three or four 5-day periods immediately after release, and hence was not responsible for the rate of diminution of returns.

It is probable also that the rapid diminution of returns from these experiments in part was due to the dispersal of mackerel from the point of release to areas less intensely fished. In both experiments tagging was done at pound nets, and even slight travel of the tagged fish in an offshore direction would take them out of reach of the gear alongshore. However, it would also bring them into the range of the purse-seine fishery. This is particularly true of those released in Provincetown. So also, movement along the shore would take them into the range of pound nets elsewhere. Inasmuch as the returns from distant points were negligible, it does not seem that the rapid diminution was due to dispersal. On the contrary, it appears more likely that the population of tagged fish of these particular experiments stayed more or less in the vicinity of their release during the remainder of the summer. By contrast, a tagging experiment done at Woods Hole, Mass., June 8–17, 1925 (table 25), affords an example of the results obtained when there is rapid dispersal. Of the returns during the first month after release, 50 percent, rather than a negligible number, came from distant points.[3] All things considered it would appear that only a part of the diminution of the early returns in experiments 2 and 7 was due to scatter of the fish, the remainder, perhaps the major portion, resulted from other causes.

Principal among the other causes is quite plainly the mortality of the mackerel during the first 2 weeks after tagging. Experiments on holding mackerel in confinement have shown that they are subject to high initial mortality as the result of catching and handling. In two experiments the loss was 36 and 70 percent and this is thought to have taken place during the first 2 weeks after catching. A 50-percent mortality per 5-day period would be the equivalent of 75 percent in 15 days. So it appears that the rate of decline in number of returns from field releases was not far different from the mortality in holding experiments. The number of holding experiments was too few to establish a reliable average-mortality expectancy, but perhaps adequate to demonstrate that the bulk of the decline in returns must have been due to mortality and only a minor part to dispersal of mackerel from tagging points.

TESTS OF THE SUITABILITY OF VARIOUS TAGS FOR MARKING MACKEREL

Thus, the foregoing experiments yielded returns that either were scanty, or fell sharply during the first few days, owing to loss of tags and to mortality of the tagged fish. It was also observed that (1) the caudal peduncles of some of the banded mackerel that were recaptured were sore; (2) some of the specimens were in an emaciated condition; and (3) a dead, banded mackerel was found stranded on the beach in the vicinity of its release 3 days after tagging. Therefore, field operations in tagging were suspended pending improvement of tagging technique.

Up to this time no means had been found to keep mackerel alive in confinement for more than a few days. In 1929, Hall (1930) in the course of studying respiration of the mackerel was led to the conclusion that this species could be held in confinement if provided sufficient space to swim about more freely

[3] This rapid scatter to other points should have caused a rate of diminution in local returns even greater than those of experiments 2 and 7. Unfortunately, the local returns were too few to be significant. There were three, two, and one returned locally in the first, second, and third successive 5-day periods after tagging, respectively. Presumably these low returns were due to the rapid departure of the mackerel from the region.

than in the relatively small aquaria customarily used for other marine species. The outdoor pool at the United States Fisheries Biological Station at Woods Hole, Mass., provided the space needed. Its dimensions, 24 feet wide, 89 feet long, and 3 to 7½ feet deep, and its tidal circulation through four openings totaling 29 square feet (providing an exchange of one-sixth to three-quarters of the water at minimum and maximum tides, respectively) proved adequate for holding mackerel alive and in good condition during the summer and autumn months.

About 70 tinker mackerel were brought from a local pound net in the live well of a small boat and placed in this pool on June 26. During the subsequent week many of these showed effects of injuries probably received while being handled and transported, for they developed conspicuous white patches, usually on the snout, tail, and sometimes on the sides of the body. After a week or 10 days, these evidences of injury disappeared, in part through healing, and in part through death of the injured individuals. From this time on, the mackerel ate eagerly of the ground fish and squid provided daily.

On July 22, 26 days after the mackerel had been placed in the pool, the 45 survivors were marked with 2 styles of ring tags.

