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# **Preliminary Studies on the Movement of Adult Sockeye Salmon (*Oncorhynchus nerka*) in Alberni Inlet, British Columbia, using Ultrasonic Telemetry**

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**1996**

SH  
223  
F55  
no.2355

**Canadian Manuscript Report of  
Fisheries and Aquatic Sciences 2355**



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**Canadian Manuscript Report of  
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**Preliminary Studies on the Movement of Adult Sockeye Salmon (*Oncorhynchus nerka*) in Alberni Inlet, British Columbia, Inlet Using Ultrasonic Telemetry**

**by**

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Cat. No. Fs 97-4/2355E ISSN 0706-6473

Correct citation for this publication:

Spohn, S., I.K. Birtwell, H. Hohndorf, J.S. Korstrom, C.M. Langton and G.E. Piercey. 1996. Preliminary Studies on the Movement of Adult Sockeye Salmon (*Oncorhynchus nerka*) in Alberni Inlet, British Columbia, using Ultrasonic Telemetry. Can. Manuscr. Rep. Fish. Aquat. Sci. 2355: 54 p.

## TABLE OF CONTENTS

PREFACE . . . . .	iv
ABSTRACT . . . . .	v
RÉSUMÉ . . . . .	vi
LIST OF TABLES . . . . .	vii
LIST OF FIGURES . . . . .	viii
INTRODUCTION . . . . .	1
STUDY AREA . . . . .	2
MATERIALS AND METHODS . . . . .	2
Transmitter Attachment . . . . .	2
Internal Placement . . . . .	3
External Attachment . . . . .	3
Acoustic Telemetry Equipment . . . . .	4
Response of Internal Temperature Transmitters to Ambient Temperature . . . . .	5
Fish Capture, Transmitter Attachment and Tracking . . . . .	6
RESULTS . . . . .	7
Horizontal Movement . . . . .	7
Depth . . . . .	9
Temperature . . . . .	9
DISCUSSION . . . . .	10
Horizontal Movement . . . . .	10
Depth . . . . .	13
Temperature . . . . .	15
ACKNOWLEDGEMENTS . . . . .	17
REFERENCES . . . . .	18
TABLES . . . . .	21
FIGURES . . . . .	31

## PREFACE

Persistent hypoxic conditions exist in the sub-halocline waters of the Somass River estuary at the head of 45 km-long Alberni Inlet, British Columbia. These conditions are related to a naturally-slow flushing rate and the input of effluent from a pulp and paper mill. Over the last forty years the oxygen demand of the effluent, which is discharged into the freshwater lens of the highly stratified estuary, has contributed to a decline in the dissolved oxygen concentrations of these surface waters by an average of  $1 \text{ mg}\cdot\text{L}^{-1}$  from pre-discharge conditions. Over the same period the corresponding decline in the deeper sub-halocline waters has been about  $4 \text{ mg}\cdot\text{L}^{-1}$ ; a reduction of almost 60%.

The progressive deterioration in the quality of the habitat used by aquatic organisms in Alberni Inlet, and especially the concern about valuable salmon resources, have prompted reviews by federal and provincial government agencies and the forest products industry. All parties are endeavoring to understand the biological effects, and improve the quality of the upper inlet waters.

The significance of the concern over the well-being of salmon is exemplified by events that occurred in 1990 during the annual migration of sockeye salmon (*Oncorhynchus nerka*) through Alberni Inlet and the Somass River to their spawning areas in Great Central and Sproat Lakes. During this summer, warm and stable climatic conditions elevated the temperature of surface waters in the Somass River and estuary to the extent that the migration of adult sockeye was delayed 2-8 weeks. Sonar records revealed that the fish were holding at depth in the cooler ( $11\text{-}12^\circ\text{C}$ ) hypoxic salt water, rather than continuing their migration through the warmer, less saline but more oxygenated surface waters. Over 100,000 adult salmon were lost, and it is likely that the cumulative effects of prolonged exposure to the adverse environmental conditions at the head of Alberni Inlet, and increased infection by a parasitic copepod (*Lepeophtheirus salmonis*), contributed to their demise.

The research reported in this document is part of a larger study endeavoring to understand the possible physiological consequences of this seemingly maladaptive behaviour of the sockeye salmon and at the same time assist all stakeholders to improve the aquatic conditions within Alberni Inlet.

**ABSTRACT**

Spohn, S., I.K. Birtwell, H. Hohndorf, J.S. Korstrom, C.M. Langton and G.E. Piercey. 1996. Preliminary Studies on the Movement of Adult Sockeye Salmon (*Oncorhynchus nerka*) in Alberni Inlet, British Columbia, using Ultrasonic Telemetry. Can. Manuscr. Rep. Fish. Aquat. Sci. 2355: 54 p.

The horizontal and vertical movement, and internal temperature of adult sockeye salmon (*Oncorhynchus nerka*) were examined using ultrasonic telemetry in Alberni Inlet, British Columbia.

The sockeye salmon were captured by commercial seiner 4 km from the head of Alberni Inlet on July 29, 1994. Four transmitters which emitted depth, and three which transmitted temperature signals were each inserted into the stomach of seven anaesthetized adult sockeye salmon. Seven other salmon were fitted with dummy transmitters and all were released at the capture site after recovery from anaesthesia. The fish were identified with a caudal tag in case of capture in the fisheries. The position of the fish was identified by a portable global positioning system over the following 6 d, after locating the fish using ultrasonic receivers and hydrophones.

