# MIGRATORY MOVEMENTS OF ADULT COHO SALMON (*ONCORHYNCHUS KISUTCH*) IN LAKE MICHIGAN AS REVEALED BY ULTRASONIC TELEMETRY METHODS:

## I. GENERAL MOVEMENTS
## II. BEHAVIOR NEAR THE POINT BEACH NUCLEAR POWER PLANT THERMAL PLUME

BY

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## ABSTRACT

Twenty-seven coho salmon (*Oncorhynchus kisutch*) were ultrasonically tracked near the Wisconsin shoreline of Lake Michigan in 1969, 1970, 1971, and 1972. Tendency to swim in the home direction and mean swimming speed increased significantly after two hours of elapsed tracking time, and magnitude of turns decreased. Possible reasons for these changes are discussed. Salmon released in near-shore water less than 10 m deep had a significant tendency to go to shore and had an average swimming speed of 48.7 cm/sec. Fish released offshore in water deeper than 15 m usually remained offshore during their tracks, and had an average swimming speed of 73.6 cm/sec. In 1971 ten coho salmon were tracked near a thermal plume, using temperature-sensitive transmitters. Five fish entered the plume area; of these, three made large changes in swimming direction at the power plant's heated water discharge structure. A new method of external transmitter attachment is reported.

Acknowledgments

Special thanks go to Mr. Peter B. Johnsen, who provided invaluable technical assistance and often-needed encouragement. The U.S. Army Corps of Engineers facility at Kewaunee was graciously placed at our disposal, with special aid rendered by Messrs. Bill Boes and Lloyd "Cactus" Anschutz. A second home was provided in Kewaunee by Mrs. Terry Boes of "the Purple House."

Others helping in the field were Messrs. T. "Magnavox" Chapp and J. Hildreth, and Masters of the R/V Aquarius J. Thenell and R. Barr. Transmitters were built by Mr. D. Niesen, and by Professors A. Scidmore and H. Guckel of the University of Wisconsin Electrical Engineering Department. Mr. J. Johnson of the National Marine Fisheries Service, Seattle, Washington, loaned us his counter-receiver unit for the 1971 field season. Mr. G. Esterberg of NMFS designed the 1971 transmitters. The University of Wisconsin Marine Studies Center also provided some of our equipment. The Wisconsin Department of Natural Resources gave us access to the home stream weir at Algoma and full cooperation in other matters.

Mr. A. Scholz contributed suggestions regarding the form of the paper. Research ideas and advice were freely given by Mr. E. Gardella and Dr. D. Madison. Professor R. Johnson of the University of Wisconsin Statistics Department offered advice on presentation and analysis of the data. Ms. S. Wangemann prepared the figures.

Professors Arthur D. Hasler, John J. Magnuson, William C. Burns, and Dr. Ross M. Horrall served as members of my committee. I am especially grateful to Dr. Horrall for his friendship and guidance during my career at the University of Wisconsin, and to Professor Magnuson for his concern and help at the time I entered the Zoology Department.

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# I. GENERAL MOVEMENTS

## A. INTRODUCTION

Coho salmon (Oncorhynchus kisutch), native to northern Pacific waters, were first introduced into Lake Michigan in March 1966 at the Platte River in Michigan. These fish had been reared from eggs supplied in 1964 by the State of Oregon Fish Commission (Stephenson 1968).

The first Wisconsin releases were made in the Ahnapee River at Algoma in the spring of 1968. These coho, comprising the first Wisconsin run of adult three year old fish, returned to the Ahnapee River in the fall of 1969 (Anon. 1969).

The life of Lake Michigan coho begins in the fall of the year with the artificial fertilization of eggs stripped from adult females captured in home streams. Eggs hatch in winter and the young are reared in hatcheries for nearly 1-1/2 years. In spring young fish are taken to holding ponds at the various release sites and remain until they smolt. The smolting process is evidenced by loss of juvenile parr markings and a change in body color. At this time, about 18 months after hatching, the smolts are allowed to migrate downstream to Lake Michigan. Some fish mature sexually at the age of two years and return that fall to the same stream in which they were released (i.e. the home stream), but most coho return the fall of the following year as three year old adults.

In 1968 and 1969 our research group, led by Drs. A. D. Hasler and R. M. Horrall, decided to conduct a study of coho spawning migrations in Lake Michigan using ultrasonic telemetry methods. Our experience with ultrasonic tracking has been extensive (Hasler et al. 1966, 1969a, 1969b, 1970; Madison et al. 1972; McCleave and Horrall 1970).

The first ultrasonic tracking of Lake Michigan coho was conducted in the fall of 1969 under the immediate supervision of Dr. Horrall. The 1970 tracks were supervised principally by Mr. John Hildreth. I was in charge of the project in 1971 and 1972.

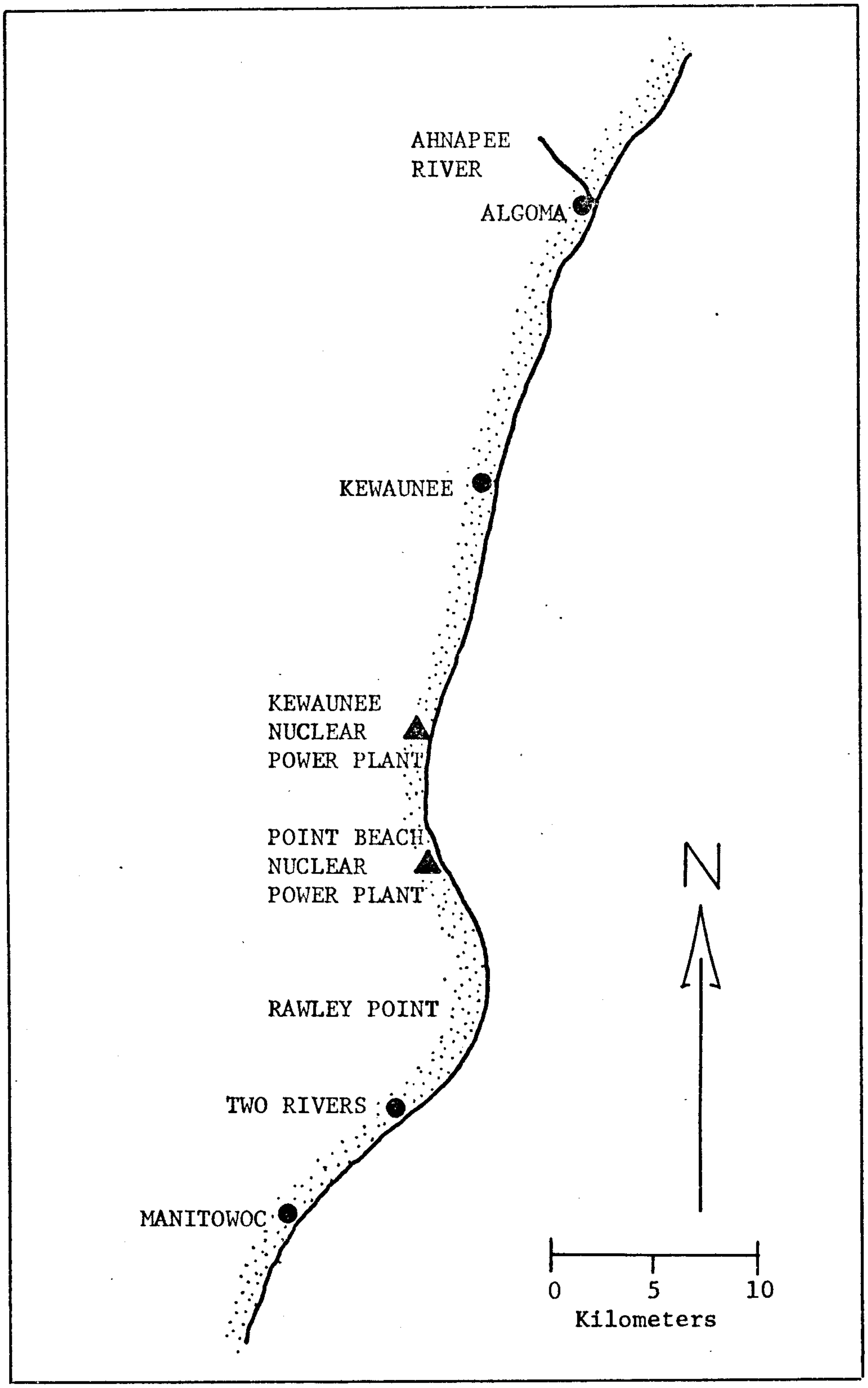
In 1969 two nuclear powered electricity generating facilities, the Point Beach and Kewaunee Plants, were under construction in the study area (Figure 1). Our original intent was to investigate possible effects the Point Beach Plant thermal plume might have on migratory behavior of adult coho salmon in the lake. The 1969 and 1970 tracks, conducted before the plume was present, were considered "pre-operational", and were for the purpose of gathering data on general migratory behavior. One of the two reactor units of Point Beach Plant became operational late in 1970. The plant discharged heated water into Lake Michigan during the 1971 tracking season, and fish bearing temperature-sensitive ultrasonic transmitters were tracked in the immediate vicinity of the thermal plume that year. In 1972 Unit No. 1 of the Point Beach Plant was shut down, and Unit No. 2 was operating at about 20% of capacity, but the resulting plume was not considered adequate for thermal tracking purposes. Therefore the 1972 field season was devoted to gathering additional data on general migratory behavior.

## B. METHODS AND EQUIPMENT

### 1. Tracking Equipment

The ultrasonic transmitters, each of which weighed 10 g in water and measured 66 mm x 15 mm, were set at a carrier frequency of 70 kHz,

Figure 1. The Study Area.


AHNAPEE
RIVER
ALGOMA
KEWAUNEE
KEWAUNEE
NUCLEAR
POWER PLANT
POINT BEACH
NUCLEAR
POWER PLANT
RAWLEY POINT
TWO RIVERS
MANITOWOC
N
0
5
10
Kilometers

which is well above the highest frequency reported audible by fish (Kleerekoper and Chagnon 1954). Madison et al. (1972) describe the transmitters in detail.

The main receiving unit for monitoring the transmitter signal consisted of a National Radio Co. HRO-500 Receiver with LF-10 Preselector, which was connected to a directional hydrophone constructed in our laboratory (Madison et al. 1972; Stasko and Polar 1972).

The 1969 tracking vessel, Susie Q, was 16 m in length and had a cruising speed of 10 knots. The University of Wisconsin's R/V Aquarius was the principal tracking vessel in 1970, 1971, and 1972, had dimensions of 12.3 m x 4.3 m, and was capable of cruising at 15.5 knots.

## 2. Handling of Salmon

Adult coho salmon were captured by seine and dip net in the Ahnapee River homestream weir, near Algoma, Wisconsin. Only fish in acceptable condition were used for study. Those salmon which were sluggish, very darkly colored, or which had external fungus infections or abrasions were not tracked.

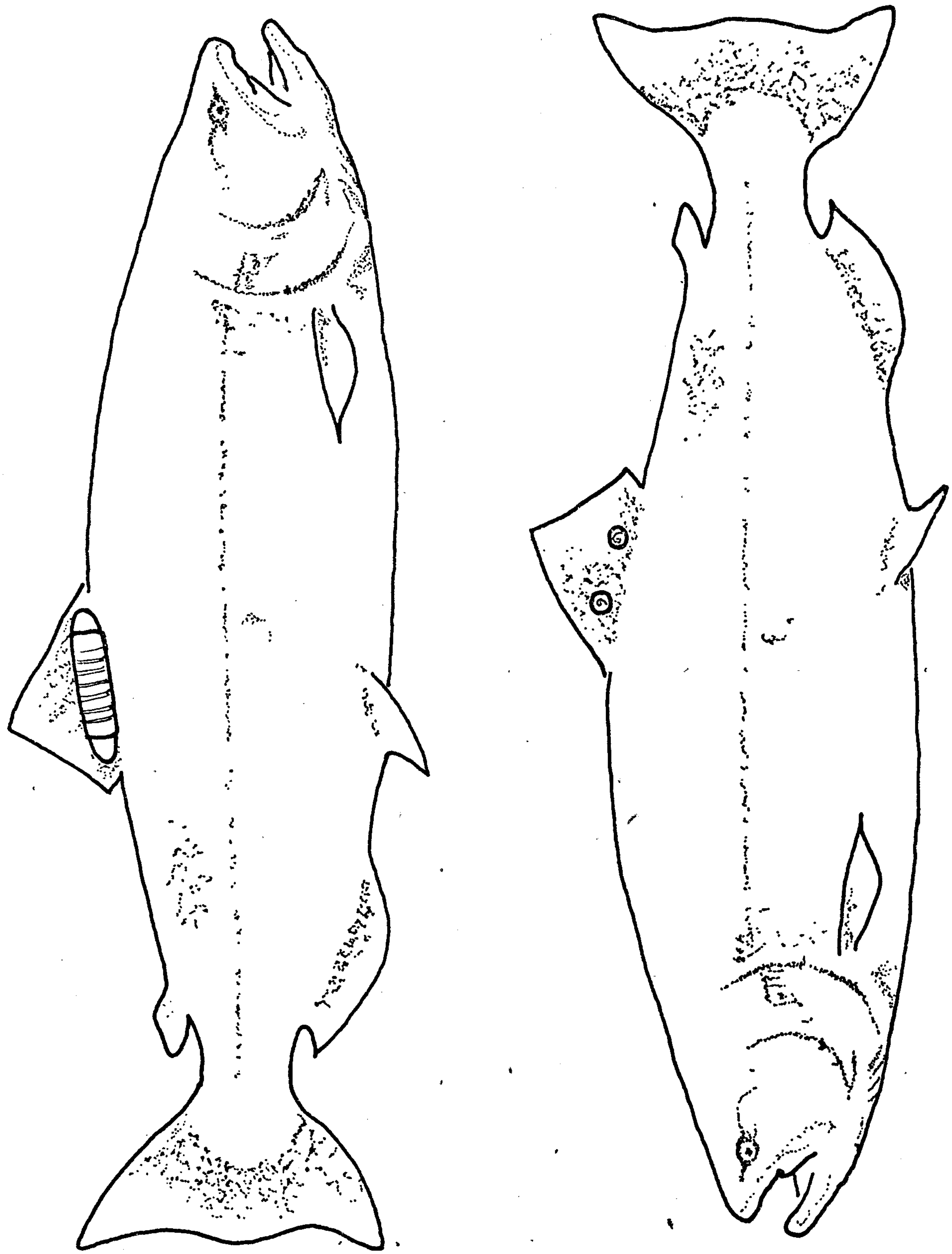
In 1969 and 1970 the fish were transported south by land to Two Rivers, Wisconsin, and put aboard the tracking vessel. In 1971 and 1972 the salmon were transported by land south to Kewaunee, Wisconsin, immediately after capture and held in nets 1 to 2 m below the surface in Kewaunee harbor (1971), or in a large flow-through circulation shore tank (1972).

The Aquarius was equipped with a large canvas bag for transporting fish from Kewaunee to release sites in 1971 and 1972. The vessel's deck pumps supplied a continuous flow of fresh lake surface water to the animals. Movement of the bag within its metal supporting frame greatly reduced buffeting the salmon received as the Aquarius proceeded to the release point. Water in the bag was at ambient harbor water temperature when fish were removed from the holding nets or shore tank and placed aboard the vessel. A knotless dip net was used for these transfers to reduce scale loss. After displacement to the release site (about 40 to 45 km south of Algoma), salmon were anesthetized in a coffin-shaped container with 2-phenoxyethanol dissolved in lake water. 2-Phenoxyethanol concentrations were approximately 50 to 70 ppm, and the average temperature of the mixture was 9.3° C. The concentration of anesthetic was varied with lake water temperature, since at lower temperature a lower concentration of 2-phenoxyethanol is needed for effective anesthesia (Sehdev et al. 1963). The transmitter was then inserted into or attached to the salmon. Transmitters were carried in the stomach in 1969 and 1970. External attachment on the anterior part of the dorsal fin base was employed in 1971 because of the need for instantaneous temperature response of the transmitter; the method worked well and its use was continued in 1972.

Our method of external transmitter attachment was a modification of that of Hallock et al. (1970): transmitters were held in place on the base of the dorsal fin by two Petersen pins inserted through the fin between rays and secured by plastic Petersen discs, as shown in Figure 2.

After transmitter attachment, the 1971 and 1972 fish were placed into the canvas transport bag and allowed to recover from anesthesia. The 1969 and 1970 salmon were also removed from the anesthetic as soon

Figure 2. Method of External Transmitter Attachment.



as transmitter insertion had been completed. Each fish was carefully released into the lake by canvas sling as soon as it had fully recovered from anesthesia, judged by normal swimming activity and maintenance of equilibrium.

In 1971 and 1972 one or two additional coho were usually released at some time during each track, most often at the same time as the salmon bearing the ultrasonic transmitter. A numbered Floy tag was inserted by needle gun into the dorsal flesh (no anesthetic was used) and the fish released by hand or dip net. These additional releases were made to examine possible transmitter effects on homing time.

## 3. Tracking Procedure

After releasing the salmon, transmitter signal directionality and signal strength were used to bring the tracking vessel close to the fish for a position determination every 15 to 45 minutes. The position of the vessel was assumed to be the position of the salmon and was determined in 1969 by radar and sextant, and in 1970, 1971, and 1972 by radar (sextant readings were also employed for the last half of the track of Salmon No. 7204).

Since motor noise might have disturbed the coho being tracked, the tracking vessel was kept at least 50 m from the salmon except when position determinations were being made.

Environmental factors which might have affected the behavior of salmon were monitored. Water temperature profiles at the position of the fish were obtained with a Whitney-type underwater thermometer during 1970, 1971, and 1972 tracks, and water depth was taken from the *Aquarius*' fathometer. Current measurements (direction and speed) were taken during one 1970 track, three 1971 and two 1972 tracks: weighted canvas drogues (1 m square and attached to "Scotchman" floats) were set and retrieved from the tracking vessel. Currents were determined to ascertain whether fish movements represented passive drifting with current or active swimming. Other environmental conditions were also monitored, but not analyzed. A log was kept during 1971 and 1972 tracks to supplement the environmental data taken at regular intervals.

Tracks were terminated for a variety of reasons, including rough lake surface conditions, fog, equipment failure, and loss of the transmitter signal.

## C. METHODS OF DATA ANALYSIS

Swimming speed, swimming direction, and angular change (i.e. turns) were the variables used for detailed analysis of movement and were obtained as follows. For each track, fish positions taken from the raw field data were plotted on a chart of the study area. These points were then connected by a line which best represented the salmon's path between position determinations. Since time intervals between position determinations varied from track to track, the method of assigning track path points at 1/2 hour intervals (Madison et al. 1972) was used.

Swimming speed for each 1/2 hour interval was calculated from the path distance between segment end points, and swimming direction for each segment was obtained from a straight line drawn between segment end points. Turns were obtained by comparing swimming direction for a segment with the swimming direction during the preceding segment. The resulting angles varied between 0° and 180° left or right. This method is also similar to that of Madison et al. (1972), who used angular means for analyses of turns. The <u>angular</u> mean of turns of several fish gives the mean change in swimming direction of the entire group at the time point under consideration. My analyses of turns were performed on the arithmetic means of magnitudes of turns without regard to turning direction. An arithmetic mean gives the average turn of each fish of a group at the time point considered. The use of arithmetic means is simpler but still permits meaningful analyses.

The single determination of current in 1970 was not reliable, but Table A-3 of the Appendix summarizes the current data obtained in 1971 and 1972. Compared to mean swimming speeds (see Table 1 and Figures 5, 6, and 7), currents were small so I did not consider it necessary to correct for them.

Analyses of swimming directions were performed on angular means, not arithmetic means. Analysis of arithmetic means is not correct for this variable (Batschelet 1965). The Watson-Williams multisample comparison for homogeneity and the V test (modified Rayleigh test) were used. The multisample comparison examines three or more population samples simultaneously for differences, and must be performed before any two of those samples can be tested for differences. The V test examines possible clustering of swimming directions about the predicted home direction. Both these tests are parametric and assume an underlying circular normal distribution, but are considered sufficiently robust to apply to samples from populations not having circular normality (Batschelet 1965). In any case, inspection of circular distribution scatter diagrams representing data to which these tests were applied indicated that the data were approximately normally distributed. Detailed descriptions of these tests can be found in Batschelet (1965 and 1972). Confidence intervals on mean swimming directions were also obtained using the sources cited above. The F table in Steel and Torrie (1960) was used for determining probabilities arising from application of the multisample homogeneity test.

Other statistical tests employed, all nonparametric, were taken from Siegel (1956) and included the Friedman two-way analysis of variance and the sign test (both for related samples); and the Kruskal-Wallis one-way analysis of variance, the Mann-Whitney U test, and the Fisher 2 x 2 test (all for independent samples).

## D. RESULTS

### 1. Tracking and Recovery Record

Three adult coho salmon were tracked in 1969, six in 1970, eleven in 1971, and eight in 1972. Salmon No. 7101 was excluded from consideration because of probable traumatization due to transmitter attachment. Salmon No. 7107 was lost upon release due to transmitter failure.

Migratory paths of adult coho are presented in Figures 3 (1969 and 1970), 4 (1972), and 15-21 (1971). Table 1 gives individual statistics for each fish and its track, and transmitter recovery information for 1971 and 1972 is presented in Table 2. Note that the homestream weir was not checked every day for returning fish. Also included in Table 2 is recovery information for salmon which were tagged with Floy tags and released during some of the 1971 and 1972 tracks.

### 2. Swimming Direction

After determining the swimming direction of each 1/2 hour track segment for each individual salmon, all the segment directions from a given track were plotted as dots on circular graph paper to give a

Figure 3a. Track Paths of Coho Salmon: 1969 and 1970.

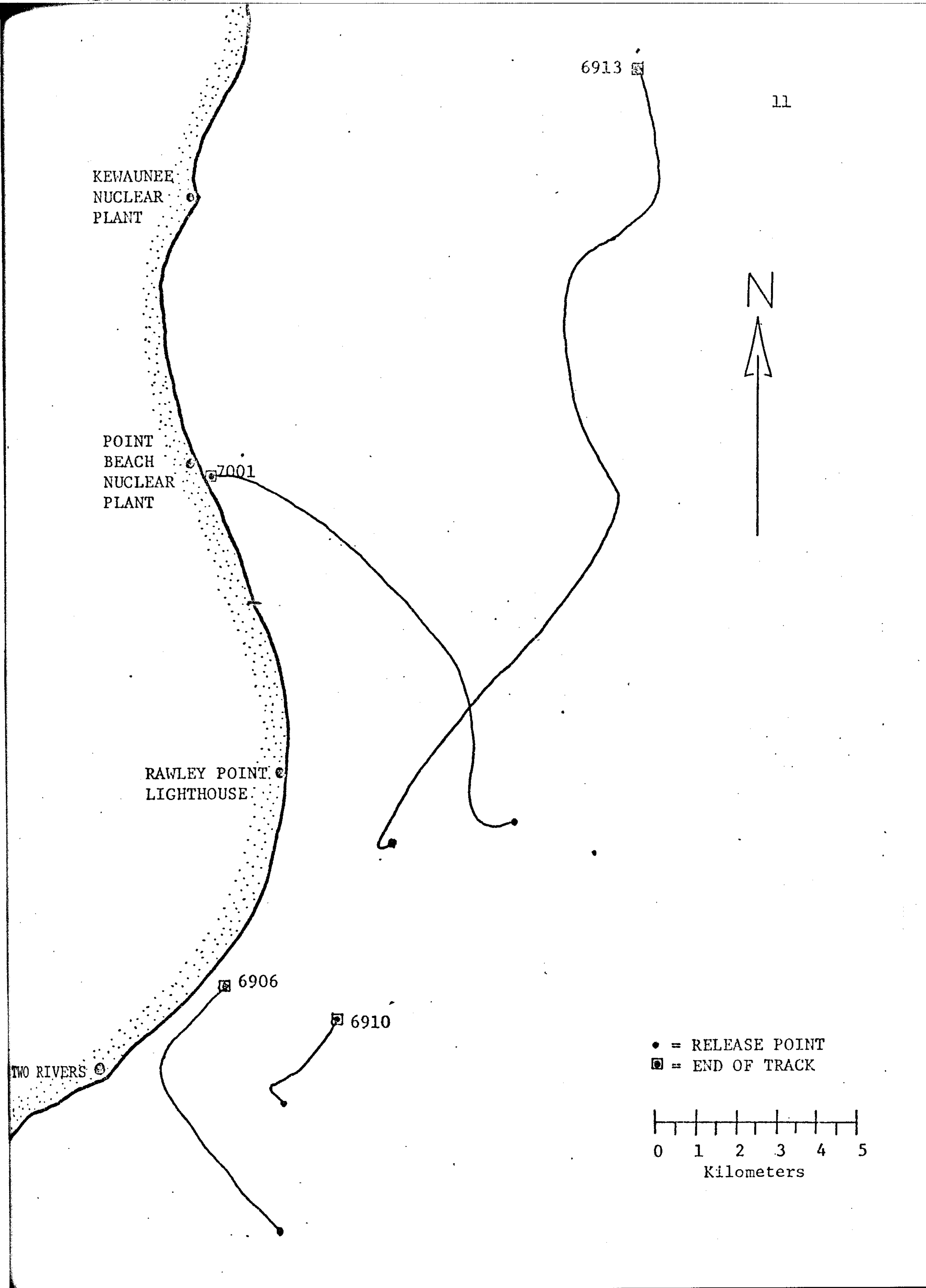

6913
KEWAUNEE
NUCLEAR
PLANT
N
POINT
BEACH
NUCLEAR
PLANT
7001
RAWLEY POINT
LIGHTHOUSE
6906
6910
TWO RIVERS
• = RELEASE POINT
▣ = END OF TRACK
0 1 2 3 4 5
Kilometers

Figure 3b. Track Path: Salmon No. 7002 Southern Section.