On July 24 and 26, 184 additional mackerel, brought from local pound nets by means of a live car, were placed in the pool with the tagged individuals. Within 3 days the newly added individuals developed sores principally on the sides of the body, and during the first week 28 dead or dying mackerel were removed from the pool. Additional carcasses were noted on the bottom. In the meantime, the tagged mackerel continued to feed as formerly and appeared not to be injured by the tagging operation. By July 31, evidences of sores had disappeared from the mackerel of the new stock and they were feeding as readily as the original stock.

On August 22, when all mackerel were removed from the pool, there were 31 survivors of the tagged fish and 55 survivors of the stock that had been added on July 24 and 26. Those with tags were returned to the pool. Of those without tags, most were marked with additional styles of tags and returned, and a few were returned without tagging, to serve as controls.

On October 24, the experiment was ended by seining out the survivors. Only 18 were found. If none eluded the seining operation, this shows a mortality of 84 percent.

Since the mortality was not due to the tags (for controls suffered mortality equal to that of the tagged fish), to lack of nourishment (the survivors were fat and plump at the end of the experiment), or to unfavorable temperatures (varying between 68° and 72° F. between July and the first half of September, temperature declined gradually to 59° F. by October 23, hence was well within the range known to be tolerated by unconfined mackerel), I am inclined to ascribe it to the effects of the heavy rains of September 17 which flooded the harbor with muddy water which persisted for 3 days and must have lowered the salinity appreciably. The turbidity of the water precluded direct observation of the condition of the fish, but a sharp reduction at this time in the readiness with which food was accepted, indicated a significant change in the condition of the fish.

Despite the few survivors at the end of the experiment, certain of the results appear significant when growth rate and mortality of the individuals marked with the different styles of tags are compared with controls.

The various styles of tags with the names used to designate them are illustrated in figure 21. The dimensions were as follows:

Celluloid band: Made of celluloid strips 0.025 inch thick, 5/16 inch wide and 2 inches long (0.635 by 8 by 50 millimeters) molded to form a circle 7/16 inch (11.1 millimeters) in inside diameter, with an overlap of about ⅓ the circumference.

Celluloid ring: Made of rods of celluloid 3/32 inch (2.5 millimeters) in diameter and 1½ inches (38 millimeters) long, cut obliquely at the ends to fit together when molded to a circle of ⅜ inch (9.5 millimeters) inside diameter.

Rubber band: Drainage tubing ⅜ inch (9.5 millimeters) in diameter with walls 0.013 inch (0.33 millimeter) thick, cut into sections to provide bands ⅜ inch (9.5 millimeters) wide.

Internal tag: Strip of celluloid 0.025 by 5/16 by 1½ inches (0.635 by 8 by 32 millimeters) rounded at the ends.

Each of these was chosen for particular reasons. The celluloid band was included to test our conclusions as to the earlier taggings with the celluloid poultry band. It was similar to the latter, except

that it was of thinner stock and of a smaller size appropriate to the smaller mackerel on which it was to be placed.[4] The celluloid rings were included, at the suggestion of Henry B. Bigelow, to see whether the smoothly rounded form would be less injurious than the sharp-cornered bands. The rubber bands were selected to see whether a soft material would be less harmful than the hard celluloid, and the internal tags were tried because of their superiority over external tags demonstrated on other species by Nesbit (1933).

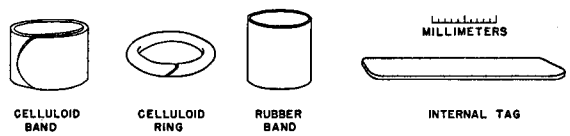

FIGURE 21.—Diagrams of tags tested in holding experiments.

In the marking of July 22 when two styles, celluloid bands and celluloid rings, were applied to the mackerel, the mackerel were tagged alternately with the bands and rings in the order that they were dipped up from the net pocket. In the marking of August 22, the mackerel were again handled in the order dipped from the pocket. Those already tagged the month before were measured and released, while the ones not bearing tags were treated in three different ways. All 27 centimeters long were tagged with rubber bands; all 27.5 centimeters long were released as controls; and the remaining sizes were marked by the insertion of internal tags. The selection of a particular size for rubber bands and controls was necessitated by their lack of individual identifying marks which required that the fish of each lot be of the same size at the time of release if their subsequent growth was to be determined.

All measurements were made to the nearest half centimeter on the measuring board described in appendix A. In table 30 the lengths are given in half centimeters just as they were originally entered in the records, but elsewhere they are given in centimeters, or decimal fractions thereof.