The movement of individual fish was not tracked continuously during the daily searches. In general the salmon were detected up to 12 km seaward from the release site. However, three fish subsequently moved back up the inlet towards the release location between the fifth and sixth day of the study. In contrast to typical speeds of migrating sockeye salmon, these fish were slower and tended to hold within an area 6-10 km from the release site. The mean depth ( $\pm$  SD) recorded for individual sockeye was  $20 \pm 1$  m ( $n=17$ ),  $48 \pm 38$  m ( $n=2$ ) and  $37 \pm 20$  m ( $n=26$ ), with a minimum and maximum value of 1 m and 75 m (the fourth depth transmitter malfunctioned). The mean temperature ( $\pm$  SD) for individual salmon was  $9.8 \pm 0.4^\circ\text{C}$  ( $n=22$ ),  $9.9 \pm 0.3^\circ\text{C}$  ( $n=2$ ) and  $9.8 \pm 0.2^\circ\text{C}$  ( $n=9$ ) with a minimum and maximum value of  $9.3^\circ\text{C}$  and  $10.8^\circ\text{C}$ .

The salmon recorded at 75 m was in waters where the dissolved oxygen concentration was approximately  $3 \text{ mg}\cdot\text{L}^{-1}$ , salinity 33‰ and temperature  $9.0^\circ\text{C}$ . The internal temperature of another salmon was  $9.6\text{-}10.1^\circ\text{C}$  which corresponded to a depth of 7-15 m where the dissolved oxygen concentration was  $3\text{-}4 \text{ mg}\cdot\text{L}^{-1}$  and salinity 31-32‰. There was no report of these fish having been captured in the fisheries within Alberni Inlet or the Somass River.

**Key words:** sockeye salmon, migration, ultrasonic tracking, Alberni Inlet, temperature, depth

## RÉSUMÉ

Spohn, S., I.K. Birtwell, H. Hohndorf, J.S. Korstrom, C.M. Langton and G.E. Piercey. 1996. Preliminary Studies on the Movement of Adult Sockeye Salmon (*Oncorhynchus nerka*) in Alberni Inlet, British Columbia, using Ultrasonic Telemetry. Can. Manuscr. Rep. Fish. Aquat. Sci. 2355: 54 p.

Le déplacement horizontal et vertical du saumon rouge (*Oncorhynchus nerka*) adulte, ainsi que sa température interne, ont été examinés à l'aide de la télémétrie ultrasonique dans l'inlet Alberni (Colombie-Britannique).

Les saumons ont été capturés par des senneurs commerciaux le 29 juillet 1994 à 4 km du fond de l'inlet Alberni. Après évaluation en laboratoire de trois méthodes de fixation, quatre émetteurs indiquant la profondeur et trois indiquant la température ont été implantés dans l'estomac de sept saumons rouges adultes sous anesthésie. Sept autres saumons ont reçu de faux émetteurs, et tous les poissons ont été libérés au point de capture après la fin de l'anesthésie. Les poissons ont été marqués par une étiquette placée sur la queue au cas où ils seraient capturés dans les pêches. La position des poissons a été suivie par un système portatif de positionnement global pendant les 6 jours suivants, après localisation grâce à des récepteurs ultrasonores et à des hydrophones.

Le déplacement de chaque saumon n'a pas été suivi en continu pendant les pistages quotidiens. En général, les poissons ont été repérés à des distances pouvant atteindre 12 km vers le large par rapport au point de libération. Toutefois, après cinq ou six jours d'étude, trois poissons retournèrent vers le fond de l'inlet le point de libération. Par rapport à la vitesse typique des saumons rouges en migration, ces poissons étaient plus lents et avaient tendance à se tenir à une distance de 6-10 km du point de libération. La profondeur moyenne ( $\pm$  ET) enregistrée pour les saumons pris individuellement était  $20 \pm 1$  m ( $n=17$ ),  $48 \pm 38$  m ( $n=2$ ) et  $37 \pm 20$  m ( $n=26$ ), avec un minimum et un maximum de 1 m et 75 m (le quatrième émetteur n'a pas fonctionné correctement). La température moyenne ( $\pm$  ET) relevée pour les saumons pris individuellement était  $9,8 \pm 0,4$  °C ( $n=22$ ),  $9,9 \pm 0,3$  °C ( $n=2$ ) et  $9,8 \pm 0,2$  °C ( $n=9$ ), avec un minimum de 9,3 °C et un maximum de 10,8 °C.

Le saumon repéré à 75 m se trouvait dans des eaux où la concentration d'oxygène dissous était d'environ 3 mg,L<sup>-1</sup>, la salinité 33 l et la température 9,0 °C. La température interne d'un autre saumon était 9,6-10,1 °C, ce qui correspondait à une profondeur de 7-15 m, où la concentration d'oxygène dissous était 3-4 mg,L<sup>-1</sup> et la salinité 31-32 l. Aucun rapport n'a indiqué la capture de ces poissons dans l'inlet Alberni ni dans la rivière Somass.

