MOVEMENTS, GROWTH, AND RATE OF RECAPTURE OF WHITEFISH TAGGED IN THE APOSTLE ISLANDS AREA OF LAKE SUPERIOR

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ABSTRACT

A total of 1,303 whitefish were marked with spaghetti streamer tags in Wisconsin waters of Lake Superior in November of 1959, 1960, and 1961 and June–July 1960. The fish tagged in June–July 1960 were mostly undersized (less than 17 inches long) whereas those captured on the spawning grounds and tagged in November 1959–61 were almost all legal size. Of the 374 recoveries (28.7 percent), nearly all were made during the first 2 years after tagging. The earliest returns were from fish which were among the largest when tagged. Over one-half of the recoveries were made within 5 miles of the tagging site; the greatest distance traveled by an individual was 25 miles. The fish tagged in June–July 1960 grew 1.6 inches the first season and 1.2 the second. Of 27 whitefish recaptured within 6 months from the November 1959–61 group, 17 (63 percent) had lost length (range from decrease 0.1 to 1.4 inches). Whitefish of the June–July group recaptured during the second growing season after tagging gave an exploitation rate of 22.6 percent. First-year returns from the November 1959–61 tagging gave an exploitation rate of 20.5 percent. The true exploitation rate probably is higher since no allowance has been made for tagging mortality, loss of tags, or unreported recaptures.

The production of whitefish, *Coregonus clupeaformis* (Mitchill), in the U.S. waters of Lake Superior declined from over 4½ million pounds in 1885 to 113,000 pounds in 1913, the lowest production recorded. Since 1913 the catch has fluctuated widely; the take exceeded 1 million pounds in 1948–50 and 1954–55 but dropped to 284,000 pounds in 1960.

The production of whitefish in Wisconsin waters of Lake Superior has contributed about 35 percent to the total U.S. output in the lake over the past 50 years. The Apostle Islands region provides nearly all of Wisconsin's production.

The progressive decline of the lake trout (*Salvelinus namaycush*) since 1955, followed by the complete closure of the lake trout fishery in 1962, has made the whitefish of increased importance to the economy of Wisconsin commercial fishermen. Sound management and rational exploitation should be based on a thorough knowledge of the species. The present paper is a contribution to this knowledge.

The first tagging study of whitefish in Lake Superior was in 1951 when staff members of the Fish and Wildlife Service marked 208 undersized (then less than 2 pounds) whitefish with nylon-streamer tags off Bete Grise, Mich. Only 23 fish (11 percent) were recaptured, all within 2 months after tagging. Except for one fish which had traveled 40 miles, all recoveries were made within 20 miles of the tagging site.

In 1955–59, the Wisconsin Conservation Department tagged 2,400 whitefish in the Apostle Islands region. Only 78 recoveries (3.3 percent) were reported, nearly all within 1 year after tagging. All of the recaptured fish were reported from the Apostle Islands region.

The limited recovery of the whitefish tagged by Wisconsin personnel was believed to reflect a high rate of tag loss. The tag used in this earlier experiment was a streamer-type attached to the

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body of the fish posterior to the dorsal fin. Nylon thread (No. 69 Nyloc) was used in 1955–57, and polyethylene thread was used in 1958–59. The difference between the percentage returns of tags held by the two types of thread was negligible.

Evidence that these types of tags are lost was given by Eschmeyer (1959), who found that only 1 of 200 streamer tags attached to lake trout with No. 34 or 46 nylon thread remained intact at the end of 1 year. Budd (1957) estimated that the loss of streamer tags on whitefish tagged in South Bay (Lake Huron), Ontario, was about 10 percent per year.

The present study is an extension of the earlier work of the Wisconsin Conservation Department. We wished to learn more about the migratory habits, growth, and exploitation rate of the Apostle Islands whitefish.