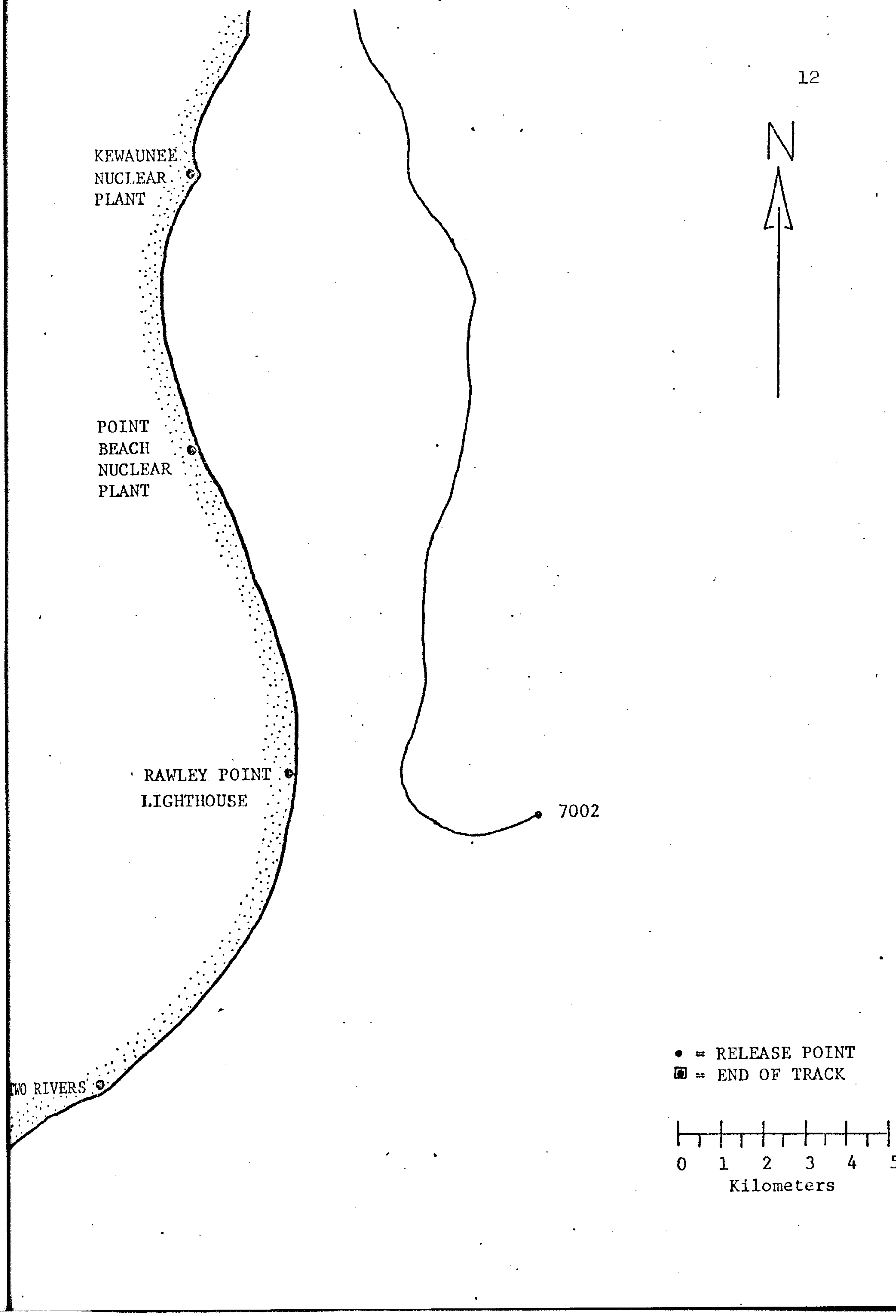

N
KEWAUNEE
NUCLEAR
PLANT
POINT
BEACH
NUCLEAR
PLANT
RAWLEY POINT
LIGHTHOUSE
7002
TWO RIVERS
• = RELEASE POINT
▣ = END OF TRACK
0 1 2 3 4 5
Kilometers

Figure 3c. Track Path: Salmon No. 7002 Northern Section.

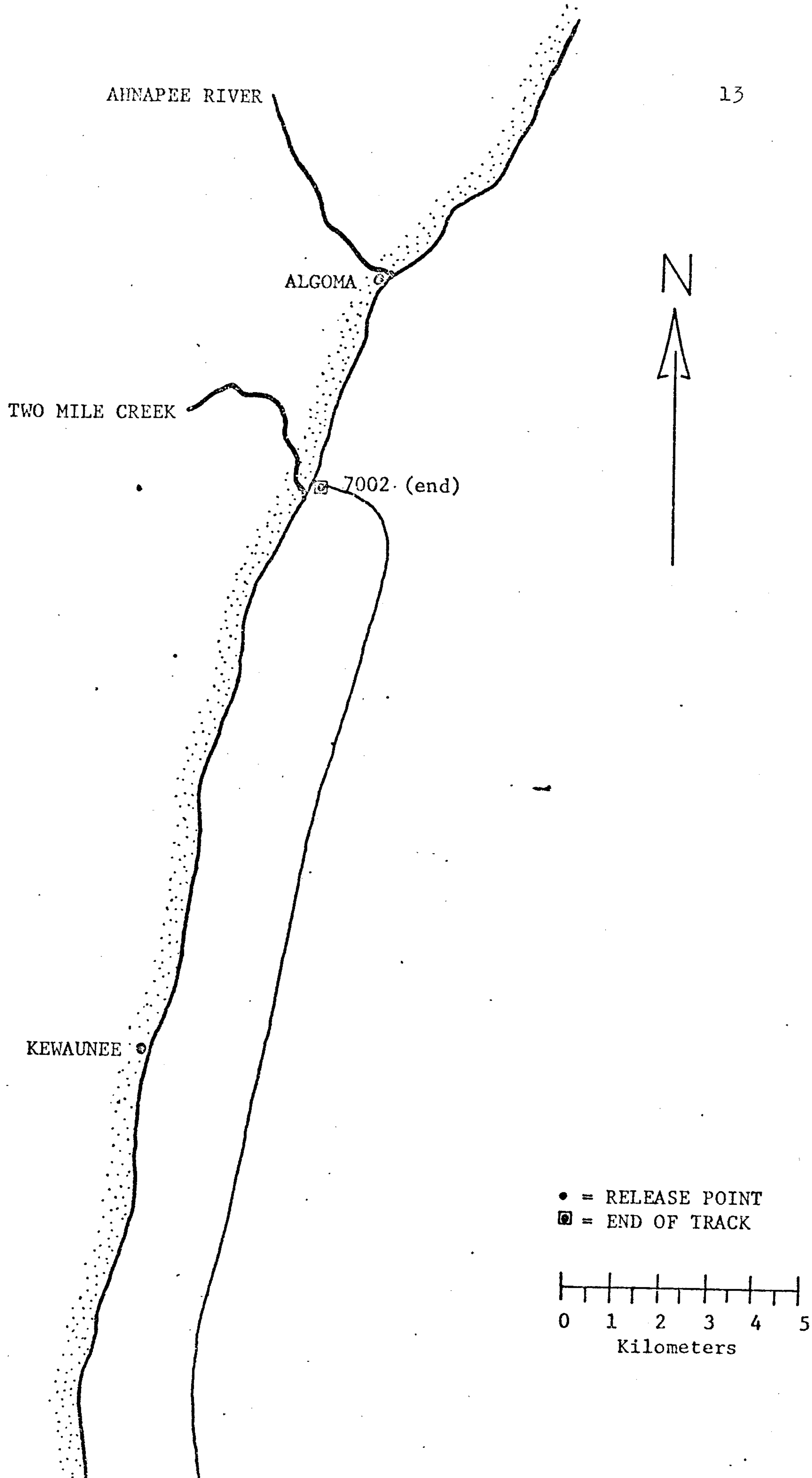

AHNAPEE RIVER
ALGOMA
TWO MILE CREEK
7002 (end)
KEWAUNEE
N
• = RELEASE POINT
▣ = END OF TRACK
0 1 2 3 4 5
Kilometers

Figure 3d. Track Paths of Coho Salmon: 1970.

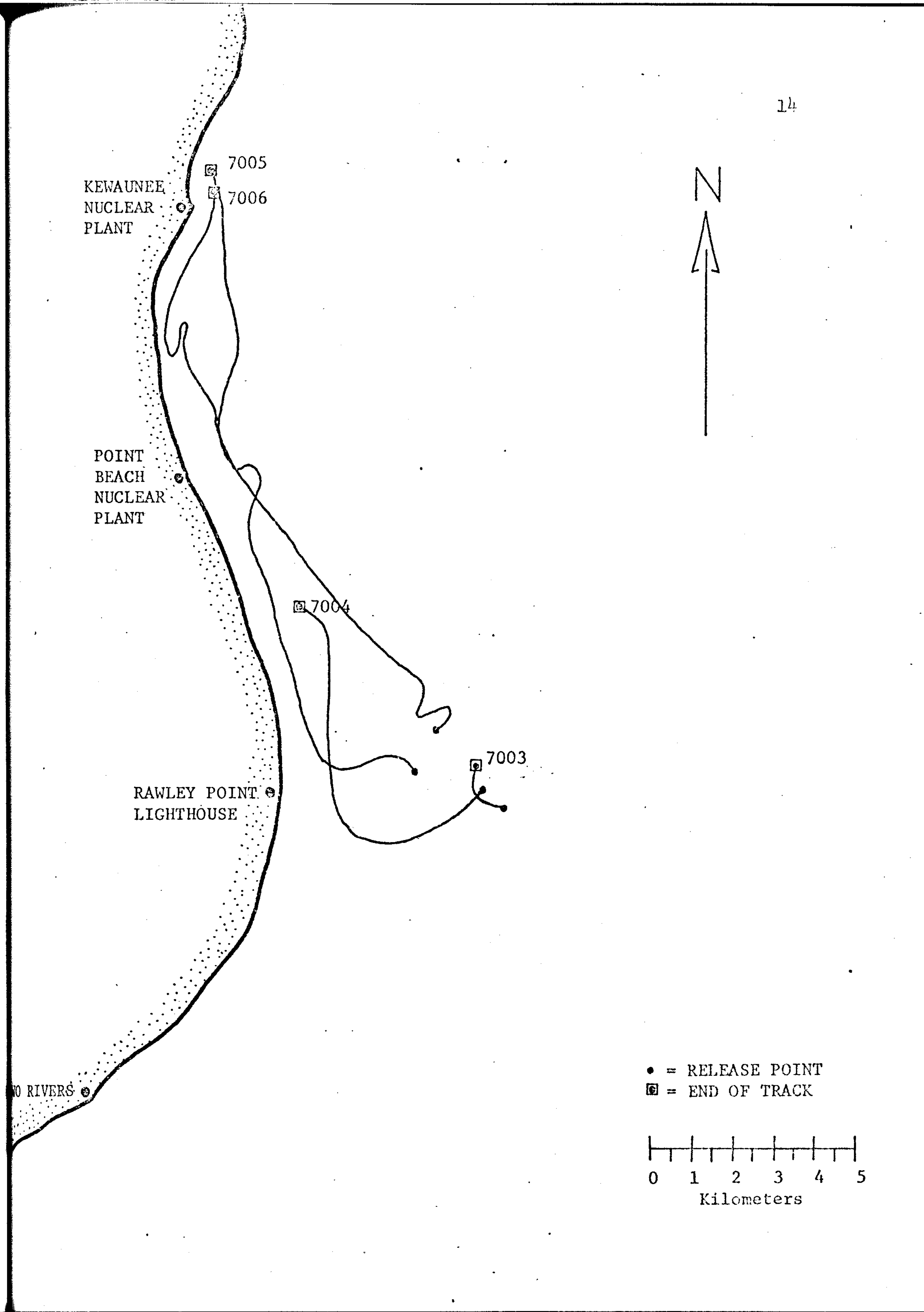

7005
7006
KEWAUNEE NUCLEAR PLANT
POINT BEACH NUCLEAR PLANT
7004
7003
RAWLEY POINT LIGHTHOUSE
O RIVERS
N
• = RELEASE POINT
▣ = END OF TRACK
0 1 2 3 4 5
Kilometers

Figure 4a. Track Paths of Coho Salmon: 1972.

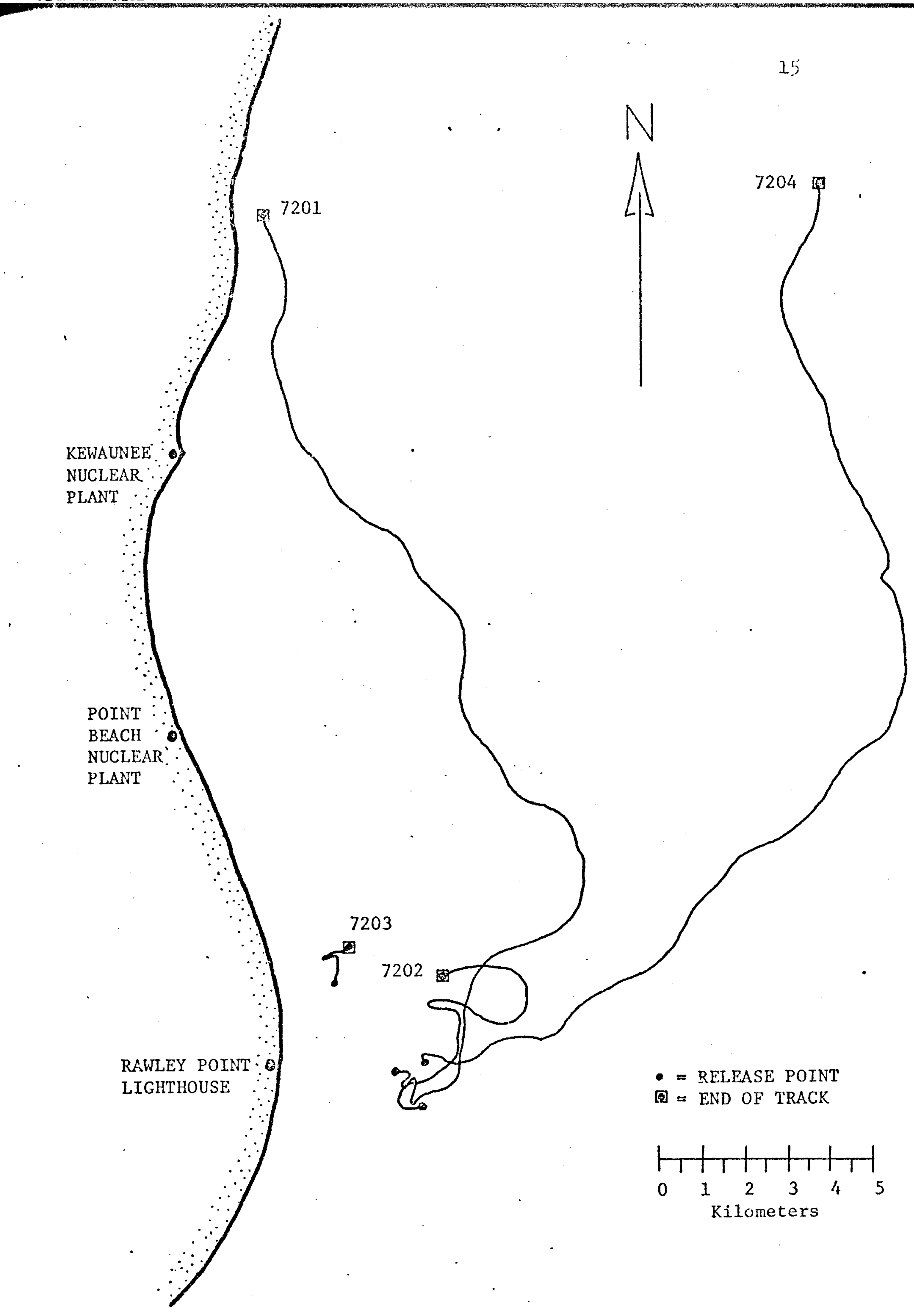

N
7201
7204
KEWAUNEE
NUCLEAR
PLANT
POINT
BEACH
NUCLEAR
PLANT
7203
7202
RAWLEY POINT
LIGHTHOUSE
• = RELEASE POINT
⊡ = END OF TRACK
0 1 2 3 4 5
Kilometers

Figure 4b. Track Paths of Coho Salmon: 1972 (Cont.).

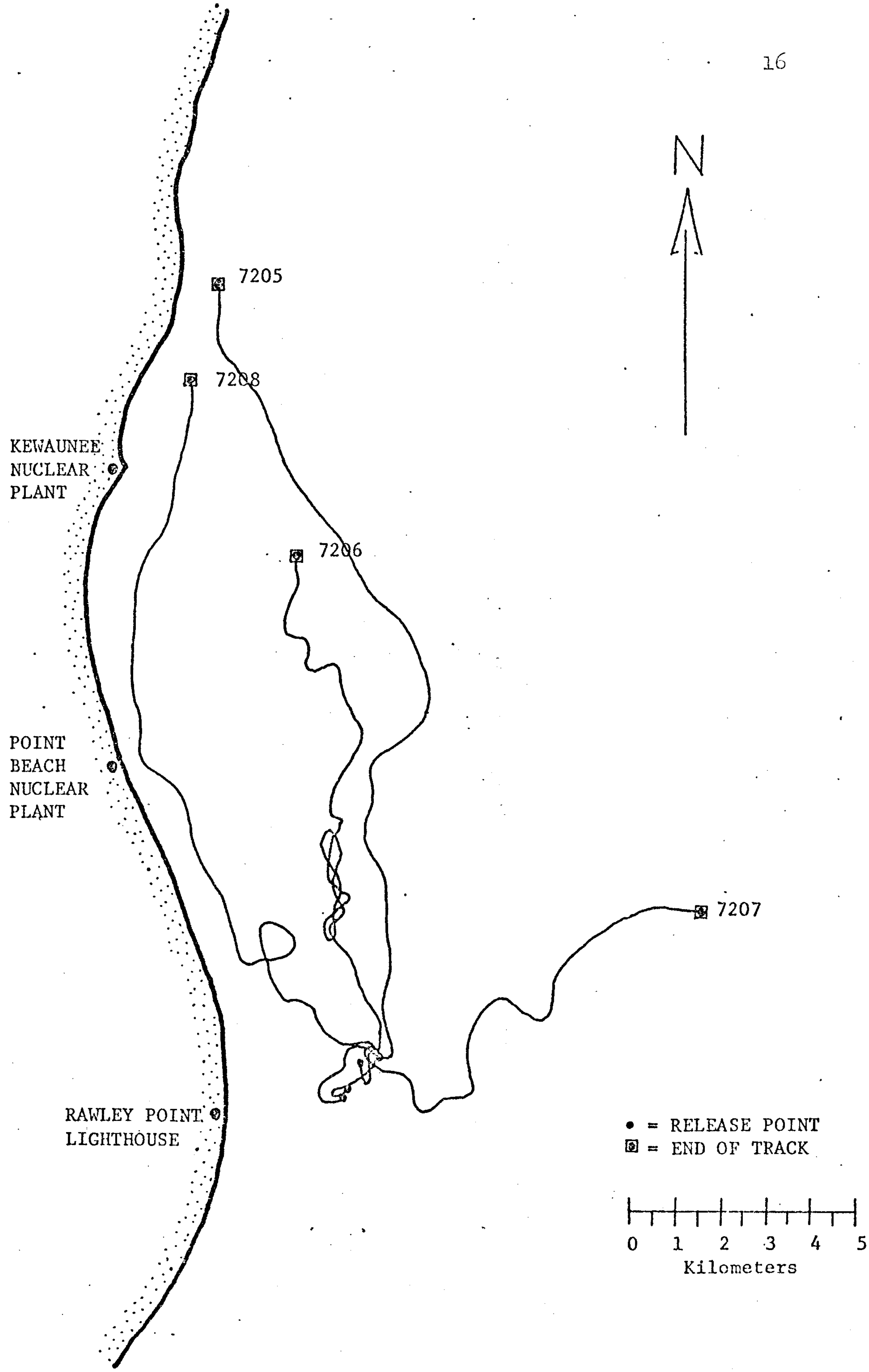

N
7205
7208
KEWAUNEE
NUCLEAR
PLANT
7206
POINT
BEACH
NUCLEAR
PLANT
7207
RAWLEY POINT
LIGHTHOUSE
• = RELEASE POINT
▣ = END OF TRACK
0 1 2 3 4 5
Kilometers

Table 1. Individual Statistics of Coho Salmon Tracked in Lake Michigan in 1969, 1970, 1971, and 1972

| Salmon No. | Sex(A) | Total Length (Mm) | Captivity (Hrs) | Transmitter Type(B) | Location of Transmitter I=internal E=external (R/L)=side of fin | Time and Date of Release (CST) | Track Duration (Hrs) | Track Distance (Km) | Mean Course Speed (Cm/Sec) | Water(C) Depth at Release Point (M) | Distance of Release Point from Shore (Km) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6906 | F | 717 | ? | SR | I | 0843, 19 Oct 1969 | 1.7 | 6.1 | 100.5 | 16 | 5.5 |
| 6910 | F | 683 | 72 | SR | I | 1035, 24 Oct 1969 | 1.5 | 2.4 | 45.3 | 22 | 3.7 |
| 6913 | F | 715 | 120 | SR | I | 0908, 25 Oct 1969 | 5.6 | 22.4 | 111.7 | 24 | 2.3 |
| 7001 | M | ? | 4-6 | SR | I | 1230, 29 Oct 1970 | 8.9 | 12.8 | 40.2 | 33-50 | 5.5 |
| 7002 | M | ? | 4-6 | SR | I | 1230, 29 Oct 1970 | 11.7 | 45.2 | 107.8 | 33-50 | 5.5 |
| 7003 | M | ? | 4-6 | SR | I | 1327, 31 Oct 1970 | 1.3 | 1.9 | 41.6 | 33-35 | 5.5 |
| 7004 | F | ? | 4-6 | SR | I | 1155, 4 Nov 1970 | 4.1 | 9.6 | 65.2 | 33 | 4.6 |
| 7005 | F | ? | 4-6 | SR | I | 1058, 5 Nov 1970 | 6.9 | 17.8 | 72.1 | 30-33 | 3.2 |
| 7006 | M | ? | 4-6 | SR | I | 1112, 6 Nov 1970 | 6.8 | 18.7 | 76.8 | 30-33 | 3.7 |
| 7101 | F | 640 | 28.6 | T | E (dorsal flesh) | 1218, 23 Sept 1971 | 5.7 | 4.4 | 21.9 | 13 | 1.8 |
| 7102 | M | 780 | 3.2 | T | E (R) | 1210, 7 Oct 1971 | 2.1 | 3.1 | 41.2 | 5 | 0.5 |

Table 1. Individual Statistics of Coho Salmon Tracked in Lake Michigan in 1969, 1970, 1971, and 1972 (Cont.)

| Salmon No. | Sex (A) | Total Length (Mm) | Captivity (Hrs) | Transmitter Type (B) | Location of Transmitter I=internal E=external (R/L)=side of fin | Time and Date of Release (CST) | Track Duration (Hrs) | Track Distance (Km) | Mean Course Speed (Cm/Sec) | Water (C) Depth at Release Point (M) | Distance of Release Point from Shore (Km) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7103 | F | 670 | 19.8 | T | E (L) | 1045, 11 Oct 1971 | 2.7 | 5.2 | 54.3 | 10 | 0.9 |
| 7104 | M | 710 | 24.0 | T | E (L) | 1458, 11 Oct 1971 | 2.1 | 3.8 | 51.2 | 8 | 0.9 |
| 7105 | M | 650 | 45.6 | T | E (R) | 1235, 12 Oct 1971 | 1.6 | 2.2 | 38.0 | 7 | 0.9 |
| 7106 | M | 660 | 3.4 | T | E (L) | 1356, 13 Oct 1971 | 3.3 | 9.0 | 76.4 | 7 | 0.5 |
| 7107 | Was not tracked due to transmitter failure upon release. | | | | | | | | | | |
| 7108 | M | 650 | 49.5 | T | E (L) | 1126, 20 Oct 1971 | 3.4 | 5.7 | 46.9 | 8 | 0.5 |
| 7109 | M | 740 | 3.0 | T | E (L) | 1214, 21 Oct 1971 | 1.7 | 1.8 | 30.3 | 8 | 0.9 |
| 7110 | M | 770 | 20.9 | T | E (L) | 1241, 25 Oct 1971 | 3.0 | 8.6 | 80.7 | 11 | 1.4 |
| 7111 | F | 740 | 43.5 | T | E (L) | 1145, 4 Nov 1971 | 4.5 | 7.8 | 48.3 | 8 | 0.9 |
| 7112 | M | 800 | 51.1 | T | E (L) | 1225, 10 Nov 1971 | 4.0 | 2.8 | 19.7 | 6 | 0.9 |

Table 1. Individual Statistics of Coho Salmon Tracked in Lake Michigan in 1969, 1970, 1971, and 1972 (Cont.)

| Salmon No. | Sex (A) | Total Length (Mm) | Captivity (Hrs) | Transmitter Type (B) | Location of Transmitter I=internal E=external (R/L)=side of fin | Time and Date of Release (CST) | Track Duration (Hrs) | Track Distance (Km) | Mean Course Speed (Cm/Sec) | Water (C) Depth at Release Point (M) | Distance of Release Point from Shore (Km) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7201 | F | 690 | 27.6 | SR | E (R) | 1016, 15 Oct 1972 | 7.8 | 27.6 | 99.1 | 30 | 2.8 |
| 7202 | M | 790 | 19.4 | SR | E (R) | 0957, 19 Oct 1972 | 3.4 | 8.9 | 73.6 | 27 | 3.7 |
| 7203 | F | 790 | 136.7 | UW | E (L) | 1045, 25 Oct 1972 | 1.3 | 1.1 | 23.4 | 13 | 1.4 |
| 7204 | F | 720 | 42.6 | UW | E (L) | 1145, 30 Oct 1972 | 9.3 | 28.1 | 84.4 | 25 | 3.2 |
| 7205 | F | 670 | 90.4 | UW | E (R) | 1137, 1 Nov 1972 | 8.1 | 22.2 | 76.8 | 23 | 2.8 |
| 7206 | F | 700 | 76.6 | UW | E (R) | 1425, 10 Nov 1972 | 8.1 | 20.2 | 69.6 | 25 | 2.8 |
| 7207 | F | 720 | 100.2 | UW | E (L) | 1402, 11 Nov 1972 | 3.9 | 11.5 | 82.8 | 25 | 3.2 |
| 7208 | F | 740 | 99.1 | UW | E (R) | 1407, 16 Nov 1972 | 7.4 | 21.5 | 81.3 | 24 | 2.8 |

(A) F = female; M = male.
(B) SR = Smith Root, Inc.; T = temperature-sensitive, designed by G. Esterberg, built by D. Niesen; UW=designed and built by A. Scidmore and H. Guckel.
(C) 1970 water depths are taken from a hydrographic chart of Lake Michigan and are approximate; all other depths are sonar data.