**Mots clés:** saumon rouge, migration, pistage ultrasonore, inlet Alberni, température, profondeur

**LIST OF TABLES**

Table 1.	Type and Identification Number of Transmitters Inserted into Sockeye Salmon on July 29, 1994 . . . . .	21
Table 2.	Fish 9892 Location and Depth Data, Alberni Inlet . . . . .	22
Table 3.	Fish 9894 Location and Depth Data, Alberni Inlet . . . . .	23
Table 4.	Fish 9897 Location and Depth Data, Alberni Inlet . . . . .	24
Table 5.	Fish 9900 Location Data, Alberni Inlet . . . . .	25
Table 6.	Response Time of Internal Temperature Transmitter to Ambient Temperature Changes . . . . .	26
Table 7.	Fish 9903 Location and Temperature Data, Alberni Inlet . . . . .	27
Table 8.	Fish 9904 Location and Temperature Data, Alberni Inlet . . . . .	28
Table 9.	Fish 9906 Location and Temperature Data, Alberni Inlet . . . . .	29
Table 10.	Dissolved Oxygen, Salinity and Temperature at 1, 5 and 10 km from the Head of Alberni Inlet on August 3, 1994. . . . .	30

**LIST OF FIGURES**

Figure 1.	Map of the Somass River Drainage and Alberni Inlet . . . . .	31
Figure 2.	Study Area in Alberni Inlet (water quality monitoring stations 1, 5 and 10 km from the head of the inlet) . . . . .	33
Figure 3.	Net Horizontal Movement of Fish 9892 . . . . .	35
Figure 4.	Net Horizontal Movement of Fish 9894 . . . . .	37
Figure 5.	Net Horizontal Movement of Fish 9897 . . . . .	39
Figure 6.	Net Horizontal Movement of Fish 9900 . . . . .	41
Figure 7.	Net Horizontal Movement of Fish 9903 . . . . .	43
Figure 8.	Net Horizontal Movement of Fish 9904 . . . . .	45
Figure 9.	Net Horizontal Movement of Fish 9906 . . . . .	47
Figure 10.	Vertical Movement of Fish 9892 . . . . .	49
Figure 11.	Vertical Movement of Fish 9897 . . . . .	50
Figure 12.	Response Time of Internal Temperature Transmitter to Ambient Temperature Changes . . . . .	51
Figure 13.	Temperature Data from Fish 9903 . . . . .	52
Figure 14.	Temperature Data from Fish 9906 . . . . .	53
Figure 15.	Dissolved Oxygen, Salinity and Temperature 10 km from the head of Alberni Inlet, August 3, 1994 . . . . .	54

## INTRODUCTION

Adult sockeye salmon migrate through Alberni Inlet and the Somass River to spawn in their natal Great Central or Sproat Lake (Figure 1). A pulp mill has been discharging effluent into the surface fresh water of the vertically stratified Somass estuary at the head of Alberni Inlet since 1947. A comparison of pre-mill dissolved oxygen levels (Tully 1949) with those recorded in 1990 near the head of the inlet (north of Polly Point, Figure 1) indicated an average decline of  $1 \text{ mg}\cdot\text{L}^{-1}$  in surface water and of  $4 \text{ mg}\cdot\text{L}^{-1}$  in sub-halocline salt water (Stucchi et al. 1990, Canada, Department of Fisheries and Oceans, Sidney, B.C., unpublished report). Despite the sub-halocline water in the inlet having a naturally slow flushing rate, pulp mill effluent and the log storage activities in the inner harbour (Figure 2) are considered to be the dominant factors responsible for the oxygen depletion (Stucchi et al. 1990).

The migration of adult salmon was delayed by 2-8 weeks in 1990 and sonar records revealed that they were holding in the deeper hypoxic salt water rather than continuing their migration through the warmer, less saline but more oxygenated surface waters of the inlet. Over 100,000 adult salmon were lost from an estimated total return of over 500,000 (Birtwell et al. 1994; Stucchi et al. 1990). Factors contributing to the delayed migration and the reduced health of the salmon were considered to be the exposure to algal blooms and hypoxic waters, increased parasitic infection during holding in the inlet and the high temperature and low flow in the Somass River due to the stable and persistent warm climatic conditions (Stucchi et al. 1990).

The tendency of the sockeye salmon to occupy sub-optimal (hypoxic) deeper cold salt water rather than warmer normoxic surface waters was examined in laboratory experiments (Birtwell et al. 1994; Piercey et al. 1993). A continuous-flow Water Column Simulator (W.C.S.) was employed to mimic conditions that occur in the vertically-stratified estuary of the Somass River. It was found that under normoxic fresh ( $20^{\circ}\text{C}$ ) overlying salt water ( $12^{\circ}\text{C}$ ) during daytime, the fish remained in the deeper sea water, but moved upwards at night and made very transient excursions into fresh water. When dissolved oxygen levels were decreased to  $5\text{-}6 \text{ mg}\cdot\text{L}^{-1}$  in sea water, the fish remained in the salt water and increased gill ventilation. When the dissolved oxygen levels in sea water were further decreased to  $3\text{-}4 \text{ mg}\cdot\text{L}^{-1}$  the sockeye salmon increased the frequency of movements into fresh water but continued to spend the majority of time ( $>90\%$ ) in hypoxic sea water (Birtwell et al. 1994). We speculated that this residence in cooler but hypoxic salt water, in preference to warmer less saline normoxic water, was detrimental to these non-feeding adult fish and could result in increased energy expenditure and therefore potentially affect, migration, spawning, and the production of progeny.