MATERIALS AND METHODS

A total of 1,303 whitefish were tagged in the Apostle Islands area during November 1959–61

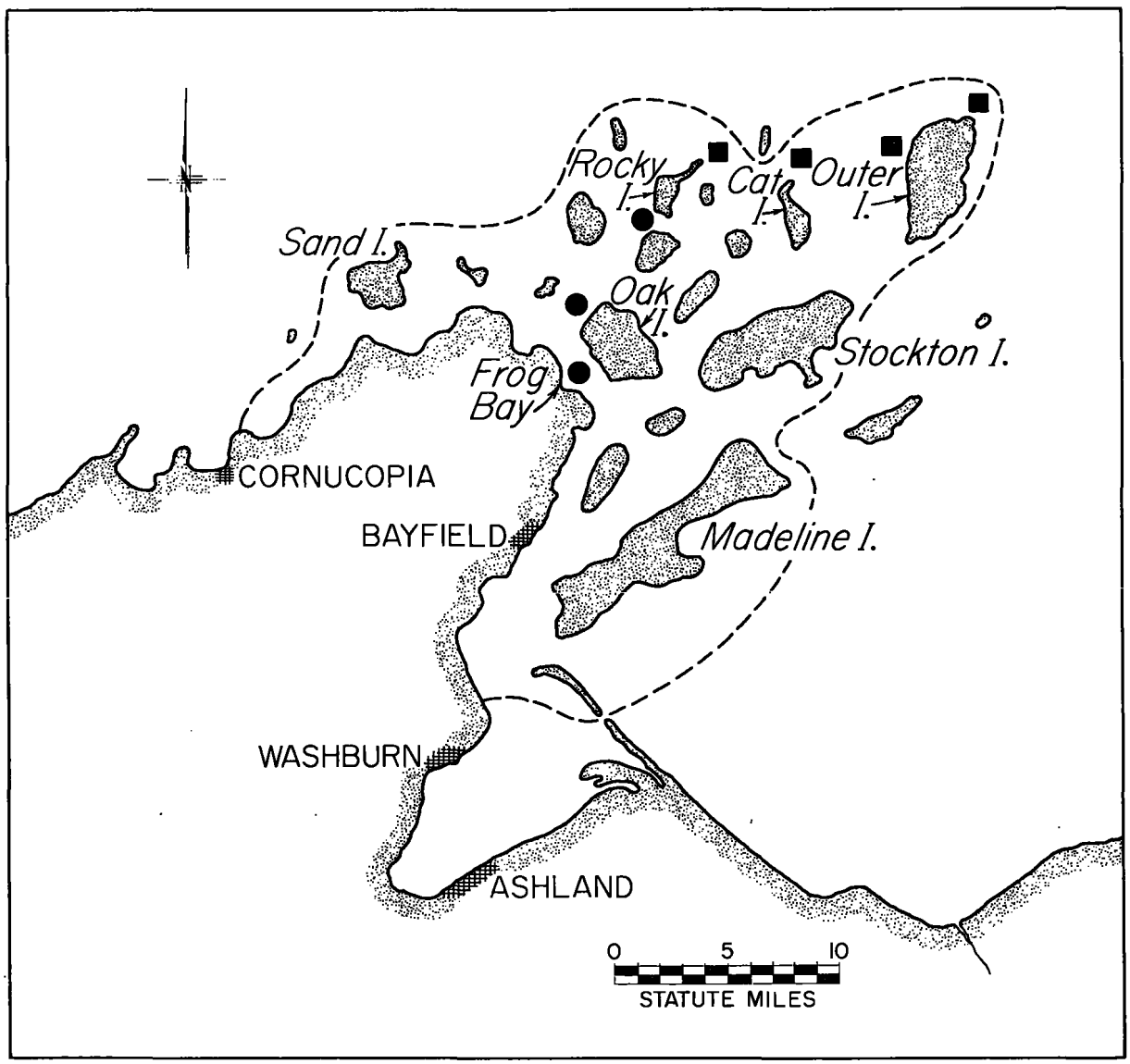

FIGURE 1.—Apostle Islands region of Lake Superior. The dots represent locations where whitefish were tagged in June–July 1960 and the squares show locations of the November 1959–61 tagging. All recoveries were made within the dotted line.