Table 2. Transmitter and Floy Tag Recovery Information for 1971 and 1972

| Transmitter or Floy Tag Number | Time and Date of Release (CST) | Time and Date of Recovery (CST) | Time Elapsed Between Release and Recovery (Days)(B) | Location of Recovery |
|---|---|---|---|---|
| Transmitter 7102 | 1210, 7 Oct 1971 | 1415, 26 Nov 1971 | 50 | Home stream(C) |
| Transmitter 7103 or 7104 | 1045 or 1458, 11 Oct 1971 | 1315, 16 Oct 1971 | 5 | Home stream |
| Transmitter 7106 | 1356, 13 Oct 1971 | 1400, 18 Oct 1971 | 5 | Mouth of home stream |
| Transmitter 7110 | 1241, 25 Oct 1971 | 1730, 30 Oct 1971 | 5 | Bear River, Petoskey, Michigan |
| Transmitter (Number Unknown) | ? | 1210, 22 Oct 1971 | - | Home stream |
| Floy Tag 00528 (Track 7107) | 1130, 14 Oct 1971 | ? | - | Algoma vicinity |
| Floy Tag 00529 (Track Unknown) | ? | ? | - | Mouth of home stream |
| Floy Tag 00533 (Track 7111) | 1615, 4 Nov 1971 | 18 Nov 1971 | 14 | Pigeon River, Sheboygan, Wisc. |
| Transmitter 7202 | 0957, 19 Oct 1972 | 1000, 9 Nov 1972 | 21 | Home stream weir |
| Transmitter 7207 | 1402, 11 Nov 1972 | 1000, 23 Dec 1972 | 42 | Tributary of the home stream |
| Floy Tag 01162 (Track 7201)(A) | 1337, 15 Oct 1972 | 1815, 28 Oct 1972 | 13 | Home stream weir |
| Floy Tag 01173 (Track 7204) | 1120, 30 Oct 1972 | 1115, 11 Nov 1972 | 12 | Home stream |

(A) The fish carrying Floy Tag 01162 was later tracked ultrasonically as No. 7204.
(B) The home stream weir was not checked every day.
(C) The home stream was the Ahnapee River near Algoma, Wisc.

circular distribution. The mean swimming direction (angular mean) for each salmon during its track was then calculated from the vectors represented by these dots, and a confidence interval for that direction determined.

For each of the four years, a mean swimming direction for all fish from a given year was calculated and the confidence interval for that direction determined.

Table 3 gives the calculated mean swimming direction and the 95% confidence interval for that direction for each salmon and for all fish from a given year. The theoretical home direction (from release points to Algoma) was very nearly 360° (True Compass). A large confidence interval for the mean swimming direction of an individual fish (e.g. $\gg \pm 90°$ for Salmon No. 7108) indicates that the track had large deviations from a straight line path.

Before further analyses of swimming directions for individual tracks or yearly groups of fish were attempted, a statistical test of homogeneity (the Watson-Williams multisample comparison test) was applied to the group of four yearly mean swimming directions. This test examines the null hypothesis that the four yearly mean swimming directions were the same. The results of the test showed that there were no differences in the directions that could not be accounted for by chance (dfn = 259, dfd = 3, F = 6.25, $P > .05$), and therefore that each of the mean yearly swimming directions can be considered to have arisen from sampling one of four identical populations. The mean swimming direction of these four samples (1969, 1970, 1971, 1972) combined, i.e. the mean swimming direction of the group consisting of <u>all</u> salmon tracked, is included in

Table 3. Mean Swimming Direction and the 95% Confidence Interval for that Direction for A, Each Salmon, and B, Each Sampling Year and All Years Combined

The theoretical home direction (from release points to Algoma) was 360° (True Compass).

A. Individual Salmon

| Fish No. | n | r(B) | Mean Swimming Direction for the Entire Track (True Compass, Degrees) | 95% Confidence Interval (Degrees) |
|---|---|---|---|---|
| 6906 | 4 | 0.84 | 342 | *(A) |
| 6910 | 4 | .66 | 359 | * |
| 6913 | 12 | .72 | 007 | ±30 |
| 7001 | 16 | .89 | 316.5 | ±14 |
| 7002 | 24 | .79 | 348.5 | ±17 |
| 7003 | 3 | .86 | 296 | * |
| 7004 | 8 | .67 | 318.5 | ±43 |
| 7005 | 15 | .81 | 327 | ±21 |
| 7006 | 14 | .71 | 343 | ±28 |
| 7102 | 4 | .64 | 320.5 | * |
| 7103 | 6 | .65 | 323.5 | ±50 |
| 7104 | 5 | .98 | 333 | ±6 |
| 7105 | 3 | .76 | 294 | * |
| 7106 | 7 | .98 | 356.5 | ±4 |
| 7108 | 7 | .40 | 310 | >>±90 |
| 7109 | 4 | .88 | 298.5 | * |
| 7110 | 7 | .30 | 157.5 | >>±90 |
| 7111 | 9 | .34 | 342.5 | >>±90 |
| 7112 | 9 | .57 | 010 | ±53 |
| 7201 | 16 | .61 | 359 | ±33 |
| 7202 | 7 | .35 | 354 | >>±90 |
| 7203 | 3 | .74 | 013.5 | * |
| 7204 | 19 | .81 | 025.5 | ±18 |
| 7205 | 16 | .69 | 350 | ±26 |
| 7206 | 17 | .54 | 346.5 | ±36 |
| 7207 | 9 | .65 | 071.5 | ±43 |
| 7208 | 15 | .71 | 349.5 | ±28 |

(A) "*" indicates that the confidence interval cannot be determined from the graph in Batschelet (1972) because of small sample size (i.e. the track was short).

(B) "r" is the length of the mean vector.

Table 3. Mean Swimming Direction and the 95% Confidence Interval for that Direction for A, Each Salmon, and B, Each Sampling Year and All Years Combined (Cont.)

B. Each Sampling Year, All Years Combined

| Year | n | $r^{(B)}$ | Mean Swimming Direction (True Compass, Degrees) | 95% Confidence Interval (Degrees) |
|---|---|---|---|---|
| 1969 | 20 | 0.72 | 360 | ±23 |
| 1970 | 80 | .76 | 331.5 | ±10 |
| 1971 | 61 | .49 | 334 | ±22 |
| 1972 | 102 | .60 | 006 | ±12 |
| All Years Combined | 263 | .61 | 347 | ±8 |

Table 3. The 95% confidence interval for that direction is also tabulated.

### 3. "Degree of Orientation" of Individual Salmon During Their Tracks

Batschelet (1972) states, "It is very likely that consecutive sections of [a] track are dependent on each other," but that the "degree of orientation" of an individual salmon can be expressed by the magnitude of V', the so-called homeward component of its entire track path. V' is a vector component of the resultant vector of an entire track, and points toward the predicted home direction. If V' is small there is no evidence that a fish is oriented toward the predicted direction, but a relatively large V' shows that the animal consistently reorients itself toward the home direction, i.e. has a high "degree of orientation". Statistics is not at present able to prove that a track is oriented, but does allow one to decide between these alternatives: (1) from time to time the salmon chooses a new swimming direction at random, or (2) the new directions chosen are clustered around the predicted home direction. The foregoing is a summary of comments made by Batschelet (1972).

I applied the V test to the resultant vector of each fish's track to determine whether or not, in each case, the animal had a high "degree of orientation" toward the home direction (i.e. North, 360° True Compass). Resulting probability values are given in Table 4. A low associated probability indicates that that salmon showed a high "degree of orientation" toward the home direction. If some of the fish whose associated probability values were large had been tracked longer, it is possible that lower values would have resulted. For example,

Table 4. V Test Probabilities for High "Degree of Orientation" Toward the Home Direction for Each Salmon

Null Hypothesis: During the track, the salmon chooses new swimming directions at random.

Alternative Hypothesis: New swimming directions chosen by a fish are clustered around the theoretical home direction (360°)

| Fish No. | n | u | Probability |
|---|---|---|---|
| 6906 | 4 | *(A) | - |
| 6910 | 4 | * | - |
| 6913 | 12 | 3.5182 | <.0001 |
| 7001 | 16 | 3.6418 | <.0001 |
| 7002 | 24 | 5.3330 | <.0001 |
| 7003 | 3 | * | - |
| 7004 | 8 | 2.0000 | .01-.05 |
| 7005 | 15 | 3.7187 | <.0001 |
| 7006 | 14 | 3.5967 | <.0001 |
| 7102 | 4 | * | - |
| 7103 | 6 | 1.8116 | .01-.05 |
| 7104 | 5 | 2.7592 | .001-.005 |
| 7105 | 3 | * | - |
| 7106 | 7 | 3.6494 | <.0001 |
| 7108 | 7 | 0.9542 | >.10 |
| 7109 | 4 | * | - |
| 7110 | 7 | -1.0514 | >.10 |
| 7111 | 9 | 1.3604 | .05-.10 |
| 7112 | 9 | 2.3986 | .005-.01 |
| 7201 | 16 | 3.4598 | .0001-.001 |
| 7202 | 7 | 1.3174 | .05-.10 |
| 7203 | 3 | * | - |
| 7204 | 19 | 4.5080 | <.0001 |
| 7205 | 16 | 3.8517 | <.0001 |
| 7206 | 17 | 3.0810 | .0001-.001 |
| 7207 | 9 | 0.8853 | >.10 |
| 7208 | 15 | 3.8066 | <.0001 |

(A) * indicates that the sample size was too small (i.e. the track was too short) to apply the test.

Salmon No. 7110 ($P > .10$) was swimming north when we terminated the track and was later recaptured much further north of its release point (see Table 2).

## 4. Tendency to Swim in the Home Direction

The V test was used to determine whether or not each yearly group of salmon had a strong tendency to swim in the home direction, a procedure similar to that already discussed for individual fish and "degree of orientation". Results of applying the V test to the resultant vector of all tracks from a given year and to the vector of all tracks combined are given in Table 5. These results indicate that the four yearly groups of salmon tracked each had a stronger tendency to swim in the home direction than could be accounted for by chance (for each group, $P < .0001$).

## 5. Salmon Released in Deeper Water: Hourly Changes in Mean Swimming Direction and Tendency to Swim in the Home Direction

The group consisting of those salmon tracked longer than two hours and released in water deeper than 20 m was examined for possible hourly changes in mean swimming direction and tendency to swim in the home direction. Included in this group of thirteen fish were Salmon Nos. 6913, 7001, 7002, 7004, 7005, 7006, 7201, 7202, 7204, 7205, 7206, 7207, and 7208. Mean swimming directions were calculated for the group at "release" (i.e. the first 1/2 hour) and for each subsequent hour of time elapsed after release, through the eighth hour of elapsed tracking time. The V test was then applied to each of these hourly mean directions to determine whether or not the group of salmon under consideration had a strong tendency to swim in the home direction. Table 6 gives the results of the tests, as well as the hourly mean swimming directions and their

Table 5. V Test Probabilities for Strong "Homing Tendency" for Each Year and All Years Combined

Null Hypothesis: Homing tendency is not apparent.

Alternative Hypothesis: The group of salmon exhibits strong homing tendency.

| Year | n | u | Probability |
|---|---|---|---|
| 1969 | 20 | 4.5686 | <.0001 |
| 1970 | 80 | 8.4741 | <.0001 |
| 1971 | 61 | 4.8303 | <.0001 |
| 1972 | 102 | 8.4691 | <.0001 |
| All Years Combined | 263 | 13.5341 | <.0001 |

Table 6. Long Tracks with Deep Water Release Points: *Hourly Changes in* Mean Swimming Direction and V Test Probabilities for Hourly Changes in Homing Tendency

For Salmon Nos. 6913, 7001, 7002, 7004, 7005, 7006, 7201, 7202, 7204, 7205, 7206, 7207, 7208.

Null Hypothesis: Homing tendency is not apparent.

Alternate Hypothesis: The group of salmon exhibits strong homing tendency.

| Time After Release (Hrs) | Number of fish | $r^{(A)}$ | Mean Swimming Direction (True Compass, Degrees) | 95% Confidence Interval (Degrees) | u | P |
|---|---|---|---|---|---|---|
| 0 (Release) | 13 | 0.29 | 255.5 | >>±90 | -0.3728 | >.10 |
| 1 | 13 | .31 | 357 | >>±90 | 1.4507 | .05-.10 |
| 2 | 13 | .74 | 007 | ±27 | 3.7411 | <.0001 |
| 3 | 13 | .83 | 355 | ±20 | 4.2317 | <.0001 |
| 4 | 11 | .64 | 358 | ±38 | 2.9988 | <.01 |
| 5 | 10 | .90 | 355.5 | ±20 | 4.0120 | <.0001 |
| 6 | 9 | .89 | 351 | ±23 | 3.7381 | <.0001 |
| 7 | 8 | .92 | 337 | ±23 | 3.3631 | <.0001 |
| 8 | 4 | .99 | 360.5 | ±5 | 2.7999 | .01 |

(A) "r" is the length of the mean vector.

95% confidence intervals. A low associated probability in Table 6 indicates that at the specified time after release the group of fish had a strong homing tendency. A very clear pattern emerges from the data in Table 6: at release the group of salmon moved randomly and did not tend to swim in the home direction ($P > .10$); at one hour after release, the preferred direction of the group was the home direction but strong homing tendency was still not evident ($.10 > P > .05$); at two hours after release and at all subsequent times during their tracks, the group had a strong homing tendency (P usually less than .0001). Possible explanations for the initial lack of homing tendency are given in the next section.

## 6. Mean Swimming Speeds: Elapsed Time After Release

For each tracking year, mean swimming speeds of all fish for each half hour of time elapsed after release were calculated and plotted. The 1969 and 1970 data were pooled for calculation of mean speeds because of the small 1969 sample size. Results are presented in Figures 5 (1969 and 1970), 6 (1971), and 7 (1972). Table A-4 of the Appendix gives the numerical values of these mean swimming speeds and the standard deviations of the data from which they were calculated. Table A-2 of the Appendix gives temperature profiles at the location of the fish for various times during 1970 and 1972 tracks. The 1971 profiles are presented in Table 7. The total length of each salmon can be found in Table 1.

Inspection of Figures 5, 6, and 7 suggests that, as a general trend for each year, mean swimming speed increased for about the first 1-1/2 hours after release, then leveled off and remained fairly constant. To further examine this apparent trend, two different statistical tests were

Figure 5. Mean Swimming Speed *vs* Elapsed Tracking Time: 1969 and 1970.

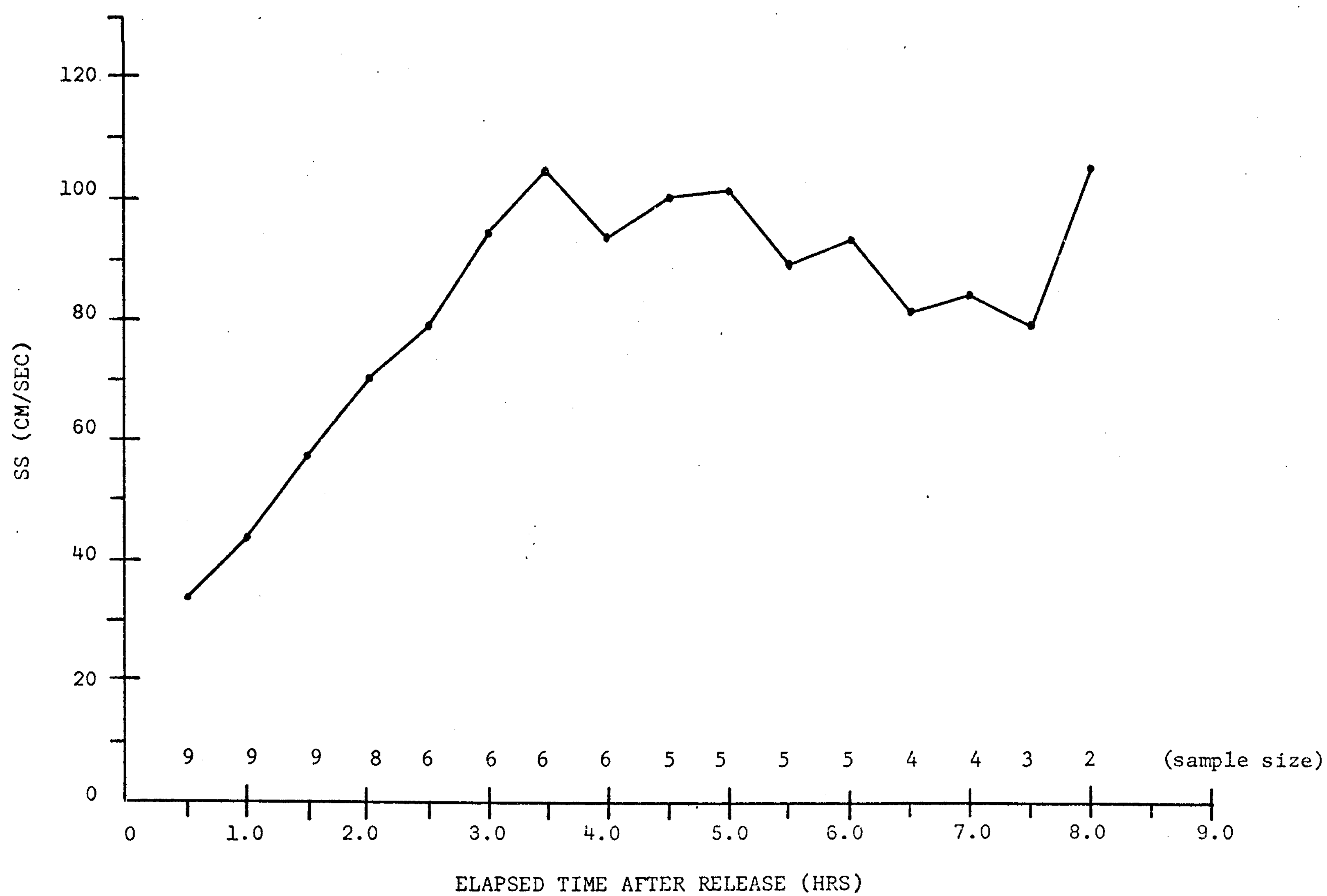

SS (CM/SEC)
0
20
40
60
80
100
120
9 9 9 8 6 6 6 6 5 5 5 5 4 4 3 2 (sample size)
0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0
ELAPSED TIME AFTER RELEASE (HRS)

Figure 6. Mean Swimming Speed vs Elapsed Tracking Time: 1971.

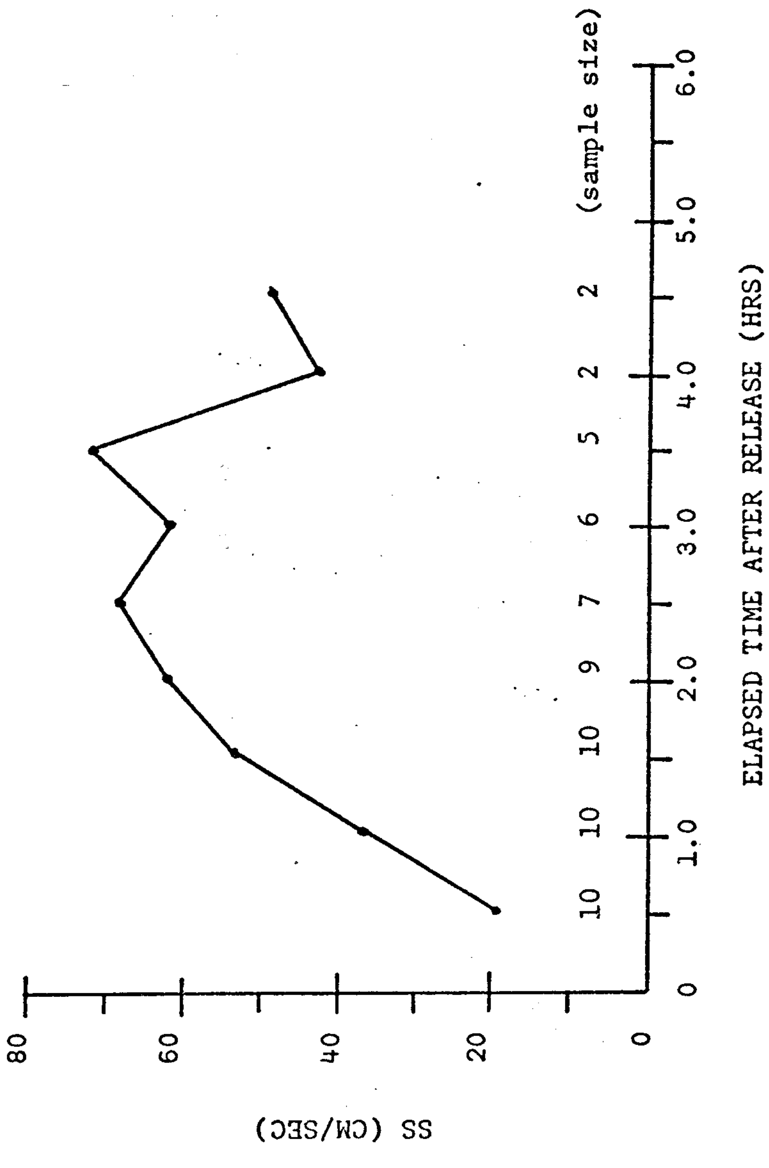
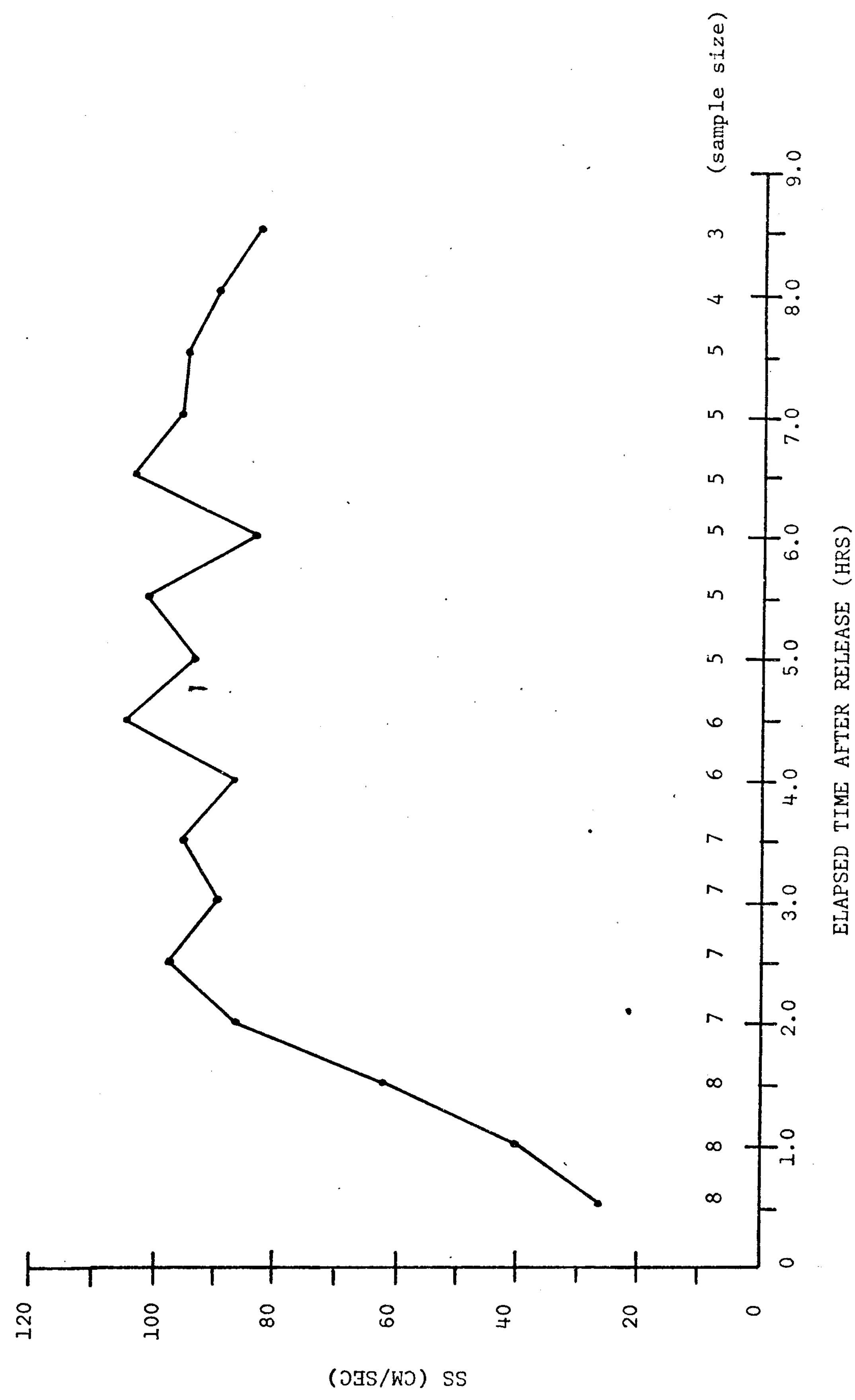

SS (CM/SEC)
80
60
40
20
0
ELAPSED TIME AFTER RELEASE (HRS)
1.0
2.0
3.0
4.0
5.0
6.0
(sample size)
10
10
10
9
7
6
5
2
2

Figure 7. Mean Swimming Speed *vs* Elapsed Tracking Time: 1972.