The volitional movement of adult sockeye salmon in Alberni Inlet and the exposure to sub-optimal conditions needs to be understood to facilitate

environmental management of the area. The objective of this preliminary study was to employ ultrasonic tracking techniques to examine the horizontal and vertical movements, and the temperature preference, of adult sockeye salmon near the head of Alberni Inlet, where deteriorated water quality conditions persist. It was anticipated that the data would reveal the exposure of the fish to ambient conditions and assist the design of controlled laboratory experiments to assess the consequences of occupying sub-optimal habitats.

## STUDY AREA

Alberni Inlet extends 45 km north and east from Trevor Channel near Barkley Sound on the west coast of Vancouver Island, British Columbia, Canada (Figure 1). The inlet varies in width from 1 to 1.5 km and is up to 306 m deep (Tully 1949). Circulation patterns are similar to other fjord-like estuaries in British Columbia. Near-surface low salinity waters flow seaward and subsurface high salinity waters move inland (Thompson 1981; Tully 1949). We focussed our studies in the upper inlet, within 15 km of the Somass River estuary (Figure 2).

## MATERIALS AND METHODS

Prior to the field component of this study, we determined the most reliable method for attaching ultrasonic transmitters to adult sockeye salmon. The response times of internally positioned temperature transmitters to changes in ambient conditions were also examined under controlled laboratory conditions. Adult sockeye salmon (ages 4<sup>+</sup> to 6<sup>+</sup>) were captured by commercial seiner in Alberni Inlet and transferred to holding facilities at the West Vancouver Laboratory on June 22, 1994. Fish were acclimated, prior to evaluation of transmitter attachment techniques, in two 3,500 L outdoor tanks (11 per tank) which were continuously supplied with 46·L min<sup>-1</sup> air-equilibrated salt water (12.3 ± 1.1°C, 24 ± 1‰ salinity, 9.0 ± 0.3 mg·L<sup>-1</sup> dissolved oxygen).

### Transmitter Attachment

Because of the high cost of transmitters, dummy transmitters were used in tests to evaluate retention and attachment techniques. Cylindrical dummy transmitters 80 x 16 mm were constructed from disposable 10 ml syringe barrels and weighted (30 g) to that of the ultrasonic transmitters. A paraffin wax cone (3-6 mm) was fitted to one end of each transmitter to prevent damaging the fish's oesophagus and stomach during insertion.

Two means of attaching ultrasonic transmitters to adult sockeye (by suture and external sling), in addition to placement in the stomach via the esophagus,

were tested. Fifteen fish (mean fork length  $56 \pm 5$  cm) were anaesthetized with tricaine methanesulfonate (MS222,  $100 \text{ mg}\cdot\text{L}^{-1}$  in an isosmotic solution; 2:1 fresh water to sea water) before the attachment or insertion of the dummy transmitter. Transmitters were inserted into the stomachs of adult sockeye using the method of Berman and Quinn (1991). The three treatment groups were identified by coloured and coded plastic tape tied around the caudal peduncle. Each fish was permitted to recover in aerated sea water in a 50 L plastic container. The fish were then transferred to 3,500 L outdoor tanks (one per treatment) at the West Vancouver Laboratory each supplied with a continuous flow ( $46\cdot\text{L min}^{-1}$ ) of air-equilibrated sea water.

### **Internal Placement**

Dummy transmitters were inserted into the stomach via the oesophagus of each of 5 fish. After removal from the anaesthetic solution each fish was placed in a V-shaped wooden trough while the gills were irrigated with sea water. To facilitate insertion, Mellas and Haynes (1985) recommended that transmitters be coated with glycerine. Mineral oil was used in this study as glycerine did not adhere to, or effectively coat, the outer surface of the dummy transmitters. A cylindrical rod was used to assist in placement. The procedure was completed for each fish in less than 1 min. The smallest fish (length 49.7 cm) that received a stomach transmitter died within 24 h and a subsequent examination showed that the stomach had been ruptured, presumably while the transmitter was being inserted. The other 4 fish retained the transmitters over the 12-d observation period.

### **External Attachment**

Dummy transmitters were mounted at the base of the dorsal fin of 5 fish. An awl, threaded with nylon twine, was used to puncture the dorsal fin between rays and the transmitter was tied in place. Although the transmitters remained in place throughout the 12-d observation period, the attachment procedure required 3-6 min to complete.

Another external attachment method was examined which was not invasive. This method used transmitters sewn into slings ( $5 \times 11$  mm) cut from woven nylon material. The sling was slipped over the head of each of 5 anaesthetized fish with the transmitter positioned ventrally. The sling was placed posterior to the pectoral fins and anterior to the dorsal fin. This non-invasive attachment procedure required less than 1 min to perform but within 2 h the sling had been discarded.

Although the dorsal fin attachment technique was successful, the potential increased handling stress due to the prolonged procedure favoured the selection of the stomach insertion technique which could be performed more rapidly.