In table 30 are given the records of those fish that bore numbered or lettered marks. The records on the mackerel not bearing numbered marks are as follows: Of the 15 mackerel, each 27.0 centimeters long when marked with rubber bands on August 22, only 1 was found on October 24. It measured 27.5 centimeters, a gain of 0.5 centimeter since tagging. Of the 16 controls, each 27.5 centimeters long at

[4] The even-numbered tags of this style had the interior corners beveled, the odd-numbered ones had "square" corners. Since we could discern no significant differences in the results with the beveled and unbeveled rings (table 29) they have not been treated separately.

TABLE 30.—*Records of experiments with celluloid bands, celluloid rings, and internal tags*

[Lengths and increments are given in half centimeters. To convert to centimeters divide by 2]

Celluloid rings						Celluloid bands				Internal tags			
Serial letter	Length			Increment		Serial No.	Length		Increment	Serial No.	Length		Increment
	July 22 [1]	Aug. 22	Oct. 24	July 22–Aug. 22	Aug. 22–Oct. 24		July 22 [1]	Aug. 22	July 22–Aug. 22		Aug. 22 [1]	Oct. 24	Aug. 22–Oct. 24
A	48	51		3		69	47			43	56		
B	54	57	61	3	4	70	49			44	56		
C	52	56	61	4	5	71	49	52	3	46	53	62	9
D	52	57	64	5	7	72	51	53	2	47	52		
E	52	55		3		73	49	(2)		48	53		
F	52					74	50			49	57	64	7
G	50					75	50			50	56		
H	51	53	59	2	6	76	52	54	2	52	53		
I	51	55	60	4	5	77	51			53	51		
J	48	51	55	3		78	47	50	3	54	56		
K	52	56	62	4	6	79	50	54	4	55	56		
L	51	54		3		80	52	53	1	56	57		
M	52	55		3		81	49			57	52	61	9
N	51	57		6		82	51	52	1	58	53	60	7
O	47	48		1		83	49	51	2	59	53		
P	50	53		3		84	51			60	57		
Q	51	54		3		85	47			61	56		
R	50	55		5		86	48	51	3	62	51		
S	51	54	62	3	8	87	49			63	52		
T	53	55		2		88	49			64	52		
U	44	47		3		89	49	50	1	65	53		
V	54	56		2		90	52			66	53		
W	50	53		3						67	51		
										68	53	58	5

[1] Tags were applied on this date.
[2] Tag was found in skiff from which tagging was done Aug. 22, evidently having slipped from the mackerel unobserved.

the time of release, August 22, four survived the experiment and were 30, 31.5, 31.5, and 32 centimeters long, respectively, an average growth increment of 3.75 centimeters during the period August 22 to October 24.

Examination of the relation of size to mortality and growth increments gave very little evidence that the size of the mackerel was correlated with its subsequent fate except in the case of the 22 mackerel marked with celluloid rings. The survivors (to October 24) of this lot were all from the upper half of the range of sizes at time of tagging. However, the numbers involved were so few that the significance of this is questionable.

Considering, first, the period of August 22 to October 24 for which there are available comparisons between all four styles of marks and the controls, it is evident that there were large differences in the rates of survival and of growth of the mackerel in various experiments (table 30). The mackerel with internal tags compare most favorably with the controls, having an average growth rate practically identical with that of the controls, and a survival rate that was not significantly different from that of the controls. The celluloid rings appeared not to have affected the survival of the mackerel but to have caused a definitely lower growth rate, their average increment of 3.0 centimeters being 21 percent less than the increment of 3.7 centimeters registered by the controls. The celluloid bands and rubber bands appear to have had markedly adverse effects on the mackerel, causing almost complete mortality and, judging by the lone survivor bearing a rubber band, this style of mark caused a 60 percent lower growth rate than was experienced by the controls. The lack of survivors among the celluloid-banded mackerel during the period August 22 to October 24 precludes comparing growth with that of the controls; but the mackerel marked with celluloid bands and celluloid rings during the period of July 22 to August 22 had an average growth of 1.0 centimeter and 1.6 centimeters respectively. If we may assume that the last-named increment (1.6 centimeters) was 20 percent less than would have been registered by untagged fish, then the growth of the celluloid-banded fish was reduced by about 50 percent, a figure not unlike that of the rubber-banded mackerel. Thus it appears that bands, either of celluloid or of rubber, caused almost complete mortality of tinker mackerel within a few months; that celluloid rings did not greatly affect the survival of mackerel, at least during a 3-month period, but caused some slackening of growth; and that internal tags produced no discernible effect, either on growth or on mortality.