TABLE 1.—*Number of whitefish tagged in the Apostle Islands region according to location and date, and the number and percentage of recaptures from each tagging, 1959–61*

Item	Tagging locality						Length when tagged	
	Rocky Island	Oak Island	Frog Bay	Cat Island	Outer Island	All locations	Average	Range
June–July 1960:							*Inches*	*Inches*
Number tagged	455	563	104	-------	-------	1,122	15.4	10.6–17.4
Number recaptured	139	169	21	-------	-------	329	------	-------
Percentage recaptured	30.5	30.1	20.2	-------	-------	29.3	------	-------
November 1959–61:								
Number tagged	73	-------	-------	96	12	181	18.8	16.0–23.7
Number recaptured	20	-------	-------	20	5	45	------	-------
Percentage recaptured	27.4	-------	-------	20.8	41.7	24.9	------	-------
All dates:								
Number tagged	528	563	104	96	12	1,303	15.9	10.6–23.7
Number recaptured	159	169	21	20	5	374	------	-------
Percentage recaptured	30.1	30.0	20.2	20.8	41.7	28.7	------	-------

and June–July 1960 (table 1, fig. 1). The 1,122 fish tagged in June–July 1960 were collected in commercial pound nets (50–70 feet deep, 4¾-inch-mesh pot); the remaining 181 whitefish came from large-mesh gill nets (from 4½- to 5½-inch mesh) fished on the whitefish spawning grounds from the Bureau of Commercial Fisheries research vessel *Siscowet*. One purpose of tagging spawning-run fish was to detect possible "homing" behavior.

The tag—a spaghetti streamer—used in this experiment was a modification of the type used by Wilson (1953) for marking tuna. It consisted of a vinyl plastic tube (outside diameter, 0.094 inch) with a yellow plastic disc attached to one end. A stainless steel tube served as a needle for piercing the back of the fish just posterior to the dorsal fin. The tubing was placed inside the steel needle; as the needle passed through the fish, the tag was carried through with it. The ends of the plastic tubing were joined by a small metal clamp, similar to a bird band. No reward was offered for the return of the tags. Although the inscription on the plastic disc instructed that the tags be forwarded to the Bureau's Biological Laboratory in Ann Arbor, Mich., most were sent directly to the field station at Ashland, Wis.

The whitefish tagged from pound nets in the summer of 1960 ranged from 10.6 to 17.4 inches long (average, 15.4 inches). The spawning-run fish tagged aboard the *Siscowet* were considerably larger (16.0–23.7 inches; average, 18.8 inches).

Most of the returns (296) came from the intensive summer pound net fishery, and the remainder (78) from large-mesh gill nets fished under the ice during the winter. The percentage of recoveries from the various tagging locations and dates varied little. Among groups of 40 or more fish tagged at one location, the percentage return ranged from 20.2 to 30.5. The total percentage return was 28.7 for all tagging combined.

The number of tag returns used for various phases of this study varies according to the information received with the tags. Complete data, i.e., date and location of capture and length of the fish were reported with most of the returns. Some reports, however, were incomplete and their usefulness was limited according to the information received. Because reports of recoveries declined sharply in the summer of 1962 the study was terminated December 31, 1962. I felt that the few additional returns that might be reported after this date would not influence the results appreciably.

TIME BETWEEN TAGGING AND RECOVERY

The time between tagging and recovery for Apostle Islands whitefish was influenced by seasonal fishing pressure and by the size of the fish when tagged. The recaptures from the group tagged in June–July 1960 were highest during the summer pound net fishery of 1961. Since whitefish tagged in June–July 1960 were mostly undersized and returned to the lake if captured, returns from them were few during the first several months out.