## Acoustic Telemetry Equipment

Two independent systems were employed to track adult sockeye. A Lotek Engineering Inc. (Newmarket, Ontario) SRX 400 receiver was fitted with a modified ultrasonic converter (SRC 400 150 mHz) and coupled with a hand-held Vemco Ltd. (Armdale, Nova Scotia) V-10 directional hydrophone. A converter changed the acoustic signal from the transmitter into an electrical current which is amplified in the receiver (Koo and Wilson, 1972). The second tracking system consisted of a Vemco Ltd. VR60 receiver and a V-10 directional hydrophone.

Four sonic pressure transmitters (Vemco Ltd. type V16P-4L) and three sonic temperature transmitters (type V16T-4L, Table 1) were used. The horizontal transmission range is reported to be at least 400 m (Cooke 1989, Canada, Department of Fisheries and Oceans, Nanaimo, B.C., unpublished report; F. Voegeli, Vemco Ltd., Armdale, N.S., personal communication). The cylindrical transmitters were 16 x 80 mm and weighed 30 g. The plastic loop on the transmitter supplied by the manufacturer was removed and a paraffin wax cone (3-6 mm) fitted to avoid damage to the fish's oesophagus during insertion. The pressure transmitters were "coded" (i.e. an identification code was transmitted with the depth signal). The temperature transmitters were "pulsed" (i.e. the temperature signal was transmitted without an identification code).

A limited number of frequencies were available from the manufacturer. A difference between the frequencies of the pulsed transmitters of at least 5 kHz is needed to ensure identification of each signal (M. Sisak, Lotek Engineering Inc., Newmarket, Ontario, personal communication). However, coded transmitters, (i.e. those which transmit an identification code) can be detected by the receiver and differentiated from a pulsed transmitter of the same frequency.

Temperature transmitters were operational within 0-30 °C and to depths of 300 m. The accuracy was  $\pm 0.3^{\circ}\text{C}$ . The depth transmitters were operational to 67 m depth and had an accuracy of  $\pm 4\%$  full scale (i.e.  $\pm 4\%$  of 67 m) plus 2% of reading (i.e. at 67 m  $\pm 1.3$  m). The 4% full scale error of the depth transmitter could be reduced to 2% full scale if the water temperature were known thereby permitting the use of a temperature correction factor unique for each transmitter (F. Voegeli, Vemco Ltd., Armdale, N.S., personal communication).

We chose depth transmitters with a maximum function at 67 m as previous researchers have found adult sockeye within the top 30 m of the water column in upper Alberni Inlet (Birtwell et al. 1983; Cooke 1989; W. Luedke, Canada, Department of Fisheries and Oceans, Nanaimo, B.C., personal communication). At depths below approximately 100 m, membrane damage could occur and the transmitter would malfunction or be destroyed (F. Voegeli, Vemco Ltd., Armdale, N.S., personal communication).

The appropriate slope and intercept for converting the signal to temperature or depth for each transmitter (provided by Vemco Ltd.) was entered into the Vemco receiver prior to use. The Vemco receiver decoded the signals and displayed temperature and depth directly.

The Lotek unit displayed values (x) which were recorded by personnel and converted to depth or temperature using the formulae:

temperature (°C)  $y^t = m (1,000 / x) + b$   
(i.e. pulsed)

depth (meters)  $y^d = m (x / 1,000) + b$   
(i.e. coded)

where:

m = slope (unique constant for each transmitter provided by manufacturer)

b = y-intercept (unique constant for each transmitter provided by manufacturer)

x = value displayed on receiver

In some circumstances, the signal was too weak to be displayed on the receiver, therefore the beats per minute (bpm) were converted to temperature by the formula:

temperature (°C)  $y^t = m (x/60) + b$ ; where x = bpm

### **Response of Internal Temperature Transmitters to Ambient Temperature**

The time required for an internal transmitter to equilibrate to, and vary with, ambient temperature was assessed. The transmitter, previously held at room temperature (21.5°C) was placed in cold (12.0°C) water and the transmitter temperature compared with that of a standard thermometer to verify the accuracy of calibration. A transmitter was also inserted into the stomach of a 2.1 kg sockeye salmon which had been held in a tank of sea water (12.7°C) and transferred to a tank containing warmer sea water (18.6 ± 0.2°C). The temperature signal from the transmitter was then monitored for 75 min and compared with the temperature of the sea water which was recorded with a standard thermometer. Subsequently the response of the transmitter to a reduction in water temperature was recorded by continuously reducing the temperature of sea water, from 18.3°C to 14.7°C over 1 h through the addition of

cold sea water. During this time the signal from the internal transmitter was recorded and compared to that of the standard thermometer which recorded the temperature of the sea water.

### **Fish Capture, Transmitter Attachment and Tracking**

Sockeye salmon were captured in a purse seine by the 75 ft commercial seiner *Viking Spirit* near Follinsbee Creek during an ebb tide on July 29, 1994 in 40 m of water at approximately 0930h. The set was made within 4 km of the head of Alberni Inlet (Figure 2). Continuous echo soundings were undertaken by the *Viking Spirit* during its movement seaward from the head of the inlet and the net was set when a suitable number of "targets" were identified. The exact position of capture was 49° 11" 889 N latitude, 124° 49" 855 W longitude.