In the case of the celluloid bands, it is evident that the mortality data cannot be taken at their face value due to loss of tags from the fish. Although designed to fit loosely so as not to exert pressure on tissues, yet closely enough to be held in place by the flaring lobes of the tail fin, some of these tags must have been slightly too large, for one was seen to slip off over the tail fin shortly after tagging; another was seen to slip off 5 days later while the mackerel were being fed; and a third came off while the mackerel were reexamined August 22, for it was found in the bottom of the skiff shortly after conclusion of the work on that day. Hence, it would appear that the 45.5 percent so-called "survival" during the period July 22 to August 22 must be a minimum, for it is known that at least three tags were lost in this period and it is probable that additional ones were lost unobserved. It is possible that almost the entire diminution in number of banded mackerel may have been due to loss of tags rather than to mortality.

TABLE 31.—*Survival and growth of mackerel marked by various means during summer of 1933*

Marks used	July 22	Aug. 22	Survived from July 22 to Aug. 22 [1]	Average growth of survivors July 22 to Aug. 22	Oct. 24	Survived from Aug. 22 to Oct. 24	Average growth of survivors Aug. 22 to Oct. 24
	Number	*Number*	*Percent*	*Centimeter*	*Number*	*Percent*	*Centimeter*
Celluloid bands	[2] 22	10	45.5	1.1	(3)	----------	----------
Celluloid rings	[2] 23	21	91.4	1.6	7	33.3	3.0
Rubber bands	----------	[3] 15	----------	----------	1	6.7	1.5
Internal tags	----------	[2] 24	----------	----------	5	20.8	3.7
Controls	----------	[4] 16	----------	----------	4	25.0	3.8

[1] The numbers in this column includes only those survivors that retained the marks. It is known that at least some of those marked with celluloid bands lost the band soon after tagging, but they could not be distinguished from the unmarked mackerel that were present in the pool on the date of reexamination.
[2] Tagged this date.
[3] None survived except 1 doubtfully identified with this experiment by means of scar around caudal peduncle.
[4] Released this date.

On the other hand, there are three reasons for believing that the subsequent losses (i. e., after August 22) of celluloid-banded mackerel must have been due mainly to mortality: (1) All that were loose fitting enough to come off had opportunity to do so during the first month; (2) all that stayed on during the first month would be far less likely to be lost later, for the mackerel, by that time, had grown so that bands would fit more closely; (3) during the first month the bands caused sufficient soreness of the tissues to leave scars that could be detected at the last examination. Only one such scarred mackerel was found, so there cannot have been other survivors; and the final mortality in this experiment may be taken as 90 percent or 100 percent depending on whether this scarred individual should be counted. Since the loss of the tag presumably increased its chances of survival, this individual hardly can be regarded as evidence of survival of mackerel marked in this manner, and it may be concluded that this style of tag caused an unknown, but perhaps substantial, mortality during the first month after tagging, and complete mortality during the next 2 months.

The rubber bands gave similarly poor results. Of the 15 mackerel tagged on August 22 only 1 survived to October 24. In this case it is certain that the loss was due to death rather than to the loss of tags, for the rubber bands were too tight rather than too loose. Although the mackerel, by actual measurement, had caudal peduncles ⅜-inch in diameter at the slenderest point, and the diameter of the band also was ⅜-inch, the width of the band was such as to cause it to extend anteriorly and posteriorly of the slenderest part of the caudal peduncle, thereby causing slight pressure at the anterior and posterior edges of the band. This evidently was sufficient to cause necrosis of the underlying tissue, for both the survior mentioned above, and another that died 5 days after tagging, lacked skin on the area underneath the band which seemed to have "eaten" down the tissue in a sharply defined band around the caudal peduncle.