The percentage of whitefish recaptured from the June–July 1960 group (table 2) increased from 6.3 percent during the first 10 months (July–April) to 19.8 percent during the 11- to 22-month (May–April) period. The cumulative percentage recovered was 26.1 percent at the end of 22 months, only 3.3 percent below the final percentage (29.4 percent) at the end of 29 months. Of the 37 recoveries made after 22 months, only 4 were reported later than 24 months. The percentage of the total number recaptured was also highest (67.3 percent) during the 11- to 22-month period and the cumulative percentage of the total stood at 88.8 percent at the end of 22 months.

TABLE 2.—*Recoveries of whitefish tagged in June–July 1960 according to length of time at liberty*

Item	Time out (months)		
	<11	11–22	23–29
Number recaptured	71	222	37
Percentage recaptured	6.3	19.8	3.3
Cumulative percentage	6.3	26.1	29.4
Percentage of total recoveries	21.5	67.3	11.2
Cumulative percentage	21.5	88.8	100.0

TABLE 3.—*Recoveries of whitefish tagged in November 1959–61 according to length of time at liberty*

Item	Time out (months)		
	<6	6–12	>12
Number recaptured	20	18	5
Percentage recaptured	11.0	9.9	2.8
Cumulative percentage	11.0	20.9	23.7
Percentage of total recoveries	46.5	41.9	11.6
Cumulative percentage	46.5	88.4	100.0

Of the 43 returns from fish tagged during the fall spawning season (November) in 1959–61 (table 3), all but 5 were reported during the first 12 months (20 were taken during the first 5 months in the winter fishery, and 18 in the following 12 months). No recoveries were made after 20 months. The cumulative percentage of recapture was 20.9 percent at the end of 12 months, only 2.8 percent below the total percentage return of 23.7. The percentage of the total recaptured was highest during the first 5 months, and the cumulative percentage stood at 88.4 percent at the end of 12 months.

The small number of returns after the first year for fish tagged in November 1959–61 and after the second year for the June–July 1960 group suggests either a high rate of tag loss or a heavy natural mortality.

DISTANCES TRAVELED

The distances traveled by tagged whitefish were relatively small regardless of the time between tagging and recapture. Of the small whitefish tagged in June–July 1960, 142 fish (64.6 percent of the total recoveries) were recaptured at distances less than 5 miles from the tagging site (table 4). Only 19 fish (8.6 percent) had traveled more than 10 miles, and the greatest distance traveled by an individual was 17 miles.

More than half (56.5 percent) of the recoveries of the larger whitefish tagged during the fall spawning seasons were within 5 miles of the tagging site, but 26.1 percent (6 fish) traveled more than 10 miles. The greatest distance traveled by a whitefish tagged during the spawning run was 25 miles. The *Siscowet* recovered only one whitefish which had returned to spawn on the same grounds where it was tagged.[1]

TABLE 4.—*Recoveries of tagged whitefish according to distance traveled from tagging site*

Tagging period and item	Distance traveled (miles)			
	<5	5–10	>10	Greatest distance
June–July 1960:				
Number recaptured	142	59	19	17
Percentage of total recaptures	64.6	26.8	8.6	----------
Cumulative percentage	64.6	91.4	100.0	----------
November 1959–61:				
Number recaptured	13	4	6	25
Percentage of total recaptures	56.5	17.4	26.1	----------
Cumulative percentage	56.5	73.9	100.0	----------

Since the major portion of the pound net fishery in the Apostle Islands is concentrated within a 20-mile radius of Bayfield, Wis., it was to be expected that most of the recoveries would come from that area. Gill nets, on the other hand, are fished along the entire south shore of Lake Superior. Had the whitefish migrated greater distances, recoveries should have been made outside the Apostle Islands region.