Adult sockeye salmon were removed individually from the seine net with a dip net, and transferred to a 150 L insulated container holding 80 L brackish surface water (19°C, 19‰ salinity) in which 4 g of MS 222 has been dissolved (50 mg·L<sup>-1</sup>) for anaesthesia. The fork length of the fish was recorded to the nearest cm, but to minimize handling, the fish were not weighed. Individual sockeye were exposed to anaesthetic from 45 sec to 2 min 53 sec depending on the time required for onset of anaesthesia and the efficiency with which the tag could be inserted. Oxygen was supplied from a cylinder through an air stone and this maintained dissolved oxygen levels in the anaesthetic bath between 7.8 and 8.9 mg·L<sup>-1</sup> (90-100% saturation). Dissolved oxygen levels were measured with a Leeds and Northrup meter, model 7932 (North Wales, PA).

One transmitter was inserted into the stomach of each of seven adult sockeye salmon. Coded, coloured tape was then tied around the caudal peduncle with the inscription "DFO test fish - do not consume, reward, phone no." This precautionary step was taken since fish anaesthetized with MS 222 are not considered safe for human consumption (Argent Chemical Laboratories 1987). Dummy transmitters were also inserted into another seven fish which were treated in the same manner as those with the functional transmitters. It was anticipated that they would provide additional information on the movement of fish if recapture information was reported from the commercial, aboriginal or recreational fisheries. After insertion of the transmitters the fish were transferred quickly to a 40 L container of aerated brackish water (9‰ salinity) to facilitate recovery prior to release. The first fish was released at 0935h and the fourteenth fish at 1040h. Due to wind and tidal movements the final position of the vessel was 49° 12" 460 N latitude, 124° 49" 350 W longitude. During this drift and the transmitter insertion process, the stock fish were held in the pursed net at the side of the *Viking Spirit*.

The search for the fish began on the first day after release and revealed that most of the tagged fish had moved seaward from the release site. During the following days, searches were concentrated in these seaward areas, however the inner harbour was searched on days 2, 3 and 6 after release. Two rigid-hulled inflatable boats, each equipped with ultrasonic receivers and hydrophones were employed at this time in addition to the use of a support vessel, the *Marila*, and the transport boat *Shimano*. The latitude and longitude of targets were determined at each location using a Trimble Pathfinder<sup>R</sup> Global Position System (Sunnyvale, California, U.S.A.). Visual landmarks were also used to determine the boat position. Between 2 and 5 tracking shifts per day (approximately 3 h each) were performed during daylight.

## RESULTS

The horizontal movement, depth and internal temperature of salmon are presented in Tables 2-5, 7-9 and Figures 3-11, 13-14. The net distance moved refers to the shortest water distance between two fish locations, consistent with Quinn and terHart (1987). To facilitate reporting, each fish that received a transmitter is referred to by the transmitter number in the following sections. The day on which these tagged fish were released is considered to be day 0 of the study. In some instances, when the signal received was weak, no depth or temperature data were displayed on the receiver and only the time and location are identified in the Tables and Figures. The signal beats could be heard through the hydrophones and counted or the Lotek<sup>R</sup> receiver was set to display the beats per min (bpm) and later converted to temperature values. Careful interpretation of location was required because of the potential to obtain signal "echoes" in an enclosed area such as Alberni Inlet (J. Candy, Canada, Department of Fisheries and Oceans, Nanaimo, B.C., personal communication). We deduced that such echoes occurred on occasions from the eastern shore of the study area (i.e. a strong signal from the same transmitter was obtained after rotation of the hydrophone towards the western shore).

### Horizontal Movement

We expected that fish captured and released near the head of Alberni Inlet would remain in this area or move toward the Somass River to continue their migration. In general, however, fish tagged moved seaward and were predominantly detected between China Creek and Mactush Bay (Figures 3-9).

Fish 9892 (Figure 3) was detected 4-5 km south of the release site (between Stamp Narrows and China Creek) 24 and 48 h after release. On day 3, and for the duration of the study, it was detected at 5 locations 8-10 km south of the release point in the area between China Creek and Mactush Bay. On day 6 it

was detected south of China Creek residing within a 0.5 km area for 3 h (data collected at 5-15 min intervals which revealed a movement of  $0.2 \text{ km}\cdot\text{h}^{-1}$ ) during the end of a flood and beginning of an ebb tide.

Fish 9894 (Figure 4) moved seaward from the release point during the first 5 days of the study period. Twenty four hours after release, it was between Follinsbee Creek and Stamp Narrows, 2 km seaward of the release site. By the second day, it had continued to move seaward to an area between Stamp Narrows and China Creek. From day 3 to 5 of the tracking period it was between China Creek and Macktush Bay. Between day 5 and 6 it moved approximately 5 km north towards Stamp Narrows and the head of the inlet.

Fish 9897 (Figure 5) was detected between Follinsbee Creek and Stamp Narrows, 2 km south of the release site on day 1. It was detected again on day 3, and periodically until the end of the tracking period at locations 6-9 km south of the release site in the area between China Creek and Macktush Bay.

Fish 9900 (Figure 6) was detected at 8 locations seaward of the release site (south of China Creek) on days 3-5. It was detected at one of these locations during a 1 h period ( $n=6$ ) near Underwood Cove on day 3. On the final day of tracking (day 6) it had moved 3 km north of its position on day 5 and toward the head of the inlet.