It is doubtful whether an improvement might be gained by using more loosely fitting rubber bands, for only a slight enlargement of the band would allow it to slip over the tail fin. Rubber bands are flexible enough to conform to the cross-sectional shape of the tail fin and thus slip off more easily than the stiffer celluloid band of the same diameter. Hence, it appears that rubber bands are unsuitable. Furthermore, the mere fact, established by these experiments, that bands must fit the caudal peduncle neither too loosely nor too tightly, renders this style of tag impractical for general use in field experiments where the variation in size of fish would require an extensive range of sizes of bands and an accurate judgment of size to apply.

The celluloid rings were intermediate between the bands and the internal tags in their effects on the mackerel. They apparently did not cause mortality but did retard the growth rate. It cannot be assumed, however, that the mortality of mackerel bearing the rings would remain unaffected over longer periods of time. At the end of the 93-day period, all mackerel marked with rings had sores encircling the caudal peduncle where the rings, although loose, came into contact with the peduncle during the lateral vibrations of the caudal region while swimming. These sores appeared as intense as the ones found August 22 on the mackerel that had carried celluloid bands during the previous month; that is, the skin was in most cases entirely absent from the sore region, leaving the flesh and sinews exposed. Though there was no active bleeding, the sores were decidedly reddish. The only generally apparent difference between the sores caused by the rings and those caused by the bands was the greater area involved and the deeper notching of the caudal lobes by the bands. That the rings as well as the bands caused soreness was surprising, for it was anticipated that their smoothly rounded surfaces could not chafe the skin as readily as the sharp corners of the bands. This makes it seem that soreness is caused by contact or impact as well as by chafing. If it may be assumed that the disturbance of internal salt-balance is one of the important effects of sore areas on the protective tissues of the fish, it is not surprising that the celluloid rings should have affected mackerel less than the celluloid bands, for the area of soreness was much smaller in the case of rings than of bands.

Inasmuch as the soreness caused by celluloid rings persisted throughout the experiment, showing no evidence of healing, considerable doubt is cast on the retention of the tags or the survival of the fish much beyond the length of time demonstrated by the experiment. Enlargement of the caudal peduncle through growth and the resultant increased pressure can be expected to lead to eventual impairment of the caudal fin as an organ of propulsion and ultimate destruction of the fish, either through impairment of

feeding or inability to escape from predators. Hence, this tag can be considered of use during only a few months when applied to young, rapidly growing fish and possibly as much as several seasons on old and slowly growing ones.

In marked contrast to the results obtained with the bands and rings, the internal tags appeared to have had no adverse effects. Not only do the records of mortality and growth rate (table 31) indicate this, but examination of the mackerel at the close of the experiment revealed no harmful effects. In all cases the incision through which the celluloid strips had been inserted, had healed, leaving only a faint scar. In all cases save one, the tag lay alongside the internal organs or partly hidden by them. No adhesions or inflamed areas were evident. In the one exception, the tag had not entered the body cavity but had lodged under the peritoneal lining of the body wall. In this position it had caused no apparent soreness of tissues with which it came into contact. Evidently this method of marking is ideal in its lack of effects on the mackerel and there is no reason to doubt its permanence.

An important objection to the internal tag is that usually it will not be found by the person who can furnish information as to the date and locality of capture, for mackerel pass from fishermen to wholesaler to retail dealer without being gutted, except for a small fraction of the catch which is salted or canned. To some extent this difficulty may be overcome by printing on the tag instructions for ascertaining the source of tagged fish bought from dealers. Whether a percentage sufficiently high to be useful can be traced to their source remains to be demonstrated. If not, marking experiments should be of two kinds: (1) The internal tag for quantitative results; (2) an external tag for short-time, qualitative results. For external marking, the celluloid ring (or some better one yet to be devised), is indicated.

In addition to demonstrating the effects on the mackerel of the several types of tags, these tests incidentally call attention to a feature of tagging operations not previously appreciated. This is the high initial mortality attending the catching and transfering of the experimental lots to impoundment. The first lot suffered 36 percent and the second lot 70 percent mortality during the first two weeks after capture. This initial mortality might have resulted from confinement of the fish, but in view of the subsequent good condition of the impounded mackerel, we are more inclined to believe it was due to the catching operations. If this is correct, mackerel tagged and released directly after catching would be subject to a high and variable initial mortality. This would need be considered in treating results quantitatively.