The lack of recoveries from outside the Apostle Islands region supports Dryer's (1963) suggestion, based on growth data, that the whitefish in the Bayfield region are one of a number of distinct stocks in Lake Superior. These stocks of fish have characteristic growth rates (Apostle Islands and Munising Bay stocks grow extremely slowly in comparison with those from Marquette and Whitefish Bay).

Smith and Van Oosten (1940) reported that of 101 returns from 457 whitefish tagged in Lake Michigan, only 4 were recovered at distances greater than 25 miles. They further indicated that no correlation could be found between distances traveled and time out. Budd (1957) reported that one whitefish had traveled 150 miles from the tagging site in South Bay, Lake Huron. His tag returns suggested, however, that the South Bay stock retains its identity and that fish return to South Bay during the winter or early spring.

[1] Since the completion of this report the Wisconsin Conservation Department has given me records of the recapture in 1963 of six whitefish from the spawning grounds on which they were tagged.

It is, of course, impossible to determine the distance traveled before an individual was recaptured. A whitefish recaptured 2 years after tagging at a point only 5 miles from the tagging site certainly could have moved extensively at some time during the 2-year interval.

GROWTH OF TAGGED WHITEFISH

The data on growth in length of tagged whitefish are summarized according to group of fish tagged and the number of growing seasons completed before recapture. Since the growth rates and recapture dates for whitefish tagged in June–July 1960 differed from those for fish tagged during the November spawning season in 1959–61, the two groups are kept separate for the discussion of growth in length.

The number of growing seasons completed for recaptured whitefish was determined as follows: fish from the June–July 1960 group which were recovered during the following November–June (5–12 months out) were considered to have completed 1 growing season; those fish which were out 17–24 months after tagging had completed 2 growing seasons. Since annulus formation occurs in mid-June for Lake Superior whitefish (Dryer, 1963), some of the fish conceivably may have completed a small amount of the current season's growth before they were tagged. This small growth, if any occurred, should not seriously impair the data on the first year's growth.

The estimates of growth of individual whitefish are the differences between lengths at recapture reported by commercial fishermen and lengths at tagging, measured by staff members. The measurements at tagging may be considered accurate within the normal limits of error common to field operations. The dependability of measurements by commercial fishermen doubtless varies from individual to individual. Many fishermen do not carry a ruler or yardstick but have a board with a mark at 17 inches, the minimum legal length for both whitefish and lake trout. The distance between this mark and the end of the tail probably was estimated for many fish to obtain the reported length. Other fish probably were measured closely. The fishermen's measurements must be recognized as less accurate than the measurements at tagging but they give a reasonably dependable estimate of average if not of individual growth.

Growth was relatively slow for the whitefish recaptured from those tagged in June–July 1960 (table 5). The increments ranged from −1.4 to 3.9 inches for fish recaptured after 1 year and from 0.9 to 7.4 inches for those recaptured after 2 growing seasons. The average increment of length was 1.6 inches for fish out 1 growing season and 2.8 inches for those out 2 growing seasons.

Since most of the whitefish tagged in June–July 1960 were undersized (average length, 15.4 inches), few returns from them were expected until they reached the legal size of 17 inches.[2] It was expected further that the first returns would come from the larger fish since they would be the first to reach legal size. The average length at tagging was 15.9 inches for fish out 5–10 months, 15.5 inches for those out 12 months, and 15.1 inches for those out 24 months. Smith and Van Oosten (1940) also found that the first recoveries of tagged whitefish in Lake Michigan were from fish which were among the largest when tagged.