Fish 9903 (Figure 7) was detected 8-10 km south of the release site (in the area between China Creek and Macktush Bay) on day 3 and on a number of occasions until day 6.

Fish 9904 (Figure 8) was detected on days 4 and 5, 6-10 km south of the release site between China Creek and Macktush Bay.

Of all fish tagged in this investigation fish 9906 (Figure 9) moved the farthest and most rapidly. On day 1 it was detected within 0.25 km of the release site. By day 3 it was between China Creek and Macktush Bay. On day 5 it was closer to the head of the inlet between Stamp Narrows and China Creek. However, within 1 h it had moved seaward to Mactush Bay during an ebbing tide, a net distance of 7 km. It was detected in this area (near Mactush Bay) 3 times in a 15-min period and reached the southern extent of the search area, 12 km south of the release site. The following day (day 6) it had moved towards the head of the inlet, a net distance of 10 km and ultimately reached a point 2 km south of the initial release site.

## Depth

Depths at which fish were detected are presented in Tables 2-5 and Figures 10 and 11. Intermittent detections of transmitter 9892 (Table 2, Figure 10) indicated that this fish was at a depth of 18-20 m once daily on days 3, 4 and 5. On day 6 it was at  $20 \pm 1$  m ( $n=14$ , range 19-22 m) during a flooding and ebbing tide (5-15 min intervals over a 3 h period). Fish 9894 (Table 3) was at a 21 m depth ( $n=1$ , day 4) and 75 m ( $n=1$ , day 6). Fish 9897 (Table 4, Figure 11) was at 11 m ( $n=1$ ) on day 3, 8-10 m ( $n=5$ ) on day 4, 32-67 m ( $n=19$ ) on day 5 and at 1 m ( $n=1$ ) on day 6. Transmitter 9900 (Table 5) malfunctioned on days 3-5 (transmitting a depth signal of 370 m in 120 m deep water). The malfunction may have been caused by the fish moving into water deeper than the depth rating of its transmitter, thereby resulting in pressure damage and the transmission of false information.

During the 6 d observation period, the mean depth occupied by fish 9892 was  $20 \pm 1$  m ( $n=17$ , range 18-22 m); that of fish 9894 was  $48 \pm 38$  m ( $n=2$ , range 21-75 m) and of fish 9897 it was  $37 \pm 20$  m ( $n=26$ , range 1-67 m). The mean depth ( $\pm$  SD) recorded for all fish was  $31 \pm 18$  m (combined data  $n=45$ ) and the range 1-75 m.

## Temperature

Laboratory tests indicated that a 30 min lag time was required for the temperature output of the internal tag to equilibrate from 12.7°C to an ambient water temperature of 18.6°C (Table 6, Figure 12). However, 90% of the response to this warming occurred within 15 min. The temperature signal from the internal tag was 0.4-1.4°C higher than ambient temperature while the ambient temperature decreased from 18.3 to 14.7°C over a 1 h period (a decrease of 1°C every 15 min).

Internal temperatures of the tagged fish released with transmitters in Alberni Inlet are presented in Tables 7-9 and Figures 13-14. The signal from transmitter 9903 (Table 7, Figure 13) revealed that the fish's internal temperature was 9.8-10.0°C ( $n=3$ ) on day 3, and 10.3°C ( $n=1$ ) on day 4. On day 5, at 1420-1430h it was between 9.8 and 10.3°C ( $n=2$ ), but 2-3 h later it was between 9.3 and 9.7°C ( $n=10$ ). A single temperature measurement of 7.2°C in fish 9903 was considered to be an artifact because water temperatures measurements this low have not been reported in Alberni Inlet (Seaconsult Marine Research 1995; Tully 1949). On day 6 the internal temperature was  $10.0 \pm 0.6$ °C ( $n=6$ ). The internal temperature of fish 9904 (Table 8) was 10.1°C ( $n=1$ ) and 9.7°C ( $n=1$ ) on days 4 and 5 respectively. The internal temperature of fish 9906 (Table 9, Figure 14) was  $9.6 \pm 0.0$ °C ( $n=5$ ) on day 5 and  $10.0 \pm 0.5$ °C on day 6 ( $n=4$ ) with a range of 9.6-10.1°C.

In summary, the mean of all temperature values ( $\pm$  SD) of fish 9903 was  $9.8 \pm 0.4^\circ\text{C}$  ( $n=22$ ); fish 9904 was  $9.9 \pm 0.3^\circ\text{C}$  ( $n=2$ ) and 9906 was  $9.8 \pm 0.2^\circ\text{C}$  ( $n=9$ ). The minimum recorded temperature was  $9.3^\circ\text{C}$ , the maximum  $10.8^\circ\text{C}$  and the mean  $9.8 \pm 0.4^\circ\text{C}$  ( $n=33$ ).