SS (CM/SEC)
0
20
40
60
80
100
120
ELAPSED TIME AFTER RELEASE (HRS)
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
(sample size)
8 8 8 7 7 7 7 6 6 5 5 5 5 5 5 4 3

performed on the data represented in Figures 5, 6, and 7. The first of these, the Friedman two-way analysis of variance, was applied to the three sets of means for the first 4-1/2 hours of elapsed tracking time. This test showed that for all years considered together, the change of mean swimming speed with elapsed time was greater than would be predicted by chance ($N = 3$, $k = 9$, $x_r^2 = 19.11$, $.02 > P > .01$). Application of the second test, the sign test, to swimming speeds of individual salmon averaged over early and late 1 or 1-1/2 hour intervals of their tracks yielded similar results: increase in swimming speed with elapsed time for each year was greater than would be predicted by chance (in each case, $N = 5$, $x = 0$, $P = .031$). This trend of slower speeds during the first 60 to 90 tracking minutes was very nearly the same as that shown by sockeye salmon (*Oncorhynchus nerka*) observed by Madison et al. (1972). Our data also indicate that homing tendency is not apparent during this time. These slower speeds and the absence of homing tendency should not be considered surprising since fish had just previously been subjected to anesthesia and transmitter attachment or insertion, and then had been released into an "unfamiliar" area of the lake. However, this delay in leaving the release area may not have been due to transmitter effects, but could have been caused by a lack of orientation.

Comparison of Figures 5, 6, and 7 also suggests that mean swimming speeds were similar in 1969-1970 and 1972, but were lower in 1971. The Kruskal-Wallis one-way analysis of variance was applied to the three entire sets of mean swimming speeds of Figures 5, 6, and 7 to determine whether it was likely that the three sets of means had been obtained from sampling identical populations. The result showed that differences among the three sets of mean swimming speeds were greater than would be predicted by chance ($N = 41$, $k = 3$, $H = 11.48$, $.01 > P > .001$). Using the Mann-Whitney U test, each set of mean swimming speeds was then compared with each of the other two sets to determine the relative stochastic rank of each set of mean swimming speeds. The 1969-1970 and 1972 sets did not differ significantly ($n_1 = 16$, $n_2 = 16$, $U = 112$, $P > .10$), but the 1971 set of mean swimming speeds was stochastically lower than either the 1969-1970 set ($n_1 = 9$, $n_2 = 16$, $U = 19$, $P = .001$) or the 1972 set ($n_1 = 9$, $n_2 = 16$, $U = 18.5$, $P < .001$).

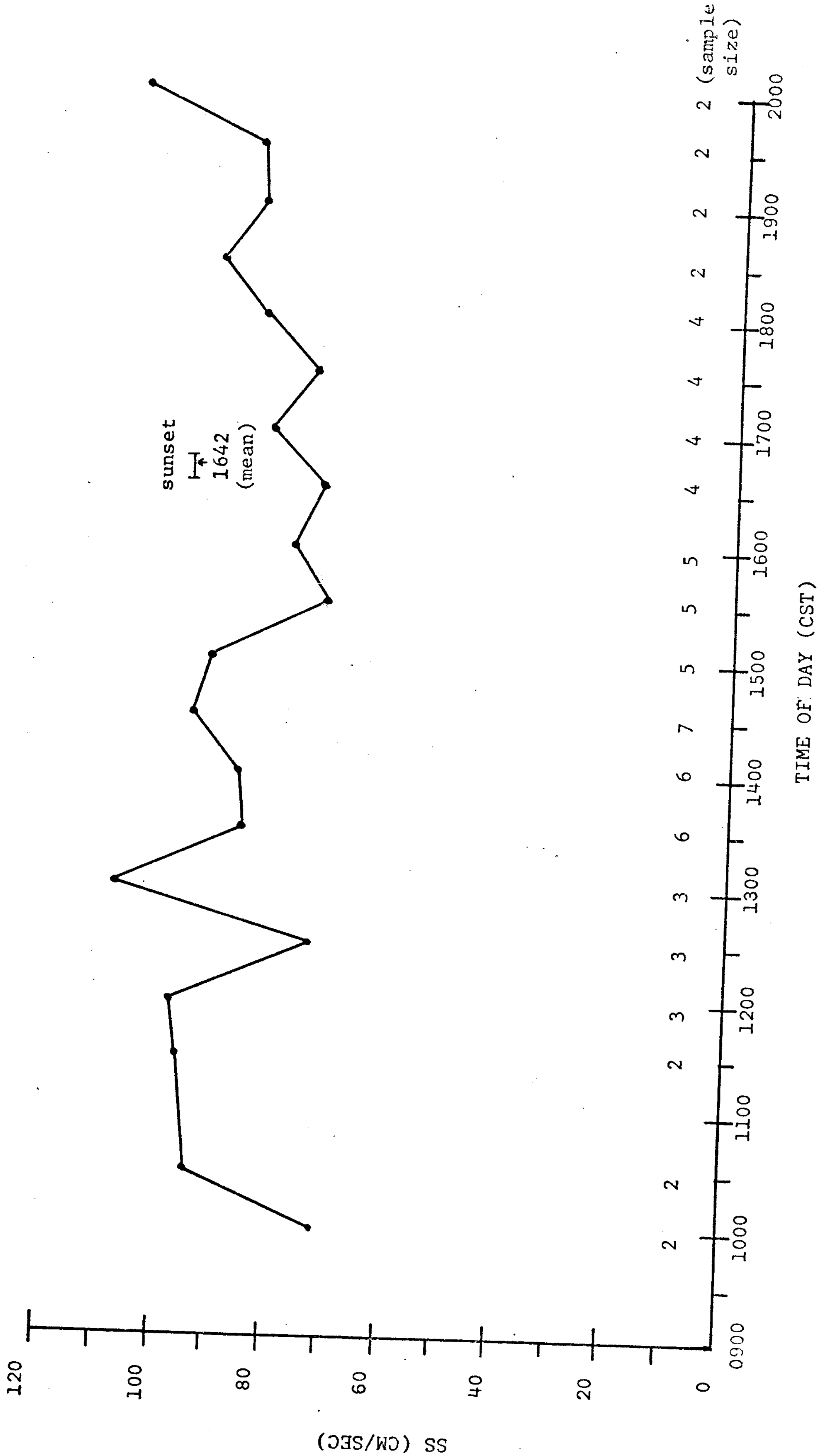
The 1971 coho were released in water less than 10 m deep, and tended to remain in shallow water during their tracks. On the other hand, 1969, 1970, and 1972 salmon were released in water deeper than 15 m and generally remained offshore.

## 7. Mean Swimming Speeds: Time of Day

Mean swimming speeds according to time of day were calculated for yearly groups of salmon, and are presented in Figures 8, 9, and 10. Swimming speeds during the first hour of each track were not included in the calculation of these mean speeds, since, as discussed in the previous section, fish did not have normal speeds during this period (see also Figures 5, 6, and 7). Again, because of the small 1969 sample size, 1969 and 1970 data were pooled for calculations of means. Table A-5 of the Appendix gives the numerical values of these mean swimming speeds and the standard deviations of the data from which they were calculated.

Because of the small sample sizes at early and late times of day, statistical testing of daily swimming speed patterns was not possible except for mean speeds around sunset for the salmon tracked in 1972. Inspection of Figure 8 suggests that the mean swimming speeds of 1969-1970

Figure 8. Mean Swimming Speed _vs_ Time of Day: 1969 and 1970.



SS (CM/SEC)
0
20
40
60
80
100
120
TIME OF DAY (CST)
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2 2 2 3 3 3 6 6 7 5 5 5 4 4 4 4 2 2 2 2 (sample size)
sunset
1642
(mean)

Figure 9. Mean Swimming Speed vs Time of Day: 1971.

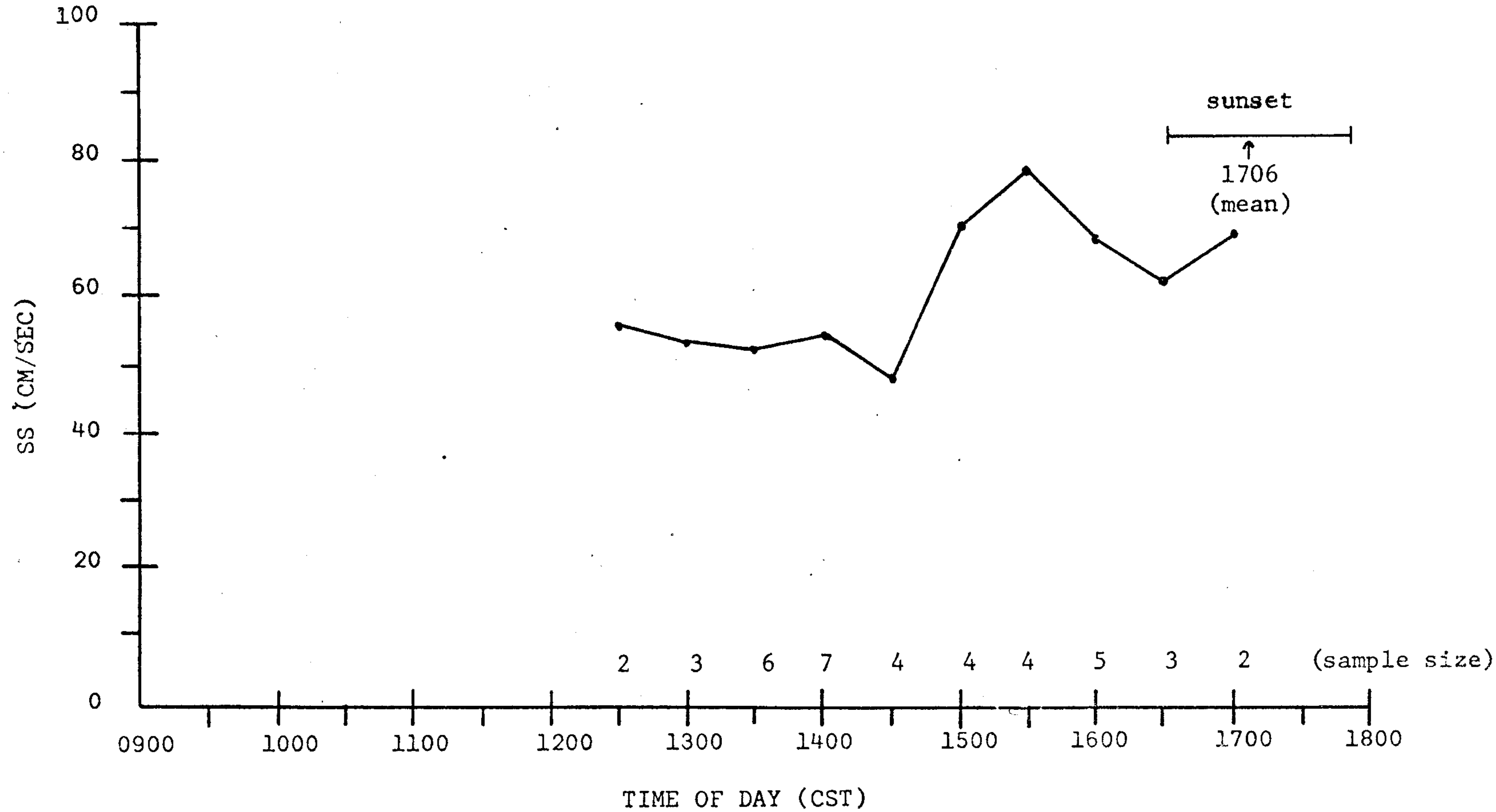
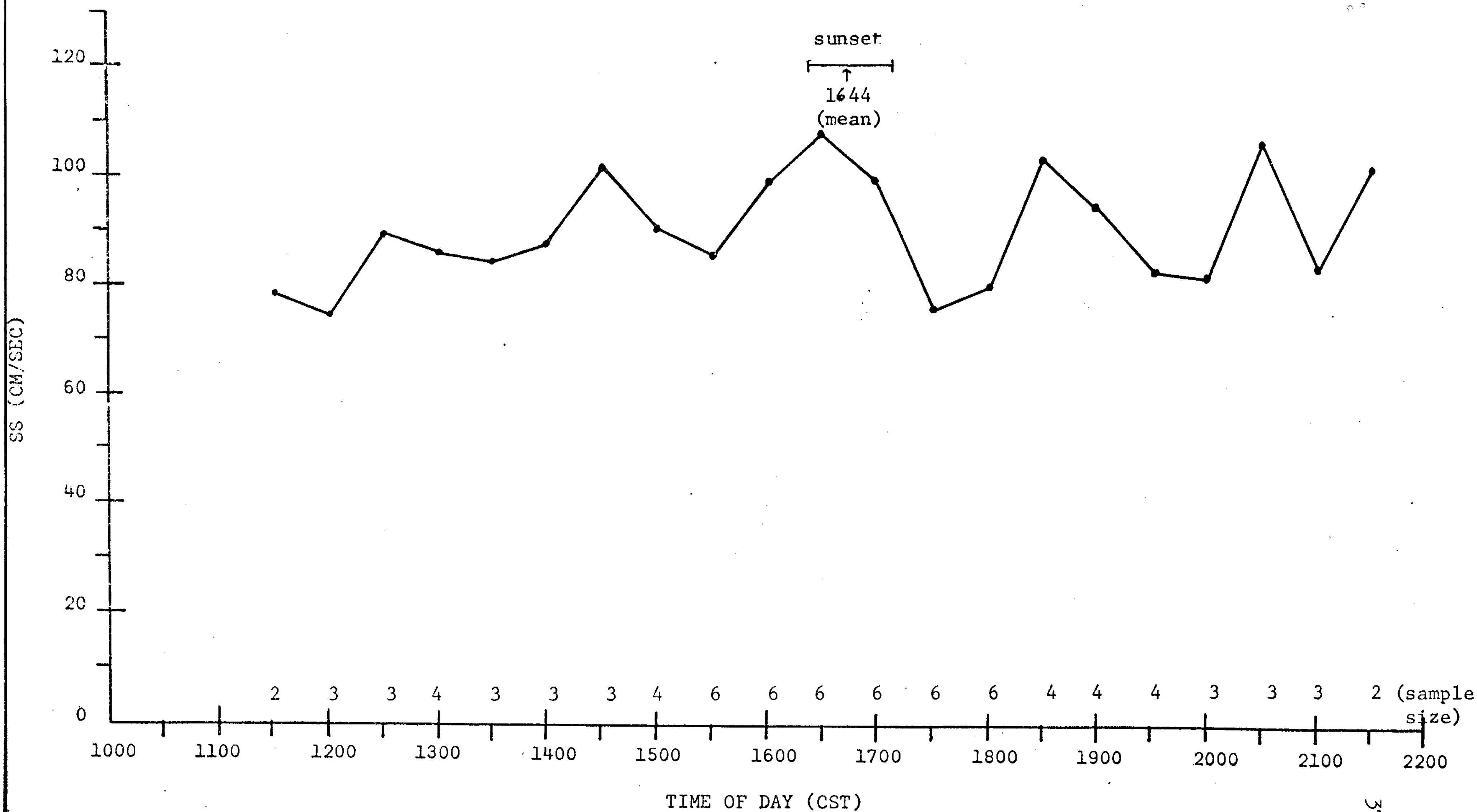

sunset
1706
(mean)
100
80
60
40
20
0
SS (CM/SEC)
2 3 6 7 4 4 4 5 3 2 (sample size)
0900 1000 1100 1200 1300 1400 1500 1600 1700 1800
TIME OF DAY (CST)

Figure 10. Mean Swimming Speed _vs_ Time of Day: 1972.


sunset
1644
(mean)
SS (CM/SEC)
0
20
40
60
80
100
120
2 3 3 4 3 3 3 4 6 6 6 6 6 6 4 4 4 3 3 3 2 (sample size)
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
TIME OF DAY (CST)

fish did not change with time of day. Fish tracked in 1971 exhibited an apparent peak in mean swimming speed between 1500 and 1600 hrs Central Standard Time (Figure 9). Of the four salmon whose swimming speeds were used to calculate the mean speeds between 1500 and 1600 hrs, three (Salmon Nos. 7110, 7111, and 7112) had first begun swimming north during this time period. The 1972 fish showed an apparent maximum mean swimming speed just before mean sunset time and an apparent minimum just after mean sunset (Figure 10). No other change with time of day was apparent for 1972 salmon, but sample sizes at early and late times of day were small. Individual swimming speeds contributing to the 1972 peak around sunset (from 1530 to 1730 hrs inclusive) were examined using Friedman two-way analysis of variance. The result showed that differences in swimming speeds at the five different time points of the peak (1530, 1600, 1630, 1700, 1730 hrs) were greater than would be predicted by chance ($N = 6$, $k = 5$, $x_r^2 = 9.90$, $.05 > P > .02$). I then applied the sign test to more closely examine possible differences in speed at each time point as compared with speeds at each of the other four time points in the peak. The results of the ten comparisons showed that differences in swimming speeds for each pair of time points considered could all be accounted for by chance ($N = 5$ or $6$; $x = 1, 2,$ or $3$; $P > .10$) <u>except</u> in the case of the comparison between speeds at 1630 hrs and 1730 hrs ($N = 6$, $x = 0$, $P = .016$). In summary then, for 1972 salmon, swimming speeds for the time interval 1715 to 1745 hrs (1/2 to 1 hour after mean sunset) were significantly lower than those for the interval 1615 to 1645 hrs (the half hour immediately preceding mean sunset).

8. Mean Angular Changes: Elapsed Time After Release

Mean angular changes (without regard to direction of turning) according to elapsed time after release were calculated for 1970 and 1972 and are presented in Figures 11 and 12. These means are the arithmetic means of turns made by individual fish at the particular elapsed times of their tracks. Table A-6 of the Appendix gives the numerical values of these means and the standard deviation of the data from which each was calculated.

One salmon in 1970 (No. 7006) and another in 1972 (No. 7206) made two large turns in succession at the approximate time-midpoint of their respective tracks. Inspection of scatter diagrams of individual angular changes versus elapsed time for 1970 and 1972 led me to conclude that in each case these large turns at an advanced elapsed track time were probably not consistent with the general trend shown by other salmon that year. Note, however, that the sample sizes were small. Additionally, if in each case the two large turns are included in calculation of mean turns, these elevated means have anomalously high corresponding standard deviations (see Appendix, Table A-6). The means including these large turns are connected by dashed lines in Figures 11 and 12; means excluding the large turns are connected by solid lines.

The apparent general trend for both 1970 and 1972 was a decrease in mean angular change with elapsed tracking time. The 1970 sample size was too small to permit statistical examination, however. The sign test was applied to the 1972 data, comparing angular changes of individual salmon averaged over early and late two hour segments of their tracks. Results indicated that decrease of angular change (i.e.

Figure 11. Mean Angular Change (Turns) *vs* Elapsed Tracking Time: 1970.