TABLE 5.—*Distribution of length increments of tagged whitefish recovered in the Apostle Islands region by time tagged and number of growing seasons.*

Increment of total length	Period of tagging and number of growing seasons		
	June–July 1960		November 1959–61
	1 season	2 seasons	<1 season
Inches			
7.0–7.4		1	
6.0–6.4		1	
4.5–4.9		2	
4.0–4.4		3	
3.5–3.9	1	3	
3.0–3.4	2	4	
2.5–2.9	16	2	
2.0–2.4	33	10	
1.5–1.9	67	4	
1.0–1.4	56	5	1
.5–.9	23	2	1
.1–.4	4		4
0.0	1		4
−.1–−.4	1		10
−.5–−.9	2		6
−1.0–−1.4	1		1
Number of fish	207	37	27
Average length when tagged	15.7	15.2	18.6
Average length when recaptured	17.3	18.0	18.5
Average increment	1.6	2.8	−.1

Nearly all of the recoveries (for which length data are available) from fish tagged in November 1959–61 were made before the start of the following growing season (less than 8 months out). Many of the spawning-run whitefish recaptured during the following December–June showed a loss

[2] Fishermen reported releasing many undersized tagged whitefish from their pound nets during the summer of 1960.

of length. Of the 27 whitefish recaptured, 17 (63 percent) had lost length (range, from −.1 to −1.4 inches) and 4 had the same length as at tagging. Six of the fish put on growth over the winter; the largest increase was 1.4 inches. Only 4 fish for which appropriate data are available were taken after completion of 1 growing season. The average growth for these fish was 0.9 inch (range, 0.3–2.5 inches).

Carbine and Applegate (1948) reported that 50 percent of the tagged northern pike (*Esox lucius*) recovered by anglers from Houghton Lake and Muskegon River, Mich., showed "negative growth." They considered the data erroneous and excluded them from their discussion of growth. Eschmeyer and Jones (1941) also found that fish recaptured soon after tagging in Norris Reservoir, Tenn., often had lost several millimeters in length.

Some animals can, of course, lose considerable length. Sea lampreys with their cartilaginous skeleton, for example, shrink considerably between December and the following spring (Parker and Lennon, 1956). Shrinkage offers a more difficult problem for those organisms which have an osseous axial skeleton; any loss of length of necessity is accommodated by a reduction in the distance between the successive vertebrae. Also to be considered in the apparent shrinkage in length is whether or not the fish is alive at the time of measurement after recapture. Measurements made several hours after recapture would undoubtedly reflect the normal shrinkage which occurs after death. Shetter (1936b) found that brook trout shrink about 2.6 percent due to rigor mortis.

Little doubt exists that the growth rate of fish is retarded by tags. The extent of retardation in growth depends on such factors as type of tag, location of the tag on the fish, and the species of fish tagged. Eschmeyer and Crowe (1955) reported that the annual length increments of walleyes bearing jaw tags averaged less than two-thirds those of untagged fish. Smith, Krefting, and Butler (1952) determined that walleyes bearing jaw tags had not formed an annulus in 2 years after tagging and that growth was negligible. Eschmeyer (1959) stated that the growth of lake trout in a rearing pond was retarded about 25 percent when the fish were tagged with Petersen, cheek, and lower-jaw tags.

EXPLOITATION RATE

Estimates of exploitation rates based on tagging studies may be prejudiced by various factors. The principal difficulties originate in four major sources of bias: loss of tags; tagging mortality; unreported returns; and increased vulnerability of tagged fish to fishing gear.

The first three sources of bias lead to underestimates of exploitation rates, and bias through increased vulnerability of tagged fish to fishing gear leads to overestimates. When estimates are based on the ratio of the number of fish returned to the number tagged, it is assumed implicitly that all of the tags remained intact, that all of the recaptures were reported, and that tagging did not cause mortality or increase vulnerability.

Tag loss and mortality from tagging are probably the most serious deterrents to the quantitative interpretation of data from any tagging study. Various experiments (Snyder, 1932; Markus, 1933; Shetter, 1936a; and Eschmeyer, 1959) have revealed losses with various types of tags ranging from 40 to 100 percent within 1 year after tagging. Data are not available on the percentage loss of the spaghetti tags used in this study but I believe it is less than that for jaw and streamer tags.

The extent of mortality caused by tagging depends on the type of tag, the hardiness of the species tagged, the condition of the fish at tagging, the method of handling the fish during tagging, and probably on other factors as well. Eschmeyer (1959) lost only 9 lake trout of 600 held in a rearing pond and tagged with Petersen, cheek, jaw, and streamer tags. The mortality of whitefish tagged with spaghetti tags is unknown.

No method exists for judging the number of tagged fish recaptured but not reported. Most fishermen intend to report tagged fish but sometimes, through neglect, they forget to return the tag. A few deliberately withhold information on tag returns.

Information is lacking also on the effect of the tag on the vulnerability of the whitefish to commercial gear. Buettner (1961) found that returns from lake trout tagged with Petersen tags were 2.6 times greater than those from fish bearing tags of other types. He concluded that the high rate of returns of Petersen-tagged fish

was due to entanglement of the tags in the webbing of the gill nets. Eschmeyer, Daly, and Erkkila (1953) also suggested that fish tagged with Petersen tags were far more vulnerable to the fishery than were fish bearing other types of tags. The relative vulnerability of fish tagged with these other types of tags is not fully known, but it seems reasonable to assume that the presence of any external tag would increase the chance of capture in certain gears, particularly gill nets.

The effect of the increased vulnerability of the tagged whitefish to the fishing gear may not be great in this study since nearly all (92 percent) of the returns of fish used for inquiry into exploitation rates came from pound nets. The heavy twine of pound nets rarely gills or otherwise entangles whitefish. Tags may, nevertheless, cause pound nets to hold a few fish that otherwise might slip through the meshes.

Even though the effect upon the data from loss of tags, unreported returns, and tagging mortality may be offset in some measure by compensating increased vulnerability of tagged fish to the fishing gear, I believe that the compensation was only partial and that data on exploitation rate offered later in this section are in fact underestimates—possibly severe ones. I have not, however, undertaken any arbitrary adjustment such as that of Smith and Van Oosten (1940) who based their estimation of fishing intensity on various species in Lake Michigan on the assumption that 50 percent of the fish had lost their tags.

Since nearly all of the 1,122 whitefish tagged in June–July 1960 were undersized at tagging, the first-year returns were so few that the rate of exploitation for them could not be estimated over the first year of freedom. The rate of exploitation was estimated from second-year returns, however, by the following procedure: the average growth in length of the tagged whitefish recaptured after completion of 1 growing season (1.6 inches—table 5) was added to each of the lengths of whitefish tagged in June–July 1960 to determine the number of tagged fish that would have reached legal size at the beginning of the second fishing season (May 1, 1961); the number of fish which would have reached legal size at the beginning of the second year (737) was reduced by 59, the number taken as legal-size fish during the first year of freedom, to obtain the adjusted number of 678 actually available; the 153 fish recaptured during the second growing season gave an estimated exploitation rate of $100 \times \frac{153}{678}$ or 22.6 percent.

The rate of exploitation for Apostle Islands whitefish was also estimated from first-year returns of the legal-size fish tagged in November 1959–61. Of the 171 legal-size fish tagged, 35 (20.5 percent) were recaptured during the following 12 months (December–November) after tagging.

The close agreement between estimates of exploitation rates of the November 1959–61 fish (20.5 percent) and the June–July 1960 group (22.6 percent) strongly suggests that the system for estimation of the exploitation rate of the latter group was reasonably sound.

Annual exploitation rates a little above 20 percent cannot be termed excessive. These estimates almost surely are minimal, and as was brought out in earlier discussions, they may be far below the true value. Strong evidence of extremely heavy exploitation of whitefish in the Apostle Islands area was given by Dryer (1963), who found that the intensive summer pound net fishery selected the legal-size whitefish from the population early in the season, leaving mostly the undersized, slowly growing members of an age group during late season. The average size of the age groups declined progressively through the summer.

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