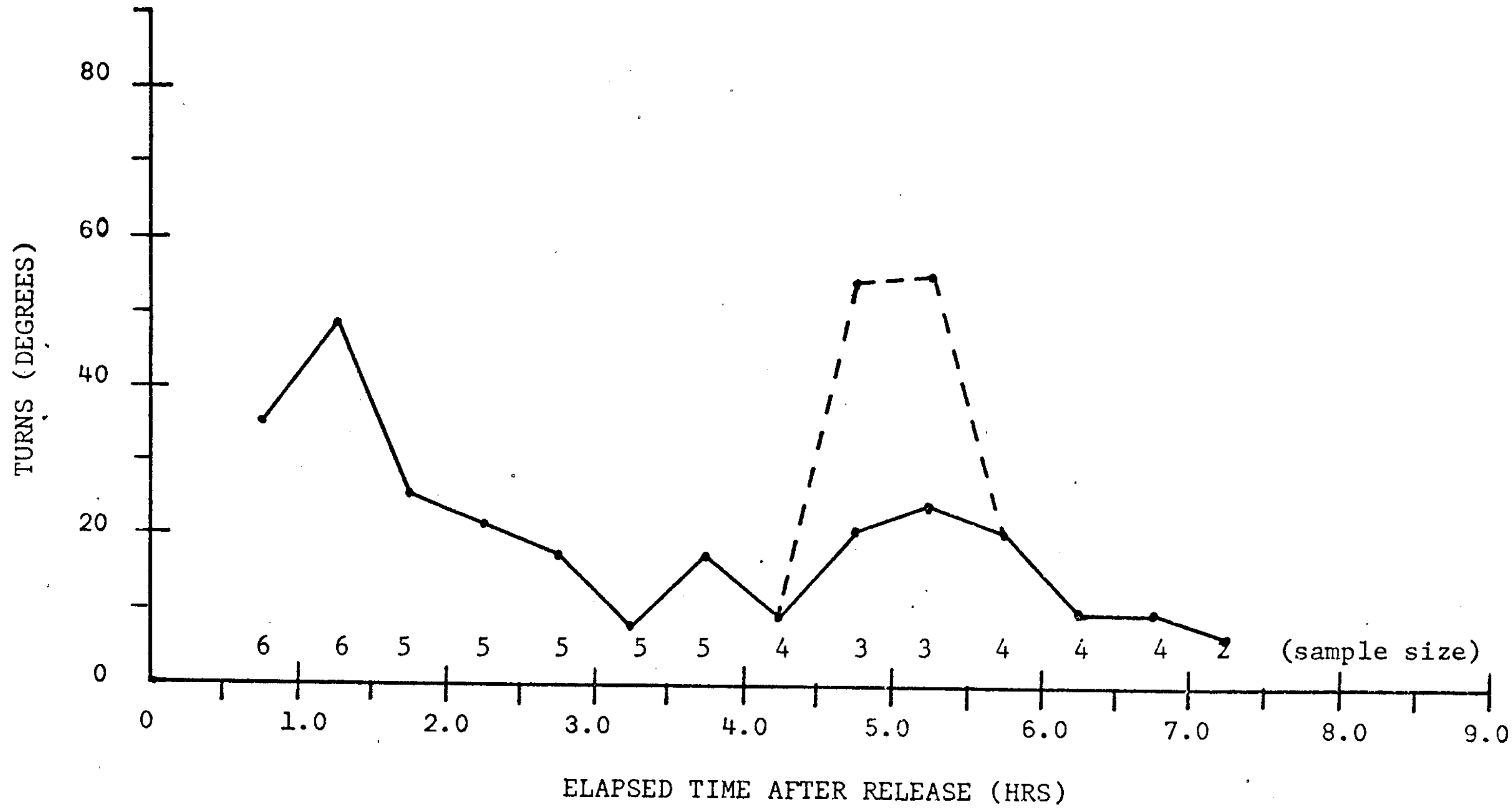
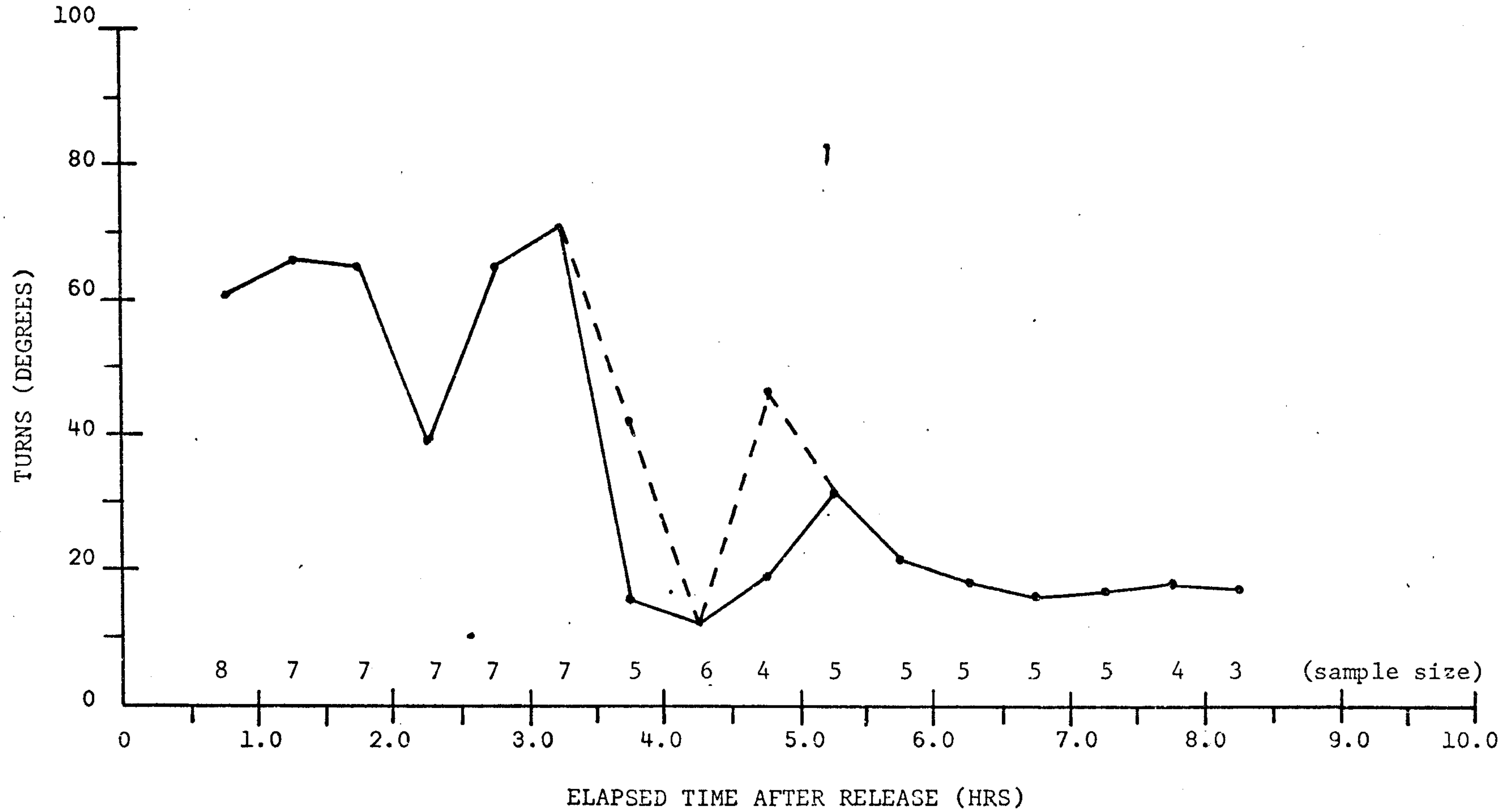

TURNS (DEGREES)
80
60
40
20
0
6 6 5 5 5 5 5 4 3 3 4 4 4 2 (sample size)
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
ELAPSED TIME AFTER RELEASE (HRS)

Figure 12. Mean Angular Change (Turns) *vs* Elapsed Tracking Time: 1972.


TURNS (DEGREES)
0
20
40
60
80
100
8 7 7 7 7 7 5 6 4 5 5 5 5 5 4 3 (sample size)
0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
ELAPSED TIME AFTER RELEASE (HRS)

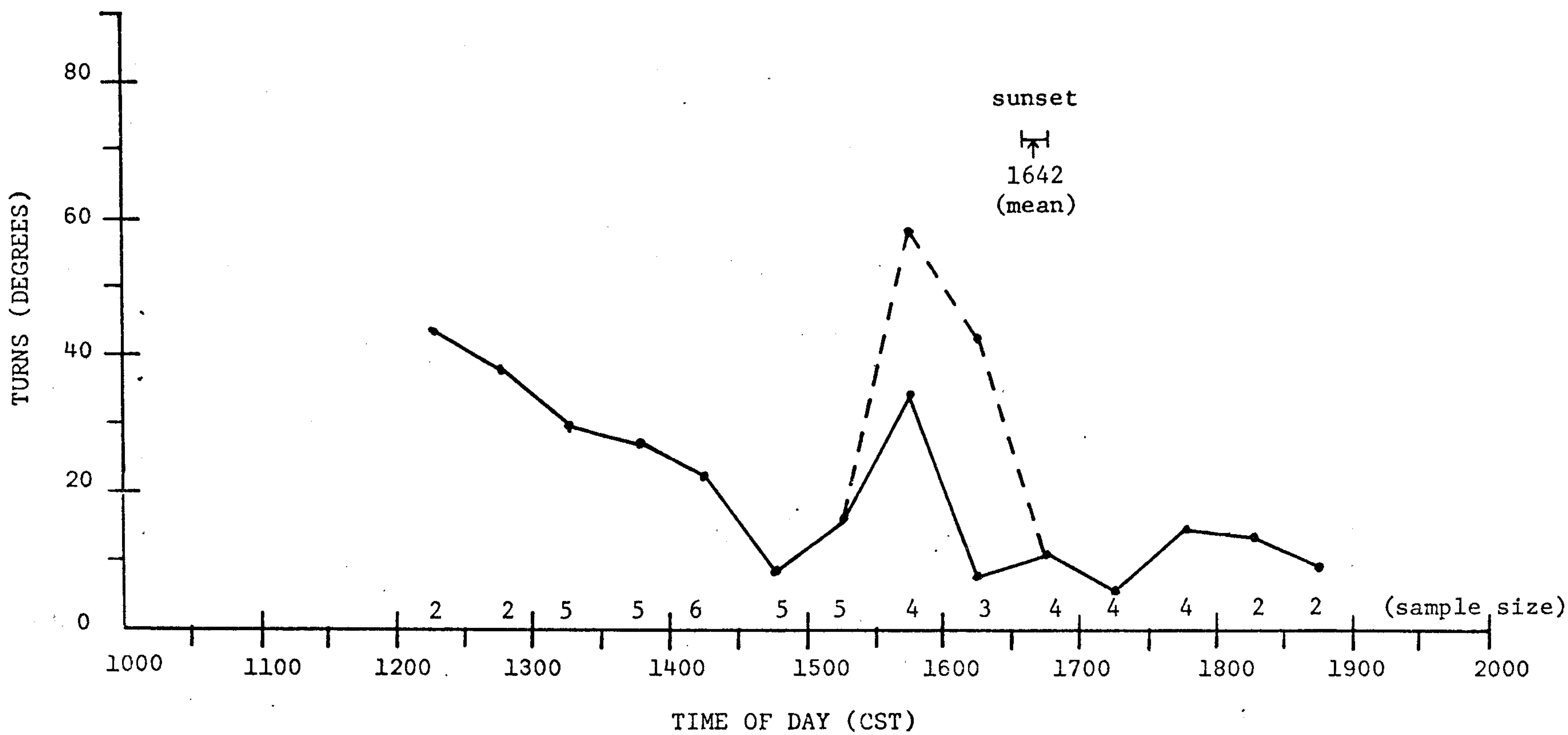
magnitude of turns) with elapsed tracking time in 1972 was greater than would be predicted by chance (N = 5, x = 0, P = .031). The 1971 mean angular changes versus elapsed time were not examined because of the probable bias due to encounters of some 1971 salmon with the Point Beach thermal plume; additionally, 1971 tracks were comparatively short.

9. Mean Angular Changes: Time of Day

Mean angular changes (arithmetic means, without regard to direction of turning) plotted versus time of day for 1970 and 1972 groups of salmon are presented in Figures 13 and 14. Table A-7 of the Appendix gives the numerical values of these means and the standard deviation of the data from which each was calculated. Angular changes during the first tracking hour were not included in the calculations of these means. The 1971 tracks were too short to allow a meaningful examination of angular change versus time of day data. Possible bias due to plume encounters of some 1971 salmon also precluded such an analysis.

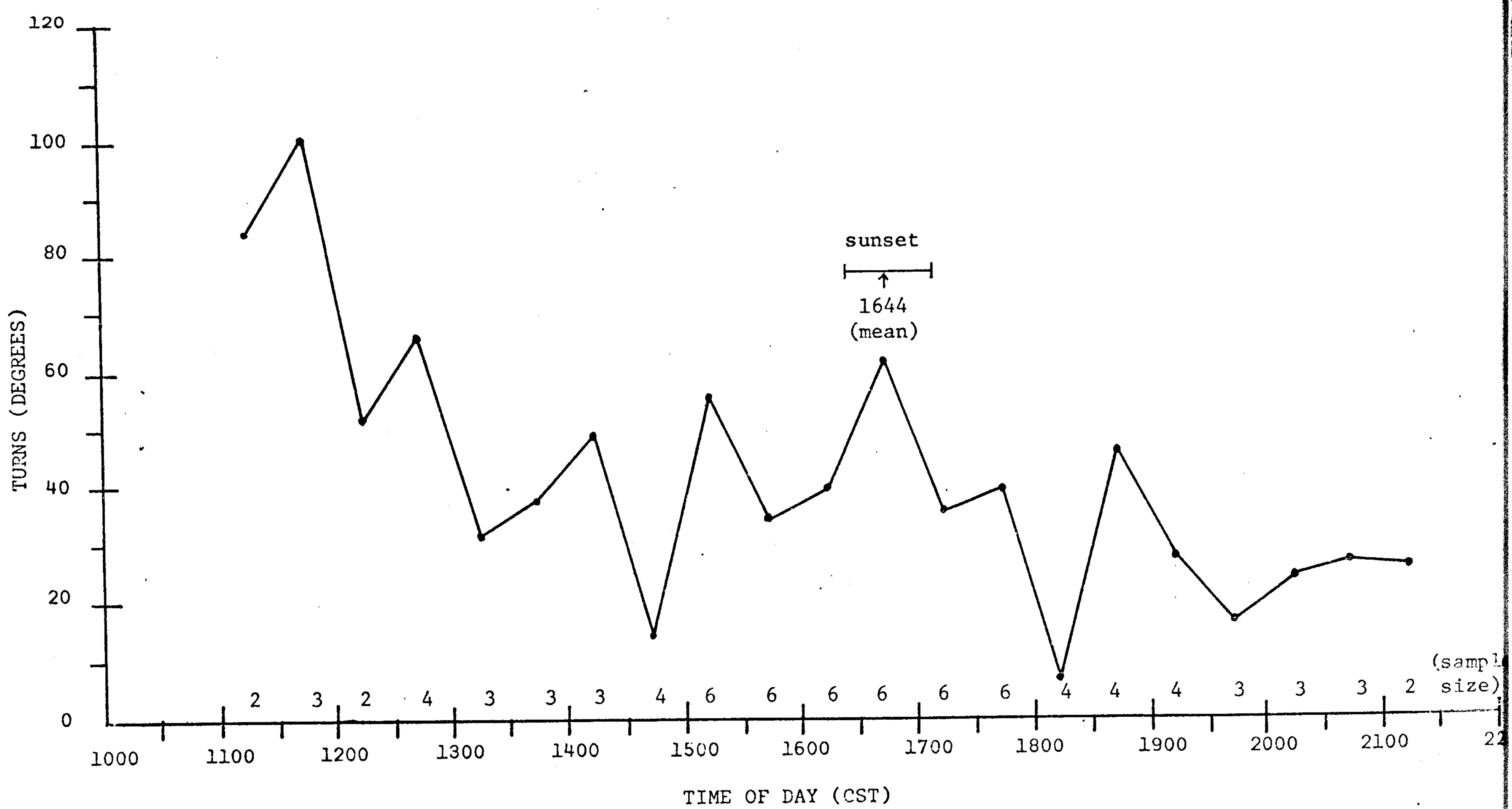
With regard to the two consecutive large turns of Salmon No. 7006 (mentioned in the previous section), inspection of a scatter diagram of individual angular changes versus time of day for 1970 again showed that these turns were probably not consistent with the general trend shown by other fish that year. Note that the sample size was small, however. The two elevated means which include these large turns of Salmon No. 7006 have anomalously high corresponding standard deviations (Appendix, Table A-7), a case similar to that pointed out in the previous section. The means including these large turns are connected by dashed lines in Figure 13, while those calculated without the turns are connected by solid lines. A similar conclusion for the large mid-track turns of

Figure 13. Mean Angular Change (Turns) vs Time of Day: 1970.



sunset
1642
(mean)
TURNS (DEGREES)
80
60
40
20
0
2
2
5
5
6
5
5
4
3
4
4
4
2
2
(sample size)
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
TIME OF DAY (CST)

Figure 14. Mean Angular Change (Turns) vs Time of Day: 1972.



sunset
1644
(mean)
TURNS (DEGREES)
0
20
40
60
80
100
120
TIME OF DAY (CST)
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
22
(sampl
size)
2 3 2 4 3 3 3 4 6 6 6 6 6 6 4 4 4 3 3 3 2

Salmon No. 7206 does not appear to be justified: a scatter diagram of 1972 individual angular changes versus time of day shows great variability throughout most of the time period considered; standard deviations of sets of data are also consistently large for most of the period (see Table A-7 of the Appendix). Therefore the two large mid-track turns of Salmon No. 7206 are included in calculation of mean angular change at 1745 hrs and 1845 hrs in Figure 14. In any event, neither inclusion nor exclusion of the large mid-track turns of Salmon No. 7206 precludes a general observation based on the 1972 data.

The apparent trend for both 1970 and 1972 was a decrease in magnitude of turns as time of day progressed. Sample size was too small for valid statistical testing of either trend.

The 1970 salmon had an apparent peak in magnitude of turns at 1545 hrs. This peak (Figure 13) might have been correlated with elapsed tracking time rather than with time of day, since there is a flatter corresponding peak in the mean angular change versus elapsed time plot (Figure 11). This question is considered in the Discussion section.

No mean angular change fluctuation is apparent around mean sunset time for 1970, but again the sample size was too small for statistical testing. However, for 1972 there is an apparent peak in angular change around mean sunset time, and a sufficiently large sample size to permit application of Friedman two-way analysis of variance to the data from the entire peak. The result of the test indicated that differences among magnitudes of turns at the five time points of the peak (1545, 1615, 1645, 1715, and 1745 hrs) could be accounted for by chance alone ($N = 6$, $k = 5$, $x_r^2 = 7.87$, $.10 > P > .05$).

### 10. Shallow Versus Deep Water Release: Tendency of Salmon to Go to Shore Early in the Track

Salmon from all years whose tracks were sufficiently long were placed into one of two categories according to water depth at their respective release points. The shallow water release group consisted of ten fish (all tracked in 1971), each released in water less than 10 m deep. There were fourteen salmon (3 from 1969, 5 from 1970, and 6 from 1972) in the deeper water release group, each of which had been released at points with water depths greater than 15 m. Each fish was then classified according to a second criterion, i.e. whether or not it had gone to shore in the immediate vicinity of its release point. Of the fourteen salmon released in deeper water, four went to shore very near their release points and ten did not. Of the ten fish released in shallow water, eight went to shore in the immediate vicinity of their release points and two did not. These data were cast in the form of a 2 x 2 table and the Fisher 2 x 2 test applied. The result indicated that the greater (lesser) tendency of shallow- (deep-) water-released salmon to go immediately to shore probably cannot be explained on the basis of chance alone ($P \leq .025$). As previously mentioned, 1971 coho had significantly lower swimming speeds than did fish tracked in other years.

## E. CONCLUSIONS

### 1. Effects of the Transmitter on Behavior of Salmon

Because of our careful attention to transmitter attachment or insertion, possible adverse effects resulting from tagging and handling operations mentioned by Verhoeven and Davidoff (1962) were considered to be minimal. Behavioral effects due to the carrying of a transmtter are unknown for salmon (Madison et al. 1972). Shepherd (1973) observed that different methods of transmitter attachment may have different effects on fish activity level. An obvious consideration for either internally- or externally-borne transmitters would be the hydrostatic adjustment required by the animals due to the negative buoyancy of the transmitters. Gallepp and Magnuson (1972) showed that bluegills (*Lepomis macrochirus*), which are physoclists, require at least four to five hours under laboratory conditions to hydrostatically adjust to the simulated weight of a transmitter.

While being held in the canvas transport bag after transmitter attachment and prior to release, many of our 1971 and 1972 coho were observed coming to the water surface and gulping air, presumably for purposes of hydrostatic adjustment, since salmonids are physostomous. The animals were probably not completely adjusted hydrostatically before release, but in all cases the fish were observed to be swimming actively just after release. Also, none of our salmon showed serious equilibrium problems just prior to release.

Salmon carrying transmitters externally in 1972 had mean swimming speeds which were comparable with 1969 and 1970 fish bearing transmitters internally. The coho tracked in 1971 with external transmitters had significantly lower swimming speeds than either the 1969-1970 fish or the 1972 group. However, the 1971 coho followed shallow water paths, whereas fish tracked in other years usually swam northward in deeper water. Thus the slower swimming speeds of 1971 fish were probably due to swimming in shallower water and not to external transmitter effects.

No differences due to internal versus external transmitters were apparent in mean swimming directions, nor in the general trend of progressively smaller turns with elapsed track time.

There was no apparent difference in general track path type due to left- versus right-side dorsal fin attachment of external transmitters for either 1971 or 1972 coho. In 1972, two fish carrying the external transmitter on the left side of the dorsal fin (Salmon Nos. 7204 and 7207) swam away from shore to the northeast for five and four hours respectively. However, two 1972 coho with transmitters on the right side (Salmon Nos. 7201 and 7205) also had initial northeasterly track path segments, lasting three hours in each case.

External transmitter attachment could be considered superior to internal insertion for the following reasons:

(1) The insertion method requires that great care be taken to avoid internal injuries to the animal, particularly rupture of the delicate esophagus or stomach walls, or deflation or rupture of the swim bladder;

(2) There is little chance a properly attached external transmitter will be dislodged from the dorsal fin base. On the other hand, internal transmitters might be regurgitated;

(3) External attachment allows rapid temperature response by the transmitter. Internal insertion of temperature-sensitive transmitters would require insulated wire leads between the temperature sensor (thermistor) in the fish's mouth and the transmitter in the stomach;

(4) Fish carrying transmitters internally must have an external tag (e.g. a Floy tag) for purposes of identification upon recapture. External transmitter attachment obviates the need for a second identification tag.

However, external attachment is probably inferior to internal insertion for these reasons:

(1) Drag and turbulence caused by external transmitters could affect swimming speed and the pattern of water flow past the dorsal fin;

(2) The salmon's center of gravity is shifted toward the dorsal surface by an external transmitter's weight. An internal transmitter of identical weight causes a smaller shift, and in the opposite direction (i.e. ventrally).

We noticed no apparent effects on homing or movement of Lake Michigan coho which could be attributed to the transmitters (except for Salmon No. 7101, which was probably traumatized due to suturing of the transmitter to the animal's dorsal flesh). Madison et al. (1972) have stated that "during ultrasonic tracking studies of 189 salmon of four species since 1967, the transmitter has not noticeably impeded sustained movement or successful return to home river systems."

2. Homing Behavior Trends

Most of the individual adult coho had a high "degree of orientation" toward the home direction. Likewise, yearly groups of fish all showed significant orientation toward the north. No day versus night differences in orientation were observed--fish continued to swim north at night with about the same swimming speeds as during daylight hours. This observation differs from that of Madison et al. (1972), who found a diurnal pattern of swimming speed and a decrease in degree of orientation at night for sockeye salmon tracked in the coastal waters of northern British Columbia.

As a group, the thirteen coho tracked more than two hours and in deeper water were not well oriented for the first hour of tracking, but subsequently showed excellent orientation toward their home stream at Algoma. Mean swimming speeds and angular changes (turns) were well correlated with this trend of progressively improving orientation: for each year, mean swimming speeds of salmon steadily increased for about the first 1-1/2 to 2 hours of tracking, then leveled off and remained fairly constant; for 1970 and 1972 (the only years for which the data were examined), mean angular changes (turns) generally tended to decrease as time after release (elapsed tracking time) progressed, leveling off about 3-3-1/2 hours after release. These trends of initially low homing tendency, low swimming speeds, and large magnitude of turns may have been due to (1) anesthesia, (2) handling and/or transmitter effects, or (3) release of the salmon into an "unfamiliar" area of the lake.

There was no apparent changes in mean swimming speed correlated with time of day, except for 1971 coho at 1530 hrs CST, and around mean sunset time (1644 hrs CST) for 1972 fish. The peak in mean swimming speed at 1530 hrs for 1971 coho was due to three fish (Salmon Nos. 7110, 7111, and 7112), each of which had just begun swimming north at this time, having previously been obviously disoriented. The peak in mean swimming speed for 1972 fish appears to be well correlated with sunset, the analysis indicating that 1972 salmon significantly reduced speed at sunset, subsequently resuming higher speeds about 1-1/2 to 2 hours after sunset.

Mean angular change (magnitude of turns) decreased as the day progressed (1970 and 1972 fish), but this apparent trend may be artificial, since sample sizes were small for early and late time segments in the time of day period considered. An apparent peak in angular change at sunset for 1972 fish was found to be not significant ($.10 > P > .05$), although further data might establish significance. Also, mean angular change (turns) versus time of day trends for 1970 and 1972 coho are very similar to those of mean angular change versus elapsed tracking time (see Figures 11, 12, 13, and 14); thus the general time of day trend (i.e. progressive decrease in magnitude of turns) may merely be a manifestation of the effect of elapsed tracking time. Elucidation of this question must await further data.

Track paths were of three general types: twelve coho went to shore soon after release and usually followed the shoreline north, six went to shore later in their tracks and continued north, and a third group consisting of six fish swam north while remaining offshore in deeper water throughout their tracks. The general path types of three salmon could not be established because of the shortness of their tracks. Fish released in shallow water (less than 10 m deep) close to shore showed a significant tendency to go immediately to shore and remain there for the duration of the tracking period. Similarly, those coho released in deeper water (depth greater than 15 m) tended to remain offshore during their tracks.

Throughout their tracks, mean swimming speeds of fish following shallow water paths in 1971 were significantly lower than swimming speeds of fish tracked in deeper water (see Figures 5, 6, and 7). The average swimming speed for 1971 coho (shallow water) was 48.7 cm/sec, and that for 1969, 1970, and 1972 fish combined (deep water) was 73.6 cm/sec. These observations differ from those of McCleave and Horrall (1970) on cutthroat trout (*Salmo clarki*) tracked ultrasonically in Yellowstone Lake. Individuals of the latter species increased their swimming speed from about 23 to 37 cm/sec when swimming near shore. Four out of five coho tracked in deeper water and which eventually went to shore late in their tracks also had generally slower swimming speeds when shallow water was entered.

Our observed average swimming speed for Lake Michigan coho salmon tracked in deep water (9.3-216.2 cm/sec; 73.6 cm/sec average) was larger than that observed by Madison et al. (1972) for sockeye salmon in coastal waters (5-170 cm/sec; 53 cm/sec average) and also larger than that observed for chinook salmon (Oncorhynchus tshawytscha) in the Columbia River (4-180 cm/sec; 49 cm/sec average) (Johnson 1960). The average swimming speed of Lake Michigan coho tracked in shallow water (4.1-117.4 cm/sec; 48.7 cm/sec average) was comparable to the values observed by Madison et al. and by Johnson.

### 3. Migration Time

The average deep water swimming speed (73.6 cm/sec) of Lake Michigan coho indicates that the animals could have covered the 45 km straight line distance from their release points to the mouth of the home stream at Algoma in as little as 17 hours. One coho (Salmon No. 7002), actually tracked to a point about 5 km south of the home stream mouth (Figures 3b and 3c), covered the 40 km straight line distance in 11.7 hours (average swimming speed 107.8 cm/sec).

### 4. Possible Differences Between 1971 and 1972 Runs

Transmitter and Floy tag recovery data (Table 2) indicate that the "minimum" time taken for return to the homestream weir was five days in 1971 and twelve days in 1972. The weir was not checked every day, however. Consequently these data may be misleading. The peak of the homing run (as judged from Wisconsin DNR seine catches at the homestream weir) occurred later in 1972 than it did in 1971, and for comparable weeks the 1972 run consisted of fewer fish than in 1971 (J. Moore, personal communication). Charter sport fishing vessels reported that in 1972, schools of coho seemed to be congregated in deeper water of the lake offshore from the Ahnapee River mouth. In 1972 the number of fish present in the homestream weir seemed to be greater after rain had fallen.

This observation would accord with those of various investigators cited in Banks (1969). During the two days following the track of Salmon No. 7201, using a portable hydrophone and receiver unit, we patrolled the Ahnapee River from its mouth to 1/2 km upstream from the homestream weir to ascertain whether the fish had continued directly from the lake into the home stream. The results of the search were negative.

It thus appeared that 1972 fish delayed their entrance into the home stream for a longer time than did 1971 salmon.

5. A Possible Case of "Straying"

As noted in Table 2, Salmon No. 7110, initially captured in the Ahnapee River at Algoma, was eventually recaptured in the Bear River at Petoskey, Michigan, five days after its release near the Point Beach Nuclear Plant water intake structure. The minimum distance travelled by this coho was 265 km, with a minimum average swimming speed of 61.5 cm/sec. Two alternative explanations are possible for this apparently anomalous behavior: (1) the Bear River was the actual home stream of the animal, but the fish had become trapped in the Ahnapee River weir while "exploring" the Wisconsin shoreline for its home stream, or (2) the Ahnapee River was the salmon's home stream, but it migrated "by mistake" to the Bear River. In regard to the former possibility, Mr. Jim Winter has informed me (personal communication) that rainbow trout (*Salmo gairdneri*) tracked near the Minnesota shoreline of Lake Superior often ascend several different streams during their spawning season migrations. As to the latter possibility, "straying" of ocean-going salmon (i.e. migrating to the "wrong" stream) is well known (Harden Jones 1968).

## II. 1971 THERMAL TRACKING

### A. INTRODUCTION

Fish can tolerate only a limited increase in water temperature, usually about 5 to 8° C over the natural extremes (Brett 1969). The lethal temperature for juvenile coho salmon is about 25° C (Brett 1952). Coutant (1969a) has shown that adult coho die in approximately 60 minutes at 25° C. Temperature studies were conducted in Lake Michigan near the Point Beach Nuclear Plant site before it began operation (Anon. 1970b). Ambient water temperature, recorded from April to November, 1969, had a natural upper extreme of 22° C in late August. It was also noted that ambient temperature in the beach zone might rise an additional 5 to 6° C every third year. Because the Point Beach Plant discharges water which is a maximum of 10° C above the temperature of intake water (Anon. 1970a), a possibly lethal situation might exist for coho salmon if they were to enter the heated discharge plume and remain there.

Another potentially lethal situation could develop if fish became acclimated to warmer water in the heated outfall area and were then subjected to low-temperature shock due to introduction of colder offshore or subsurface water into the area. Such a case occurred at the Consumers Power Company Campbell Plant at Port Sheldon, Michigan, in 1968 (Robinson 1969).

Sublethal effects of temperature increase have also been documented. Temperature increase can be a 'releaser' for reproductive activity; a heated outfall area may abnormally influence fish spawning migrations (Morgan 1969). This could cause mistiming of spawning or complete failure to spawn.

In studies conducted near the Hanford Nuclear Complex on the Columbia River, Washington, chinook salmon and steelhead trout (*Salmo gairdneri*) were tracked with ultrasonic transmitters. Fish migrated along the shoreline, avoiding the reactor side of the river when heated water was being discharged. Few fish encountered the maximum temperatures of mid-river discharges (Coutant 1969b). In an earlier study, migrating salmon would not enter the Snake River from the Columbia and did not spawn, possibly because of heated effluents (Johnson, personal communication). Johnson and Monan (unpublished data) also performed studies at the Hanford Complex using a transmitter which gave both fish position and water temperature. Fish tracked when the reactors were operating avoided the thermal discharges. When the reactors were off, the salmon swam along both shores in the areas where the heated plumes ordinarily occurred. In this preliminary study with the newly developed transmitter, Monan (personal communication) has indicated that temperature data were limited and difficult to interpret.

Scarpace and Green (1972 and 1973) have stressed the extreme complexity and rapid change of the structure of the Point Beach Plant thermal plume. They state (1973, p. 152)

> To the extent that fairly rapid temperature changes are important to the biota, the instantaneous plume, rather than a time average or climatological plume, is also important. The data strongly indicate that the standard methods of measuring the characteristics of thermal plumes do not reveal actual large temperature gradients, and can also easily lead to erroneous pictures of the mean plume.

It thus appears that the only sensible way to approach the problem of how salmon react to a thermal plume is by using temperature-sensitive fish-borne transmitters. These transmitters must respond rapidly to changes in water temperature and, of course, must be dependable as well as rugged.

The 1971 thermal tracks were performed near Point Beach Nuclear Plant to help answer the following questions:

(1) Will coho salmon which encounter plume temperature gradients attempt to avoid the area, or will they pass through or beneath the plume; i.e. what is their specific behavior in relation to the plume?

(2) If fish pass through or reside in the plume, will their subsequent migratory behavior be adversely affected?

(3) What proportion of naturally migrating coho might be expected to enter the general plume area?

Complete answers to these questions will be necessary for a full assessment of possible effects of thermal plumes on migratory behavior of salmon.

## B. METHODS AND EQUIPMENT

Mr. G. Esterberg of the National Marine Fisheries Service (NMFS) Laboratory, Seattle, Washington, provided the design for our 1971 temperature-sensitive transmitters. The transmitter signal varied directly with water temperature, and was monitored aboard the Aquarius with a gated digital read-out counter-receiver unit connected to a directional hydrophone. The receiver unit was loaned by Mr. J. Johnson of NMFS, Seattle.

We calibrated the temperature-sensitive 70 kHz transmitters in the thermal plume just before each track was begun. A transmitter and the probe of a Whitney-type thermometer were taped to the cone of a small directional hydrophone and the entire apparatus lowered through the plume. Simultaneous readings of transmitter signal from the counter-receiver unit and temperature from the thermometer were recorded and a calibration curve subsequently determined. This type of transmitter had been used previously in thermal tracking studies in the Columbia River (Monan, personal communication).

Salmon No. 7101 carried the transmitter on a plastic saddle attached to the dorsal flesh by suture thread. During its track, we thought it probable that the animal had been severely traumatized by this method of transmitter attachment, judging from its sustained swimming direction (South, away from the home stream) and very low swimming speed (21.9 cm/sec for 5.7 hrs). Therefore for all subsequent 1971 tracks the transmitter was attached to the base of the dorsal fin of the fish as described previously (see Figure 2).

In addition to the Aquarius, a rubber boat 4.2 m in length was used extensively as an auxiliary tracking vessel, since many of the salmon tracked swam into water too shallow for the Aquarius to follow safely. The auxiliary boat was equipped with a portable receiver and hydrophone. Determination of the position of the auxiliary boat using the Aquarius' radar gave accurate fish positions during these shallow water tracks. Tracking vessels were kept at least 50 m from the salmon except when position determinations were being made. Temperature profiles were taken at fish locations at varying time intervals during the tracks. Other environmental data were taken, but not analyzed. Handling of salmon and additional details of tracking procedure have been described in the Methods section of Part I.

General plume location was sometimes evident from differences in turbidity between plume water and lake water. At other times, it was difficult to visually assess plume location.

Fish tracked in 1971 were released near shore about 3 km south of the Point Beach Plant outfall structure, in water less than 10 m deep.

We felt shallow water releases would increase the chance that salmon would later contact the plume.

## C. RESULTS AND DISCUSSION OF THERMAL TRACKING

The pre-track temperature experience of each fish is given in Table A-1 of the Appendix. Track paths of 1971 coho are presented in Figures 15-21, and a running time account of the transmitter-indicated temperatures for each track is given in Table 8. Thermal profiles (taken at fish locations) are presented in Table 7. Table 9 gives swimming speeds of individual salmon which entered the plume.

These data indicate that of ten coho salmon tracked in 1971, five encountered the Point Beach Plant thermal plume during their tracks (Salmon Nos. 7102, 7103, 7105, 7108, and 7109). Of these five fish, three (Nos. 7103, 7105, and 7108) changed swimming direction upon reaching the Plant outfall structure. The transmitters attached to the other two salmon (Nos. 7102 and 7109) failed before sufficient data on plume-associated behavior could be obtained.

Salmon No. 7102 (Figure 15) swam close to shore for most of its track. The transmitter failed near the Point Beach Plant outfall structure, where the water temperature was approximately 16-18° C.

No. 7103 (Figure 16) approached the outfall from the south, swimming about 30 m from shore. During this time, water temperature was 11.0-11.8° C along the animal's path. When the salmon reached the outfall area, it turned offshore, swam 100 m, then turned north. The water temperature at the location where the fish turned offshore was 15.0° C.

Figure 15. Track Path: Salmon No. 7102.

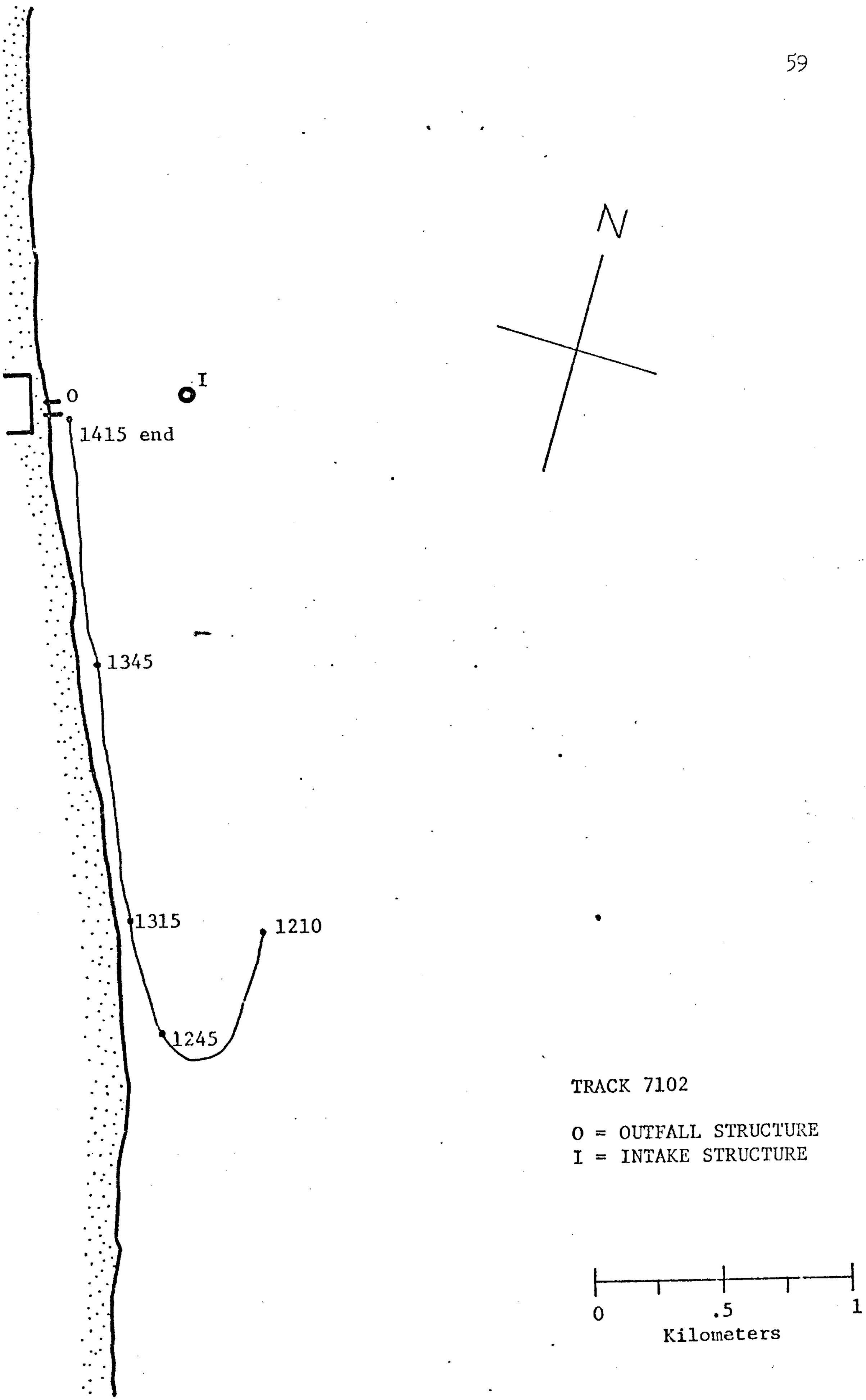

N
O
I
1415 end
1345
1315
1210
1245
TRACK 7102
O = OUTFALL STRUCTURE
I = INTAKE STRUCTURE
0
.5
1
Kilometers

Figure 16. Track Path: Salmon No. 7103.

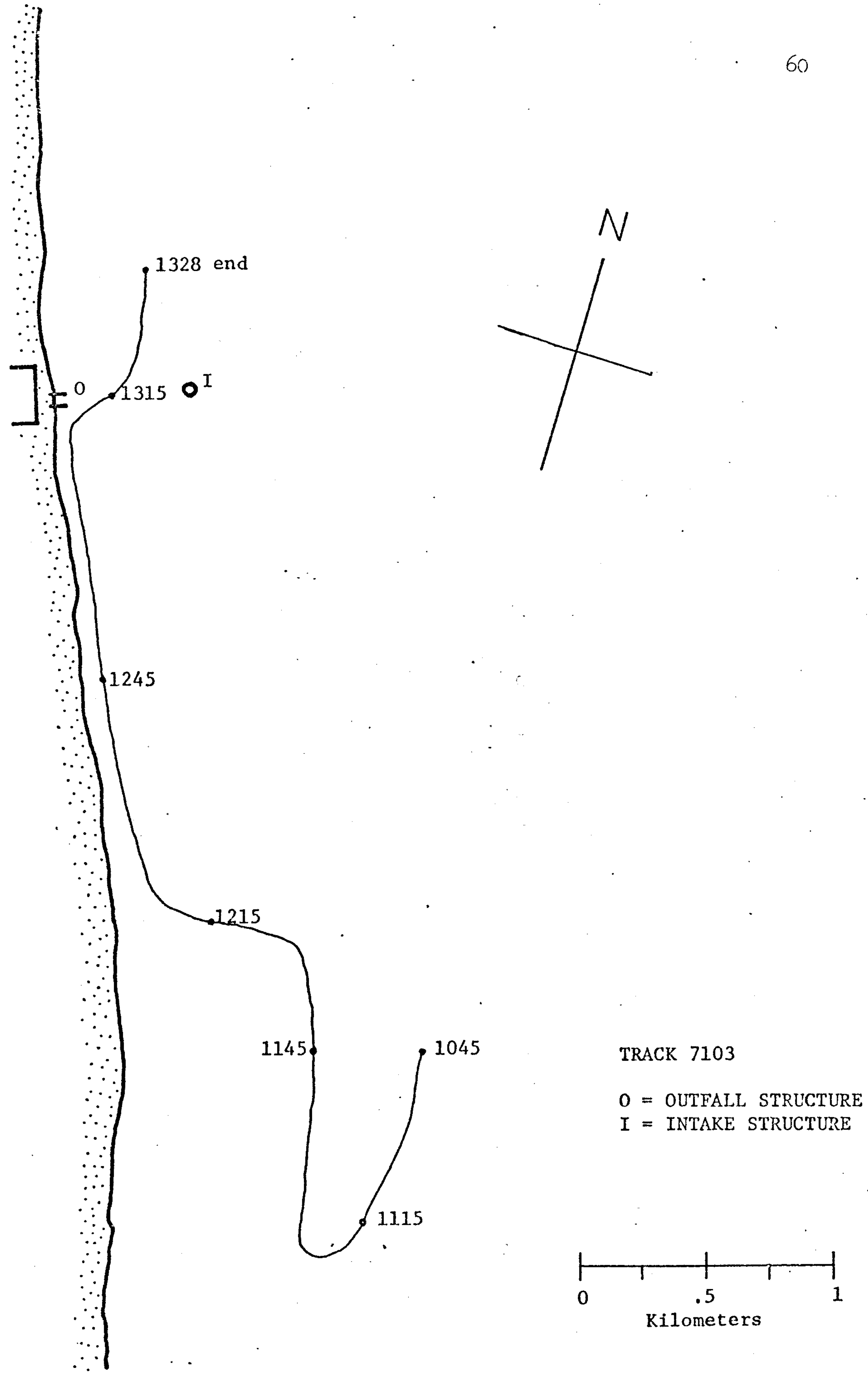

N
1328 end
O
1315
I
1245
1215
1145
1045
1115
TRACK 7103
O = OUTFALL STRUCTURE
I = INTAKE STRUCTURE
0
.5
1
Kilometers

Figure 17. Track Path: Salmon No. 7104.

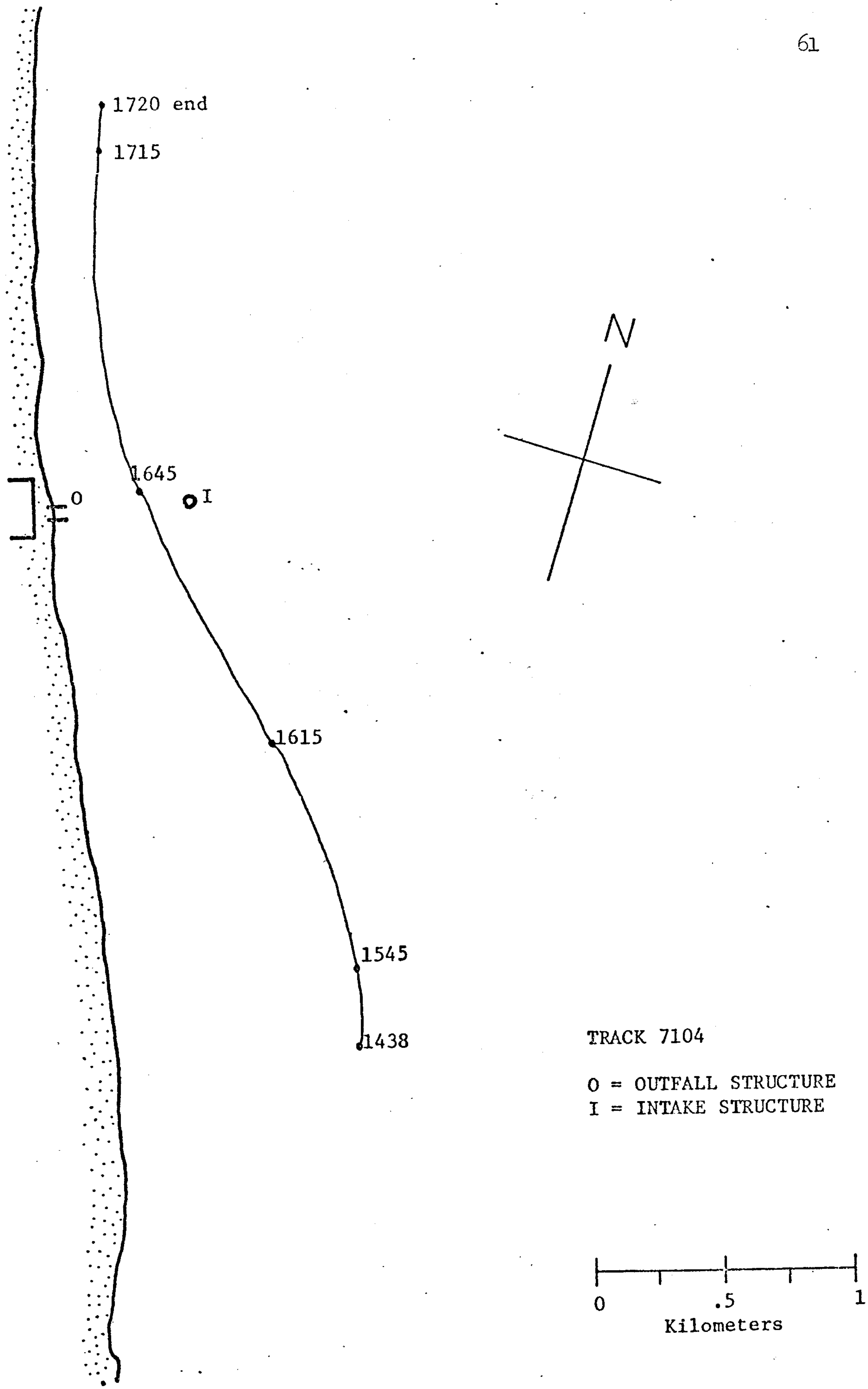
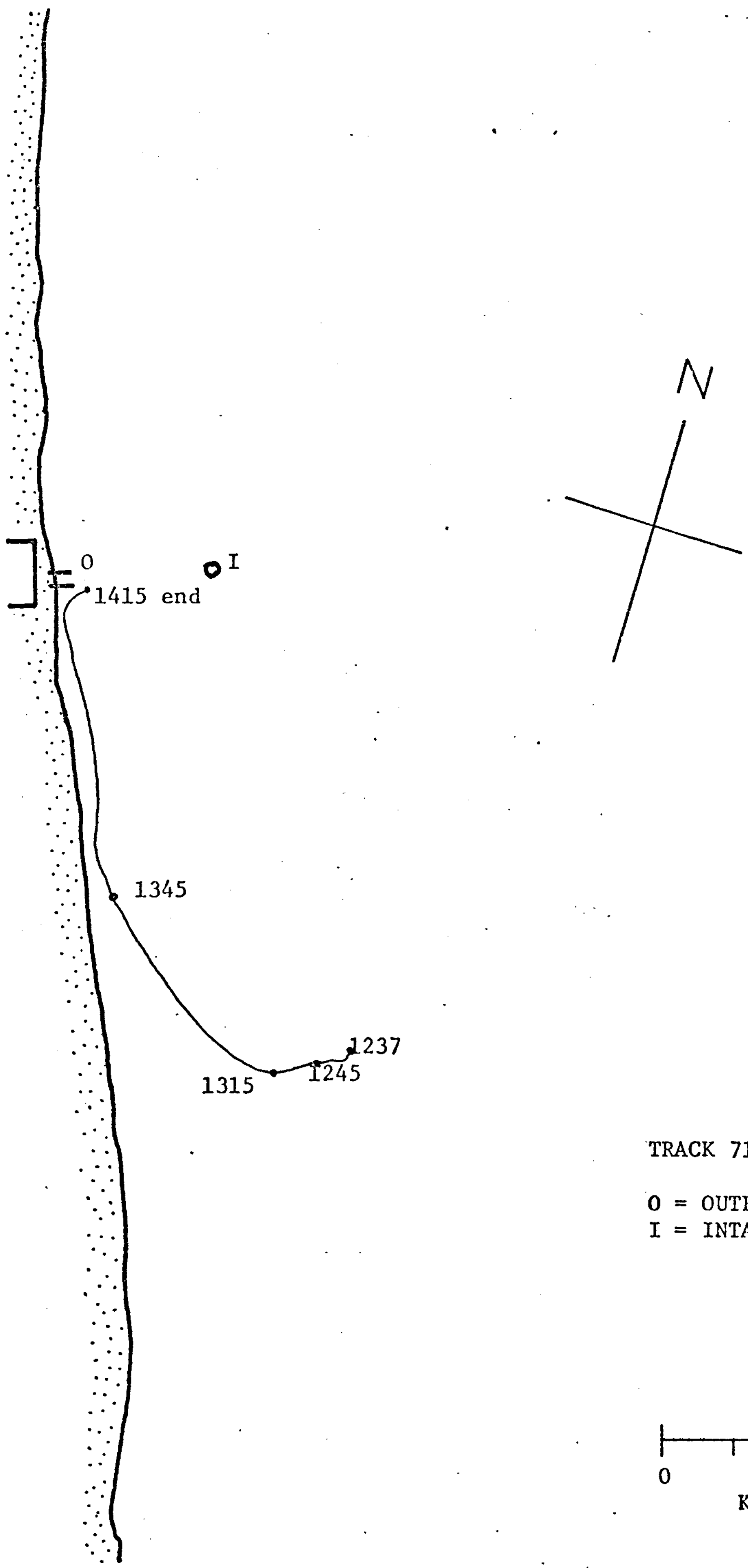

1720 end
1715
1645
O
I
N
1615
1545
1438
TRACK 7104
O = OUTFALL STRUCTURE
I = INTAKE STRUCTURE
0
.5
1
Kilometers

Figure 18. Track Path: Salmon No. 7105.

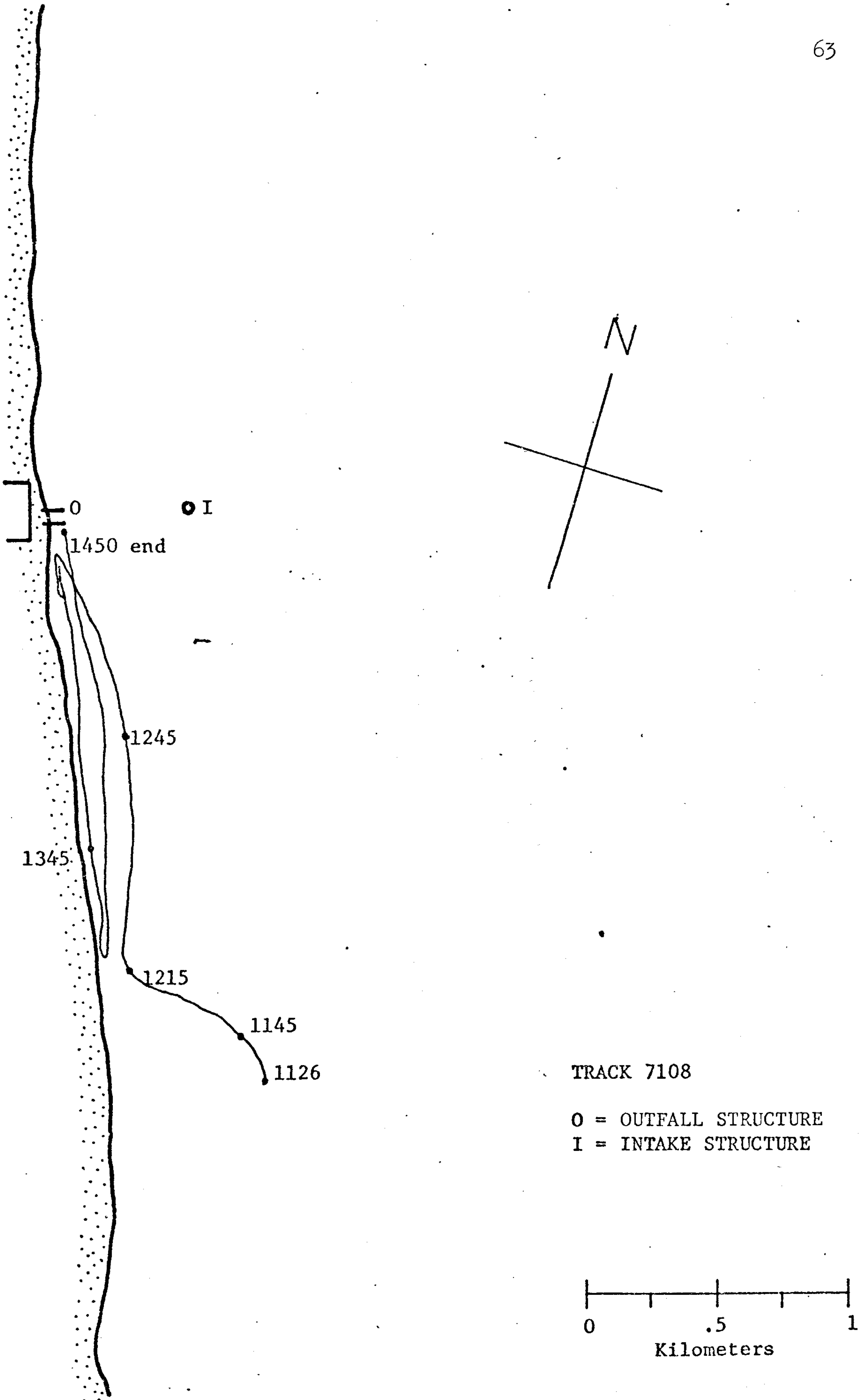



TRACK 7105

O = OUTFALL STRUCTURE
I = INTAKE STRUCTURE

0 .5 1
Kilometers

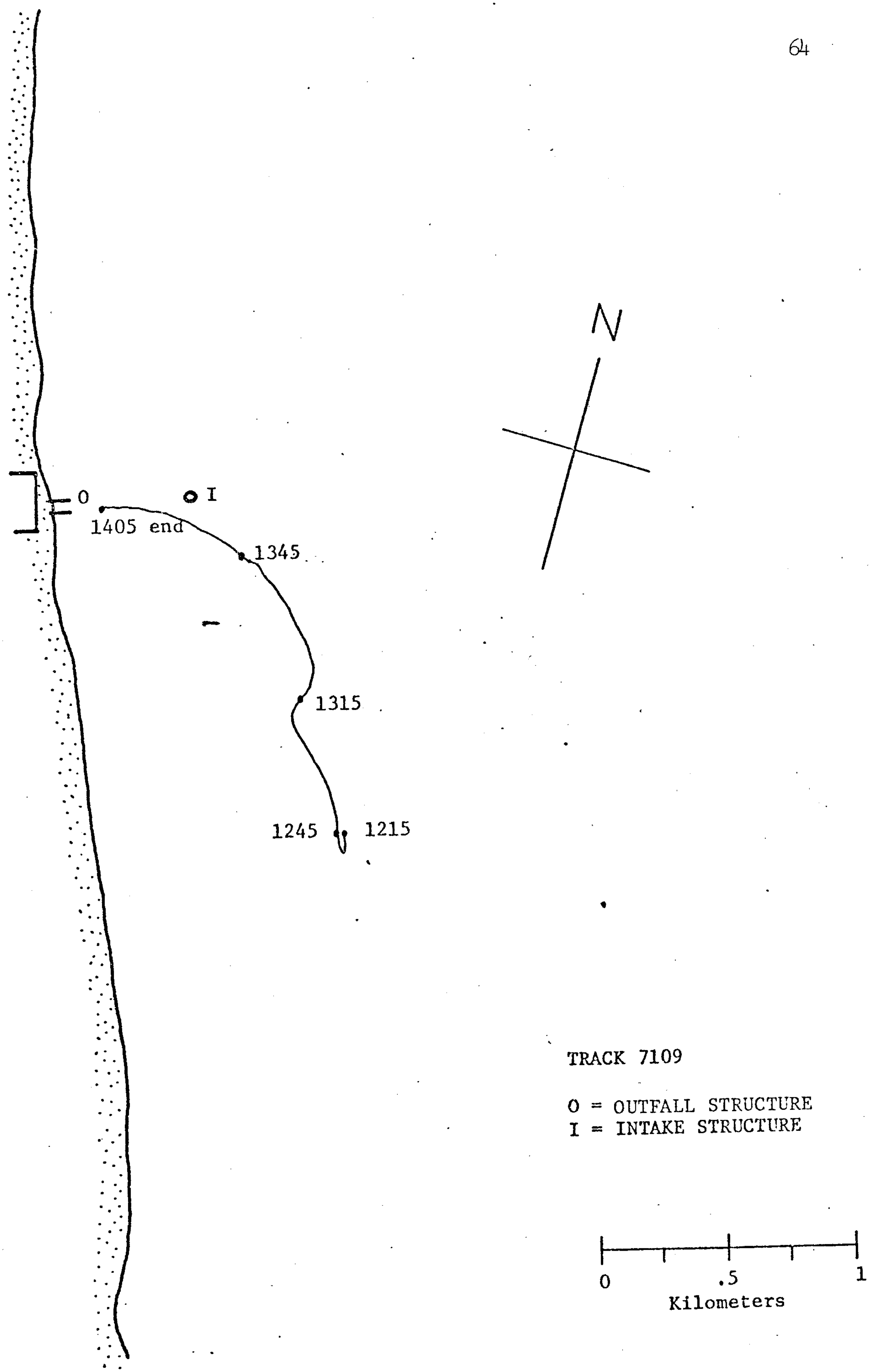
Figure 19. Track Path: Salmon No. 7108.




TRACK 7108

O = OUTFALL STRUCTURE
I = INTAKE STRUCTURE

Figure 20. Track Path: Salmon No. 7109.




TRACK 7109

O = OUTFALL STRUCTURE
I = INTAKE STRUCTURE

Figure 21. Track Paths: Salmon Nos. 7106, 7110, 7111, and 7112.

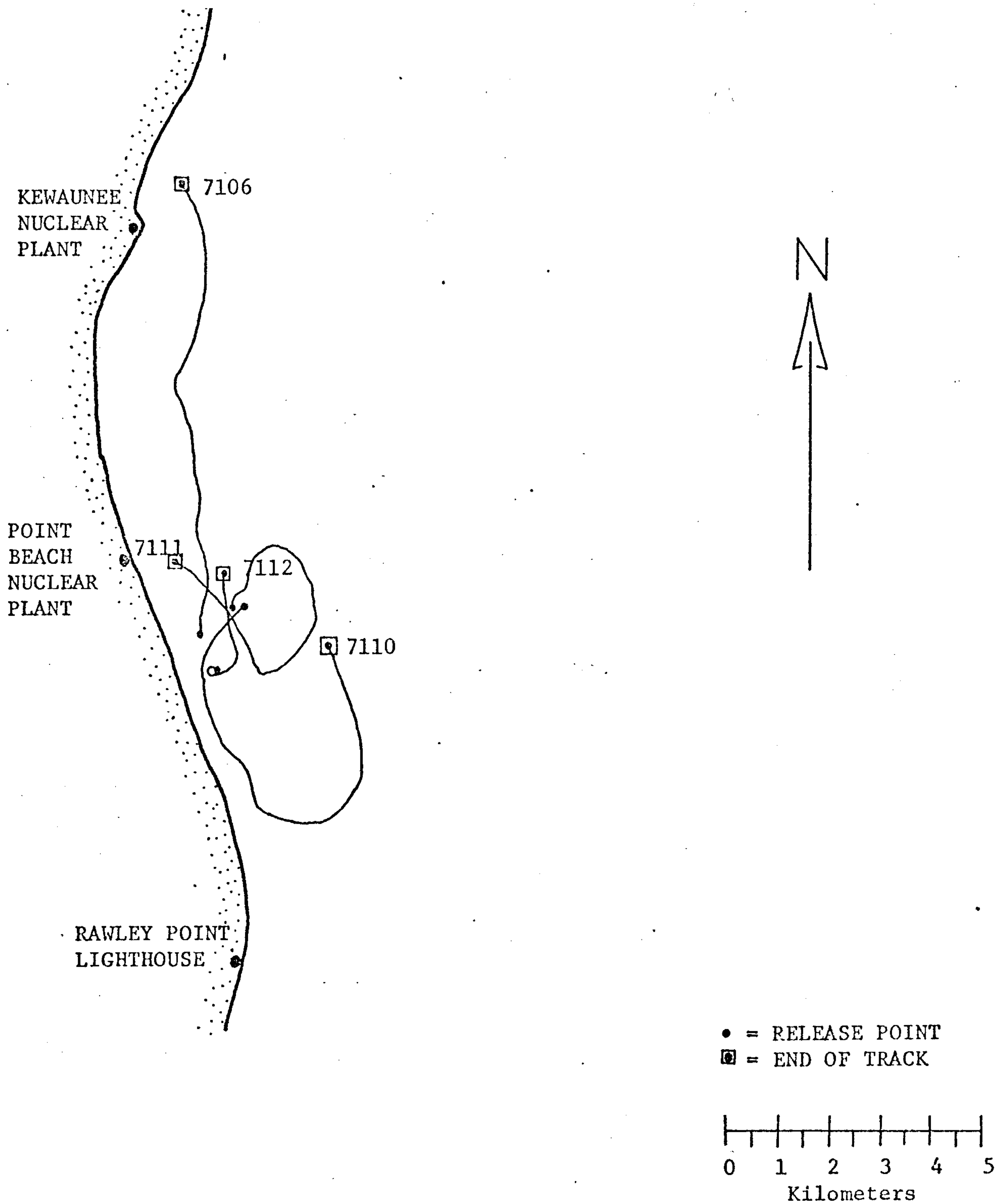

KEWAUNEE
NUCLEAR
PLANT
7106
POINT
BEACH
NUCLEAR
PLANT
7111
7112
7110
RAWLEY POINT
LIGHTHOUSE
N
• = RELEASE POINT
▣ = END OF TRACK
0 1 2 3 4 5
Kilometers

Table 7. 1971 Thermal Profiles at Fish Locations, Determined by Whitney Thermometer

For depths, (b) signifies "bottom". All times are Central Standard.

Track 7102 - No profiles taken

Track 7103
1045 hrs; surface to 7 m: 10.6-10.4° C

1156 hrs; surface to bottom: 10.6° C

1227 hrs; surface to bottom: 11.8° C

Track 7104
1458 hrs; surface to 5 m: 10.7° C

1700 hrs; surface to 4.5 m (bottom): 10.4° C

Track 7105

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1315 hrs | m: | S-1 | 2 | 3 | 4 | 5 | 6(b) |
| | °C: | 11.6 | 11.4 | 11.4 | 11.2 | 10.7 | 10.7 |

1351 hrs; surface to 1.5 m (bottom): 14.0° C

1410 hrs; surface to 2.0 m (bottom): 14.2° C

Track 7106

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1350 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6 | 6.5(b) |
| | °C: | 12.2 | 12.2 | 12.05 | 11.95 | 11.75 | 11.4 | 11.25 | 11.2 | 11.1 |
| 1407 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6(b) | |
| | °C: | 12.5 | 12.4 | 12.2 | 12.0 | 11.8 | 11.5 | 11.35 | 11.3 | |
| 1437 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6-9(b) | |
| | °C: | 12.5 | 12.3 | 12.1 | 11.7 | 11.3 | 11.2 | 11.0 | 10.9 | |

Table 7. 1971 Thermal Profiles at Fish Locations, Determined by Whitney Thermometer (Cont.)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Track 7106 | | | | | | | | | | | | | |
| 1446 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9(b) | |
| | °C: | 12.5 | 12.3 | 12.2 | 12.0 | 11.8 | 11.5 | 11.4 | 11.0 | 10.9 | 10.9 | 10.8 | |
| 1505 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10(b) |
| | °C: | 12.1 | 12.0 | 11.7 | 11.6 | 11.3 | 11.25 | 11.1 | 10.9 | 10.8 | 10.8 | 10.6 | 10.6 |
| 1543 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9(b) | |
| | °C: | 11.4 | 11.3 | 11.1 | 10.8 | 10.7 | 10.6 | 10.5 | 10.4 | 10.4 | 10.3 | 10.0 | |
| 1612 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6-9 | 10 | 11(b) | | |
| | °C: | 11.3 | 11.3 | 11.2 | 10.9 | 10.8 | 10.7 | 10.6 | 10.5 | 10.05 | 10.0 | | |
| 1657 hrs | m: | S | .5 | 1 | 2 | 3 | 4-8(b) | | | | | | |
| | °C: | 10.5 | 10.5 | 10.4 | 10.3 | 10.1 | 10.0 | | | | | | |
| Track 7108 | | | | | | | | | | | | | |
| 1125 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6(b) | | | | |
| | °C: | 13.9 | 13.85 | 13.8 | 13.3 | 12.8 | 12.6 | 11.6 | 11.0 | | | | |
| 1206 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5(b) | | | | | |
| | °C: | 14.1 | 14.1 | 14.05 | 13.85 | 13.8 | 13.7 | 13.0 | | | | | |
| 1248 hrs | m: | S | .5 | 1 | 2 | 3(b) | | | | | | | |
| | °C: | 14.95 | 14.9 | 14.1 | 13.9 | 12.5 | | | | | | | |
| 1300 hrs | m: | S | .5 | 1 | 2(b) | | | | | | | | |
| | °C: | 15.0 | 15.0 | 14.7 | 13.1 | | | | | | | | |
| 1430 hrs | m: | S | .5 | 1 | 2 | 2.5(b) | | | | | | | |
| | °C: | 15.2 | 15.2 | 14.9 | 14.9 | 14.8 | | | | | | | |

Table 7. 1971 Thermal Profiles at Fish Locations, Determined by Whitney Thermometer (Cont.)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Track 7108** | | | | | | | | | | | | | |
| 1445 hrs | m: | S | .5 | 1(b) | | | | | | | | | |
| | °C: | 16.7 | 15.9 | 15.0 | | | | | | | | | |
| At location where fish twice turned from plume: | m: | S | .5 | 1 | 2(b) | | | | | | | | |
| | °C: | 15.3 | 14.8 | 13.2 | 13.0 | | | | | | | | |
| At location a few meters south and inshore of discharge structure mouth; surface to 2 m (b): 15.0° C | | | | | | | | | | | | | |
| At mouth of discharge structure where transmitter failed: | m: | S | .5 | 1 | 2(b) | | | | | | | | |
| | °C: | 21.0 | 21.0 | 21.0 | 20.7 | | | | | | | | |
| At location a few meters north and inshore of discharge structure mouth; surface to 2 m (b): 12.8° C | | | | | | | | | | | | | |
| **Track 7109** | | | | | | | | | | | | | |
| 1205 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6(b) | | | | |
| | °C: | 13.0 | 12.9 | 12.9 | 12.9 | 12.5 | 11.9 | 11.8 | 11.8 | | | | |
| 1319 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5(b) | | | | | |
| | °C: | 14.2 | 14.2 | 14.2 | 13.8 | 11.8 | 11.7 | 11.7 | | | | | |
| **Track 7110** | | | | | | | | | | | | | |
| 1237 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10(b) |
| | °C: | 14.0 | 14.0 | 13.9 | 13.9 | 13.65 | 13.3 | 13.2 | 13.5 | 13.05 | 12.9 | 12.85 | 12.8 |
| 1337 hrs | m: | S | .5 | 1 | 2 | 3 | 4-6(b) | | | | | | |
| | °C: | 14.0 | 13.95 | 13.8 | 13.0 | 12.85 | 12.8 | | | | | | |

Table 7. 1971 Thermal Profiles at Fish Locations, Determined by Whitney Thermometer (Cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Track 7110 | | | | | | | | |
| 1416 hrs | m: | S | .5 | 1 | 2 | 3 | 4(b) | |
| | °C: | 13.5 | 13.4 | 13.4 | 13.25 | 13.1 | 13.15 | |
| 1601 hrs; surface to 5 m: 13.1° C | | | | | | | | |
| Track 7111 | | | | | | | | |
| 1145 hrs | m: | S | .5 | 1 | 2 | 3 | 4 | 5 |
| | °C: | 8.0 | 8.0 | 8.1 | 8.0 | 8.0 | 7.9 | 7.9 |
| 1455 hrs | m: | S-4 | 5 | | | | | |
| | °C: | 7.9 | 7.6 | | | | | |
| Track 7112 | | | | | | | | |
| 1225 hrs | m: | S | .5 | 1-4 | 5(b) | | | |
| | °C: | 4.3 | 4.3 | 4.2 | 4.1 | | | |
| 1341 hrs | m: | S | .5 | 1 | 2 | 3-5 | | |
| | °C: | 4.2 | 4.15 | 4.2 | 4.15 | 4.1 | | |
| 1435 hrs | m: | S-1 | 2 | 3 | 4 | 5 | | |
| | °C: | 4.7 | 4.65 | 4.65 | 4.6 | 4.6 | | |

Table 8. 1971 Temperatures Indicated by Transmitters

A (*) in the "Temperature" column signifies the temperature reading was reasonably accurate as compared with temperature profiles presented in Table 7. "Comments" are observations made independently of transmitter temperature information.

| Coho No. | Time (CST) | Temperature (°C) | Comments |
|---|---|---|---|
| 7102 | - | - | Johnson counter not working; no temperature data |
| 7103 | 1100 | * 10.5 | |
| | 1126 | * 10.25 | |
| | 1227 | No signal | 1156-1227: fish went to shore |
| | 1300 | * 13.2-14.3 | 1254: fish in plume area |
| | 1310 | * 14.2-15.2 | 1306: fish at discharge structure |
| | 1311 | * 13.9-14.2 | 1312-1319: fish is past discharge structure and moving north |
| | 1312 | * 10.5-11.1 | |
| | 1328 | No signal | 1345: crew terminated track north of plume |
| 7104 | 1458 | * 9.8 | 1640-1658: fish went to shore, passing inshore of intake str. at 1645 |
| | 1539 | * 10.6 | |
| | 1640 | No signal | 1640: fish moving very rapidly |
| | 1720 | No signal | 1720: fish probably out of acceptable range |
| | | | 1730: crew terminated track north of plume |
| 7105 | 1237 | * 10.7 | |
| | 1315 | 2.7-6.7 | 1315-1345: fish went to shore |
| | 1351 | 18.6-20.6 | 1351: fish 25-30 m offshore |
| | 1410 | No signal | 1410: fish 40 m offshore |
| | | | 1414: transmitter failed, fish at discharge structure |
| 7106 | 1356 | 10.1 | |
| | 1410 | * 9.4-10.8 | |
| | 1415 | * 10.6 | |
| | 1418 | * 10.8 | |
| | 1427 | * 10.8 | |
| | 1431 | * 10.6 | |
| | 1437 | * 10.8 | |
| | 1443 | * 9.4-10.8 | |

Table 8. 1971 Temperatures Indicated by Transmitters (Cont.)

| Coho No. | Time (CST) | Temperature (°C) | Comments |
|---|---|---|---|
| 7106 | 1451 | * 10.25 | |
| | 1459 | * 10.25 | |
| | 1502 | * 9.9 | |
| | 1513 | * 10.1 | |
| | 1522 | * 10.25 | |
| | 1524 | * 9.7 | |
| | 1541 | * 10.6 | |
| | 1550 | * 10.1 | |
| | 1601 | * 9.9 | |
| | 1610 | * 10.1 | |
| | 1625 | * 7.3-9.4 | 1625: 2.1 km from Kewaunee Plant - possible noise interference from discharge area |
| | 1658 | * 10.4 | 1655-1713: fish went to shore<br>1713: crew terminated track near Kewaunee Plant |
| 7108 | 1126 | * 13.6 | |
| | 1138 | * 11.7 | |
| | 1153 | * 13.7 | 1153-1216: fish went to shore |
| | 1202 | * 13.7 | |
| | 1216 | Poor signal | |
| | 1223 | Poor signal | |
| | 1232 | * 14.7 | |
| | 1248 | No signal | |
| | 1301 | No signal | 1301: fish "repelled" by plume - first time |
| | 1311 | No signal | |
| | 1319 | No signal | 1319-1326: fish "repelled" by plume - second time |
| | 1348 | * 11.8-15.2 | |
| | 1352 | * 13.3-14.3 | |
| | 1354 | * 14.5-15.2 | |
| | 1402 | * 14.2 | |
| | 1410 | * 12.5-13.4 | |
| | 1412 | * 14.0-14.5 | |
| | 1417 | * 14.3 | |
| | 1429 | * 13.8-14.3 | |
| | 1442 | No signal | 1450: transmitter failed, fish at discharge structure |

Table 8. 1971 Temperatures Indicated by Transmitters (Cont.)

| Coho No. | Time (CST) | Temperature (°C) | Comments |
|---|---|---|---|
| 7109 | 1214 | 16.7-17.4 | |
| | 1222 | 16.6 | |
| | 1231 | 16.1 | |
| | 1240 | 17.0 | |
| | 1244 | 16.1-16.6 | |
| | 1252 | 16.4 | |
| | 1258 | 16.5 | |
| | 1309 | 15.7-16.2 | |
| | 1319 | 16.2-16.9 | |
| | 1334 | 16.6 | |
| | 1339 | 16.7 | |
| | 1342 | 16.7-17.4 | 1342-1405: fish swam directly toward discharge structure |
| | 1347 | 15.7-16.4 | |
| | 1352 | 17.0 | |
| | 1355 | 10.7-15.6 | 1355: fish appeared to be in plume |
| | 1404 | 16.7 | 1405: transmitter failed, fish near discharge structure |
| 7110 | 1241 | * 12.9 | |
| | 1245 | * 13.5 | |
| | 1251 | * 12.4-13.4 | 1251-1337: fish went to shore |
| | 1305 | * 13.2-13.7 | |
| | 1335 | * 13.2 | |
| | 1337 | * 13.7 | |
| | 1346 | * 12.9 | |
| | 1400 | Poor signal | 1400: fish very near shore |
| | 1411 | * 13.0 | |
| | 1415 | * 13.4 | 1415: fish moving offshore |
| | 1421 | * 13.4 | |
| | 1425 | * 13.1 | |
| | 1431 | * 13.5 | |
| | 1447 | * 13.1 | |
| | 1451 | * 14.1 | |
| | 1519 | * 14.0 | |
| | 1531 | * 12.8 | |
| | 1540 | Poor signal | |
| | 1601 | * 13.1-14.0 | 1601: crew terminated track |
| 7111 | 1145 | 10.4 | |
| | 1156 | 10.5-10.8 | |
| | 1200 | 10.5 | |
| | 1212 | 10.4 | |

Table 8. 1971 Temperatures Indicated by Transmitters (Cont.)

| Coho No. | Time (CST) | Temperature (°C) | Comments |
|---|---|---|---|
| 7111 | 1225 | 10.4 | |
| | 1257 | 10.3-11.0 | |
| | 1314 | 10.3 | |
| | 1323 | Poor signal | |
| | 1340 | Poor signal | |
| | 1409 | No signal | |
| | 1436 | No signal | |
| | 1452 | 10.2 | 1511-1605: either transmitter failed or fish swam very rapidly and was out of range |
| | 1504 | 10.3 | |
| | 1511 | 9.9-12.3 | 1605: weak signal picked up for a few seconds |
| 7112 | 1225 | 7.1 | |
| | 1238 | 6.1 | |
| | 1251 | 6.8 | |
| | 1306 | 6.2 | |
| | 1317 | 6.0-6.7 | |
| | 1341 | 6.5-7.2 | |
| | 1401 | 6.8 | |
| | 1422 | 6.0-6.5 | |
| | 1435 | 6.5 | |
| | 1509 | 6.4 | |
| | 1523 | 6.4 | |
| | 1555-1610 | 6.2-6.8 | |
| | 1625 | 6.4 | 1625: crew terminated track |

Table 9. Swimming Speeds of Individual 1971 Coho Salmon which Entered the Point Beach Plant Thermal Plume

| Fish No. | Segment of Track (Time of Day, CST) | Swimming Speed (Cm/Sec) |
|---|---|---|
| 7102 | 1210-1237 | 34.5 |
| | 1237-1315 | 24.7 |
| | 1315-1415 | 55.6 |
| 7103 | 1045-1126 | 38.1 |
| | 1126-1156 | 66.9 |
| | 1156-1227 | 30.9 |
| | 1227-1306 | 83.9 |
| | 1306-1319 | 18.5 |
| | 1319-1328 | 87.5 |
| 7105 | 1237-1248 | 27.3 |
| | 1248-1315 | 7.2 |
| | 1315-1351 | 46.3 |
| | 1351-1410 | 64.3 |
| | 1410-1414 | 58.7 |
| 7108 | 1126-1138 | 7.7 |
| | 1138-1153 | 32.9 |
| | 1153-1216 | 25.7 |
| | 1216-1223 | 55.6 |
| | 1223-1248 | 47.9 |
| | 1248-1301 | 81.9 |
| | 1301-1311 | 24.2 |
| | 1311-1319 | 23.7 |
| | 1319-1354 | 70.0 |
| | 1354-1412 | 5.1 |
| | 1412-1429 | 88.0 |
| | 1429-1442 | 48.9 |
| | 1442-1450 | 79.3 |
| 7109 | 1214-1240 | 6.2 |
| | 1240-1258 | 27.3 |
| | 1258-1309 | 42.7 |
| | 1309-1319 | 21.1 |
| | 1319-1342 | 34.0 |
| | 1342-1355 | 74.6 |

Although Salmon No. 7104 passed inshore of the Point Beach Plant intake structure (Figure 17), it did not enter water warmer than 10.6° C.

After coming to shore, Salmon No. 7105 (Figure 18) swam northward 25-30 m offshore for the rest of its track. Offshore temperatures shortly after release were approximately 11.0° C (see Table 7 for complete profiles). Upon reaching the outfall structure, the fish turned offshore and swam about 70 m before the transmitter failed. Water temperature along shore just before the salmon turned was 13.0° C. Temperature at the location where the transmitter failed was 16.1° C.

Salmon No. 7108 came to shore soon after release and swam within 30 m of the shoreline until the transmitter failed (Figure 19). This fish approached the outfall area from the south three times, and turned away twice to the south. The salmon's average speed when approaching the outfall the first time was 81.9 cm/sec. After turning away, its average speed was 24.2 cm/sec. The second approach was made ten minutes later at an average speed of 23.7 cm/sec, but upon turning south away from the outfall the second time, the fish swam at an average speed of 70.0 cm/sec. The third approach 90 minutes later was made at about 60 cm/sec. The transmitter failed shortly after the salmon entered the outfall area for the third time. Water temperatures along shore about 1.8 km south of the outfall were 13.0-14.1° C. Temperature along shore gradually increased as the outfall was approached, and at the points where the salmon twice turned away from the outfall area, the water temperature profile was: surface, 15.3° C; 0.5 m, 14.8° C; 1 m, 13.2° C; 2 m (bottom), 13.0° C. The transmitter signal failed at a location where water temperature was isothermal at 21.0° C (surface to bottom at 2 m).

Temperature just north of the outfall structure was isothermal at 12.8° C (surface to bottom at 2 m).

The last salmon which entered the plume in 1971, No. 7109, did not approach shore until later in its track (Figure 20). The fish swam directly toward the outfall structure for the last 30 minutes of the track; the transmitter failed when the salmon was about 0.2 km from the outfall structure. Water temperatures at offshore points of the track path were typically about 13-14° C in the upper 2 m of the lake. Water temperature at the point the transmitter failed was about 16-18° C.

These data are not sufficient to support a conclusive statement about plume-associated behavior of coho salmon. However, it would appear that the fish were able to sense the presence of the warmer plume water, as indicated by the change in behavior (i.e. swimming direction) of three coho.

Data on behavior of fish after encountering the plume were too limited to allow close examination of post-encounter behavior, although one animal (Salmon No. 7102) which had entered the plume was later recaptured in the home stream.

The 1971 coho, released in water less than 10 m deep, showed a significant tendency to go to shore in the immediate vicinity of their release points. Fish released in deeper water in 1969, 1970, and 1972 generally remained offshore during their tracks. These results bear on the third question raised above, i.e. "What proportion of naturally migrating coho might be expected to enter the general plume area?". Our data show that Algoma coho had highly oriented homing behavior in both open waters and in shallow near-shore waters of the lake. Thus to home successfully, a fish apparently need not follow the study area shoreline, i.e. need not pass through the plume area during migration. Before this point can be completely resolved, however, the migratory routes of coho salmon in Lake Michigan must be further investigated. In such studies special attention should be paid to any tendency the fish might show to swim consistently along the shoreline, and to any consistent points of landfall. Rawley Point would be a prime candidate for such a landfall for fish moving from south to north.

### D. SIGNIFICANCE OF THERMAL TRACKING RESULTS

Our 1971 temperature-sensitive transmitters certainly could not be considered dependable, since they invariably failed when a fish entered water warmer than about 16° C. Nevertheless, most of the transmitters did give reasonably accurate temperature data. The accuracy of each transmitter-indicated temperature, based on comparison with the appropriate thermal profile, is noted in Table 8.

Of the nine transmitters, five (Nos. 7103, 7104, 7106, 7108, and 7110) gave reasonably accurate data throughout tracks, three (Nos. 7109, 7111 , and 7112) gave data not consistent with temperature profiles, and one (No. 7105) gave an initial accurate reading then two poor ones. Inaccurate readings were very likely due to one or more of the following factors: signal attenuation due to destructive (i.e. out of phase) interference from bottom reflections in shallow water, interference from shore noise or outfall noise from Point Beach Plant, signal attenuation due to too great a distance between the salmon and the Aquarius, or finally, improper calibration of transmitters. This last is a distinct possibility in the cases of Transmitters Nos. 7109, 7111, and 7112, which gave consistently inaccurate readings. In addition, two of these, Nos. 7111 and 7112, may have been operating near the lower end of their sensitivity ranges, since lake surface temperature had decreased from about 14° C on the day of Track 7110 to 8° C during Track 7111, and to about 4° C during Track 7112 (see Table 7 for complete temperature profiles).

In view of these difficulties with the 1971 temperature-sensitive transmitters, and since only five fish were observed while in or near the plume, further data are needed to more clearly define behavior of coho salmon near thermal plumes.

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# APPENDIX

Table A-1. Pre-track Temperature Experience of 1971 Coho

All temperatures are in degrees Centigrade.

| Coho No. | Captivity (Hrs) | Homestream Temperature at Capture | Temperature at Holding Nets at Capture | Temperature, Nets and Deck Bag on Track Day | Lake Temperature at Release (1 m Depth) |
|---|---|---|---|---|---|
| 7102 | 3.2 | 10.1 | ? | 10.4 | ? |
| 7103 | 19.8 | 12.4 | 10.5 | 10.7 | 10.6 |
| 7104 | 24.0 | 12.4 | 10.5 | 10.7 | 10.7 |
| 7105 | 45.6 | 12.4 | 10.5 | 10.7 | 11.6 |
| 7106 | 3.4 | 11.6 | ? | 10.8 | 12.05 |
| 7108 | 49.5 | ? | ? | 12.4 | 13.8 |
| 7109 | 3.0 | 14.6 | ? | 13.1 | 12.9 |
| 7110 | 20.9 | 13.75 | 13.6 | 13.3-14.0 | 13.9 |
| 7111 | 43.5 | 7.8 | 10.8 | 8.7 | 8.1 |
| 7112 | 51.1 | 0.0 | 5.8 | 4.8 | 4.2 |

Table A-2. 1970 and 1972 Thermal Profiles at Fish Locations, Determined by Whitney Thermometer

For depths, (b) signifies "bottom". All times are Central Standard.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Track 7003 | | | | | | | | | | | |
| 1335 hrs | m: | S | 1 | 3 | 5 | 7 | 10 | 15 | 20 | 25 |
| | °C: | 11.3 | 11.3 | 11.2 | 11.2 | 11.2 | 10.3 | 11.2 | 11.1 | 11.0 |
| Track 7004 | | | | | | | | | | |
| 1157 hrs; surface to 25 m: 10.75° C | | | | | | | | | | |
| 1342 hrs | m: | S | 1-5 | 7 | 10 | 15-30 | | | | |
| | °C: | 10.25 | 10.3 | 10.2 | 10.3 | 10.5 | | | | |
| 1504 hrs | m: | S-3 | 5 | 7 | 10 | 13.5(b) | | | | |
| | °C: | 10.1 | 10.05 | 9.85 | 9.8 | 9.7 | | | | |
| 1538 hrs; surface to 15 m (b): 10.0° C | | | | | | | | | | |
| 1620 hrs | m: | S | 1 | 3 | 5 | 7 | 9(b) | | | |
| | °C: | 9.85 | 9.9 | 9.95 | 9.9 | 9.7 | 9.55 | | | |
| Track 7005 | | | | | | | | | | |
| 1104 hrs | m: | S-15 | 20(b) | | | | | | | |
| | °C: | 10.8 | 7.9 | | | | | | | |
| 1246 hrs | m: | S | 1 | 3 | 5 | 7(b) | | | | |
| | °C: | 9.6 | 9.6 | 9.7 | 9.65 | 9.5 | | | | |
| 1441 hrs | m: | S-3 | 5 | 7(b) | | | | | | |
| | °C: | 9.5 | 9.25 | 9.0 | | | | | | |
| 1528 hrs | m: | S | 1-4 | 5 | 6 | 7 | 8(b) | | | |
| | °C: | 8.85 | 8.9 | 8.85 | 8.85 | 8.8 | 8.75 | | | |

Table A-2. 1970 and 1972 Thermal Profiles at Fish Locations, Determined by Whitney Thermometer (Cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Track 7005 | | | | | | | |
| 1715 hrs | m: | S-3 | 5(b) | | | | |
| | °C: | 8.7 | 7.9 | | | | |
| 1810 hrs | m: | S-2 | 3 | 4 | 5 | 5.5(b) | |
| | °C: | 10.0 | 9.2 | 9.0 | 9.2 | 8.6 | |
| Track 7006 | | | | | | | |
| 1316 hrs; surface to 25 m: 10.55° C | | | | | | | |
| 1420 hrs | m: | S-7 | 10(b) | | | | |
| | °C: | 10.3 | 10.1 | | | | |
| 1430 hrs; surface to 9 m (b): 9.6° C | | | | | | | |
| 1440 hrs | m: | S-3 | 5-9(b) | | | | |
| | °C: | 9.6 | 9.4 | | | | |
| 1450 hrs | m: | S | 1 | 3 | 5 | 8 | |
| | °C: | 9.4 | 9.4 | 9.3 | 9.3 | 9.25 | |
| 1505 hrs; surface to 7 m (b): 9.15° C | | | | | | | |
| 1517 hrs | m: | S | 1 | 3-6 | | | |
| | °C: | 8.7 | 8.7 | 8.65 | | | |
| 1610 hrs | m: | S | 1-6 | | | | |
| | °C: | 8.5 | 8.45 | | | | |
| 1710 hrs; surface to 7 m (b): 8.8° C | | | | | | | |
| 1730 hrs | m: | S | 1-5 | 8 | | | |
| | °C: | 8.6 | 8.7 | 8.6 | | | |

Table A-2. 1970 and 1972 Thermal Profiles at Fish Locations, Determined by Whitney Thermometer (Cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Track 7006 | | | | | | | |
| 1745 hrs | m: | S-3 | 5 | 9(b) | | | |
| | °C: | 8.6 | 8.55 | 8.45 | | | |
| 1800 hrs | m: | S | 1 | 3-7 | | | |
| | °C: | 8.2 | 8.2 | 8.25 | | | |
| Track 7201 at release; surface to 10 m: 10.45° C | | | | | | | |
| Track 7202 at release | m: | S | .5 | 1 | 2 | 3-22 | |
| | °C: | 8.5 | 8.6 | 8.65 | 8.7 | 8.7 | |
| Track 7203 at release | m: | S | .5-10 | | | | |
| | °C: | 6.8 | 6.7 | | | | |
| Track 7204 at release | m: | S | .5-10 | | | | |
| | °C: | 6.95 | 6.9 | | | | |
| Track 7205 at release; surface to 10 m: 6.95° C | | | | | | | |
| Track 7206 at release; surface to 10 m: 6.6° C | | | | | | | |
| Track 7207 at release; surface to 10 m: 6.95° C | | | | | | | |
| Track 7208 at release; surface to 10 m: 6.8° C | | | | | | | |

Table A-3. Current Data for 1971 and 1972

All current measurements were performed during the track, except for Track 7208, when the drogue was set and retrieved before releasing the fish. Each measurement was performed in an area through which the salmon being tracked swam.

| Track No. | Current - 1 m depth | Current - 2 m depth |
|---|---|---|
| 7105 | Alongshore current moving northward at 7.2 cm/sec | Water less than 2 m deep |
| 7108 | Alongshore current moving southward at 6.2 cm/sec | Same as 1 m current |
| 7110 | Current moving due North at 11.8 cm/sec | Alongshore current moving northward at 9.3 cm/sec |
| 7202 | Current moving due South at 26.8 cm/sec | Not measured |
| 7208 | Negligible | Not measured |

Table A-4. Numerical Values and Standard Deviations of Data for Mean Swimming Speeds Plotted in Figures 5, 6, and 7

| Time Elapsed After Release (Hrs) | 1969-1970 | | | 1971 | | | 1972 | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | Mean Swimming Speed (Cm/Sec) | Standard Deviation (Cm/Sec) | n | Mean Swimming Speed (Cm/Sec) | Standard Deviation (Cm/Sec) | n | Mean Swimming Speed (Cm/Sec) | Standard Deviation (Cm/Sec) |
| 0.5 | 9 | 34.0 | 25.6 | 10 | 20.4 | 13.7 | 8 | 26.5 | 9.8 |
| 1.0 | 9 | 44.0 | 36.8 | 10 | 37.0 | 20.8 | 8 | 40.5 | 16.9 |
| 1.5 | 9 | 57.4 | 28.8 | 10 | 53.8 | 21.7 | 8 | 62.5 | 23.3 |
| 2.0 | 8 | 70.5 | 41.1 | 9 | 63.0 | 25.8 | 7 | 86.9 | 18.5 |
| 2.5 | 6 | 79.5 | 42.5 | 7 | 68.7 | 24.5 | 7 | 97.7 | 31.4 |
| 3.0 | 6 | 94.8 | 40.0 | 6 | 62.5 | 37.2 | 7 | 89.6 | 28.4 |
| 3.5 | 6 | 105.0 | 44.3 | 5 | 73.2 | 30.4 | 7 | 96.0 | 11.6 |
| 4.0 | 6 | 93.8 | 26.8 | 2 | 43.5 | 24.7 | 6 | 87.0 | 28.7 |
| 4.5 | 5 | 101.4 | 55.5 | 2 | 49.5 | 24.7 | 6 | 104.7 | 18.4 |
| 5.0 | 5 | 102.2 | 71.0 | - | - | - | 5 | 94.2 | 19.6 |
| 5.5 | 5 | 89.6 | 48.9 | - | - | - | 5 | 101.8 | 15.1 |
| 6.0 | 5 | 93.8 | 33.5 | - | - | - | 5 | 84.2 | 40.2 |
| 6.5 | 4 | 82.2 | 43.4 | - | - | - | 5 | 104.2 | 26.9 |
| 7.0 | 4 | 85.2 | 41.3 | - | - | - | 5 | 96.4 | 18.1 |
| 7.5 | 3 | 79.7 | 45.6 | - | - | - | 5 | 95.2 | 33.5 |
| 8.0 | 2 | 106.5 | 31.8 | - | - | - | 4 | 90.0 | 29.2 |
| 8.5 | - | - | - | - | - | - | 3 | 82.7 | 8.0 |

Table A-5. Numerical Values and Standard Deviations of Data for Mean Swimming Speeds Plotted in Figures 8, 9, and 10

| Time of Day (CST) | 1969-1970 n | 1969-1970 Mean Swimming Speed (Cm/Sec) | 1969-1970 Standard Deviation (Cm/Sec) | 1971 n | 1971 Mean Swimming Speed (Cm/Sec) | 1971 Standard Deviation (Cm/Sec) | 1972 n | 1972 Mean Swimming Speed (Cm/Sec) | 1972 Standard Deviation (Cm/Sec) |
|---|---|---|---|---|---|---|---|---|---|
| 1000 | 2 | 71.5 | 55.9 | - | - | - | - | - | - |
| 1030 | 2 | 94.5 | 53.0 | - | - | - | - | - | - |
| 1100 | 1 | - | - | - | - | - | - | - | - |
| 1130 | 2 | 95.5 | 53.0 | - | - | - | 2 | 79.0 | 25.5 |
| 1200 | 3 | 97.7 | 76.8 | - | - | - | 3 | 75.3 | 27.6 |
| 1230 | 3 | 74.0 | 47.5 | 2 | 56.5 | 10.6 | 3 | 90.3 | 64.3 |
| 1300 | 3 | 107.7 | 62.0 | 3 | 54.0 | 18.7 | 4 | 86.5 | 27.5 |
| 1330 | 6 | 85.7 | 68.9 | 6 | 53.0 | 23.9 | 3 | 85.3 | 37.6 |
| 1400 | 6 | 86.7 | 48.7 | 7 | 55.1 | 26.8 | 3 | 88.3 | 36.7 |
| 1430 | 7 | 95.0 | 39.1 | 4 | 48.5 | 24.1 | 3 | 102.3 | 7.5 |
| 1500 | 5 | 91.8 | 31.9 | 4 | 71.0 | 30.9 | 4 | 90.7 | 16.5 |
| 1530 | 5 | 72.4 | 25.0 | 4 | 78.7 | 41.9 | 6 | 86.2 | 23.2 |
| 1600 | 5 | 78.2 | 32.5 | 5 | 69.4 | 32.2 | 6 | 99.8 | 14.6 |
| 1630 | 4 | 73.0 | 45.5 | 3 | 63.0 | 31.0 | 6 | 108.3 | 19.8 |
| 1700 | 4 | 82.5 | 31.0 | 2 | 69.5 | 4.9 | 6 | 99.7 | 24.7 |
| 1730 | 4 | 74.5 | 36.2 | - | - | - | 6 | 76.0 | 20.7 |
| 1800 | 4 | 84.2 | 36.4 | - | - | - | 6 | 80.3 | 31.7 |
| 1830 | 2 | 92.0 | 72.1 | - | - | - | 4 | 103.5 | 22.1 |
| 1900 | 2 | 84.5 | 64.3 | - | - | - | 4 | 94.5 | 27.8 |
| 1930 | 2 | 85.5 | 62.9 | - | - | - | 4 | 83.2 | 4.3 |
| 2000 | 2 | 106.5 | 31.8 | - | - | - | 3 | 82.0 | 30.5 |
| 2030 | - | - | - | - | - | - | 3 | 105.7 | 11.0 |
| 2100 | - | - | - | - | - | - | 3 | 82.7 | 8.0 |
| 2130 | - | - | - | - | - | - | 2 | 101.0 | 63.6 |

Table A-6. Numerical Values and Standard Deviations of Data for Mean Angular Changes Plotted in Figures 11 and 12

| Time Elapsed after Release (Hrs) | 1970 | | | 1972 | | |
|---|---|---|---|---|---|---|
| | n | Mean Angular Change (Degrees) | Standard Deviation (Degrees) | n | Mean Angular Change (Degrees) | Standard Deviation (Degrees) |
| 0.75 | 6 | 34.7 | 52.2 | 8 | 63.0 | 50.4 |
| 1.25 | 6 | 47.8 | 27.5 | 7 | 68.0 | 45.4 |
| 1.75 | 5 | 35.0 | 21.1 | 7 | 67.1 | 37.4 |
| 2.25 | 5 | 21.0 | 25.0 | 7 | 40.4 | 48.9 |
| 2.75 | 5 | 17.0 | 20.9 | 7 | 66.4 | 50.4 |
| 3.25 | 5 | 7.4 | 6.1 | 7 | 72.4 | 46.6 |
| 3.75 | 5 | 16.8 | 20.7 | 5[C]<br>6[D] | 17.0[C]<br>43.5[D] | 12.1[C]<br>65.8[D] |
| 4.25 | 4 | 9.2 | 6.8 | 6 | 14.0 | 9.4 |
| 4.75 | 3[A]<br>4[B] | 20.6[A]<br>54.0[B] | 23.3[A]<br>69.3[B] | 4[C]<br>5[D] | 20.7[C]<br>48.2[D] | 8.3[C]<br>61.8[D] |
| 5.25 | 3[A]<br>4[B] | 24.0[A]<br>55.0[B] | 31.2[A]<br>67.0[B] | 5 | 32.8 | 9.6 |
| 5.75 | 4 | 20.5 | 14.9 | 5 | 23.2 | 23.8 |
| 6.25 | 4 | 9.7 | 9.9 | 5 | 19.6 | 4.4 |
| 6.75 | 4 | 9.7 | 7.5 | 5 | 17.6 | 17.3 |
| 7.25 | 2 | 6.5 | 4.9 | 5 | 18.0 | 14.6 |
| 7.75 | - | - | - | 4 | 19.0 | 25.3 |
| 8.25 | - | - | - | 3 | 18.3 | 11.5 |

(A) Without Salmon No. 7006.
(B) Including Salmon No. 7006.
(C) Without Salmon No. 7206.
(D) Including Salmon No. 7206.

Table A-7. Numerical Values and Standard Deviations of Data for Mean Angular Changes Plotted in Figures 13 and 14

| Time of Day (CST) | 1970 n | 1970 Mean Angular Change (Degrees) | 1970 Standard Deviation (Degrees) | 1972 n | 1972 Mean Angular Change (Degrees) | 1972 Standard Deviation (Degrees) |
|---|---|---|---|---|---|---|
| 1115 | - | - | - | 2 | 82.5 | 3.5 |
| 1145 | - | - | - | 3 | 100.0 | 41.7 |
| 1215 | 2 | 44.5 | 60.1 | 2 | 51.0 | 42.4 |
| 1245 | 2 | 39.0 | 1.4 | 4 | 66.7 | 70.5 |
| 1315 | 5 | 30.6 | 22.5 | 3 | 31.3 | 32.3 |
| 1345 | 5 | 28.0 | 24.5 | 3 | 37.3 | 37.9 |
| 1415 | 6 | 23.2 | 29.8 | 3 | 49.0 | 48.5 |
| 1445 | 5 | 8.8 | 8.4 | 4 | 13.7 | 6.5 |
| 1515 | 5 | 16.6 | 17.6 | 6 | 55.5 | 47.1 |
| 1545 | 4[A] 5[B] | 35.5[A] 59.2[B] | 23.7[A] 56.8[B] | 6 | 34.0 | 25.8 |
| 1615 | 3[A] 4[B] | 8.7[A] 43.5[B] | 9.1[A] 70.1[B] | 6 | 39.3 | 26.1 |
| 1645 | 4 | 11.7 | 14.9 | 6 | 61.5 | 47.9 |
| 1715 | 4 | 6.2 | 4.0 | 6 | 35.5 | 45.8 |
| 1745 | 4 | 15.0 | 13.5 | 6[C] | 39.5[C] | 67.5[C] |
| 1815 | 2 | 14.0 | 12.7 | 4 | 6.7 | 5.9 |
| 1845 | 2 | 9.5 | 6.4 | 4[C] | 46.0[C] | 74.7[C] |
| 1915 | - | - | - | 4 | 28.2 | 13.0 |
| 1945 | - | - | - | 3 | 16.7 | 5.1 |
| 2015 | - | - | - | 3 | 24.0 | 11.3 |
| 2045 | - | - | - | 3 | 26.3 | 15.5 |
| 2115 | - | - | - | 2 | 26.0 | 24.0 |

(A) Without Salmon No. 7006.
(B) Including Salmon No. 7006.
(C) Including Salmon No. 7206.