## DISCUSSION

It is possible that the combination of capture, anaesthesia and tagging procedures used in this investigation may have temporarily altered the normal migratory behaviour of the tagged fish and been instrumental in the initial seaward displacement. Such behavioural changes after handling and tagging fish have been reported or speculated upon by other researchers. Madison et al. (1972) noticed a tendency for adult sockeye to delay leaving the tagging area near the mouth of the Nass River for 30-60 min, although they were not able to conclude that the delay was due to the tagging procedure itself. Cooke (1989) found that stomach-tagged adult sockeye salmon in Alberni Inlet dove to depths of 10-25 m for 1 h, then approached the surface. He speculated that the fish returned to the surface to obtain air for buoyancy correction due to the weight of the transmitter. Quinn et al. (1989) also observed an abrupt dive to 30-60 m, (following 30-60 min of holding to recover from anaesthesia) in 20 of 28 stomach-tagged adult sockeye salmon in the waters between Vancouver Island and mainland British Columbia. Rosberg and Greer (1985) held stomach-tagged adult sockeye and chum salmon for 24 h (for anaesthesia recovery) and considered erratic movements up or downstream after release to be the result of handling stress. Recently tagged adult steelhead initially moved downstream rather than continue their upstream movement in the Skeena River (R. Alexander, LGL Ltd., Sidney, B.C., personal communication). In another study Haynes and Gray (1979) found that tagged adult salmonids failed to migrate past hydro-electric dams whereas untagged fish completed the migration successfully.

### Horizontal Movements

Interpretation of the exact pattern of the movements of the fish is not possible because we did not continuously monitor fish movement. Instead our search effort was designed to collect data from a number of transmitters during a tracking shift. This resulted in the random identification of fish location and compromised a more detailed pattern of the movement of fish that would have resulted from continuously tracking individual fish. This tactic was deliberately chosen in this preliminary study so that the logistics of tracking more than one individual could be evaluated and a more complete study undertaken at a later date. Accordingly there was often long time intervals between the detection of signals from the same fish: for the majority of fish only the general movement will be discussed.

Fish 9906 appeared to move the largest net distance in the shortest time, travelling 7 km seaward from China Creek in a one hour period during an ebbing tide on day 5. This speed is faster than the  $0.2-6 \text{ km}\cdot\text{h}^{-1}$  for sockeye salmon determined by Madison et al. (1972) at the mouths of the Nass and Skeena Rivers and the  $0.2-0.4 \text{ km}\cdot\text{h}^{-1}$  recorded by Cooke (1989) in Alberni Inlet. Ocean migration speeds for sockeye salmon reported by Brett (1995) ranged from  $1.3-3.0 \text{ km}\cdot\text{h}^{-1}$ . The large distances moved by fish 9906 may have been assisted by ebbing tidal currents (which are typically 1.5 knots at Sproat Narrows, Canada, Department of Fisheries and Oceans 1990). It is also feasible that this apparently large net movement may have been affected by interference from a location echo (as described in Results) as the southernmost transmitter signal was weak. However, even accounting for this potential problem it is apparent that this fish had travelled quickly in the upper inlet waters.

All of the tagged fish moved seaward after release and remained in the same general area as the majority of other salmon in upper Alberni Inlet as deduced from the location of sport fishing boats and from echo soundings. This could indicate that the behaviour of the tagged fish after release was eventually similar to that of other wild fish and that they had possibly recovered from handling stress.

Tagged salmon were expected to move north toward the mouth of the Somass River to continue their spawning migration to Sproat or Great Central Lake. Sports fishing boats were numerous in the study area during the tracking period. Their location indicated that the majority of sockeye salmon were not migrating continuously throughout the inlet, rather holding or moving little, as was observed for tagged salmon during this 6-d study. Escapements to the Somass River were lower than the 13 year average (1980-1993) between July 10 and early September, 1994 (W. Luedke, Canada, Department of Fisheries and Oceans, Nanaimo, B.C., personal communication). Nevertheless some sockeye had moved through the Somass River and arrived at the fishways at Stamp and Sproat Falls (Figure 1) early in June and their migration continued until early November, 1994.

The apparent residence time of tagged fish in the upper inlet is consistent with the deductions of K. Hyatt (Canada, Department of Fisheries and Oceans, Nanaimo, B.C., personal communication) regarding the migration of sockeye salmon through this region. Hyatt mentioned that adult sockeye salmon typically move from Barclay Sound to the mouth of the Somass River in 4-7 d, moving more quickly in late summer than in June. It is also thought that the fish hold in the inlet for up to 8 weeks when the migration is delayed (e.g. in 1990; Stucchi et al. 1990).

Fish tagged in this study exhibited a holding behaviour and did not rapidly commence migration into the Somass River. The mean Somass River discharge (measured by a flow gauge below the confluence of the Stamp and

Sproat Rivers, Figure 1) during the study period was  $27.9 \text{ m}^3 \cdot \text{s}^{-1}$  which is close to the summer minimum flow of  $25.2 \text{ m}^3 \cdot \text{s}^{-1}$  (the summer maximum was  $78.3 \text{ m}^3 \cdot \text{s}^{-1}$ , Water Survey Canada, Vancouver, B.C., unpublished data). This low river flow may have created conditions unfavourable to upstream migration similar to, but not as strong as those which occurred in 1990. Such delays are not uncommon in response to river water flows. Clarke et al. (1991) found that Atlantic salmon in south Wales delayed entry into the river during periods of low, falling river flows. Hereditary differences between runs appeared to influence the timing of the upstream movement of Atlantic salmon from the Sheet Harbour estuary (Brawn 1982). Fall run Atlantic salmon appeared to move into the estuary and exhibit passive, holding behaviour for 3.5 months before migration whereas early run salmon continued their river migration (Brawn 1982).

Notwithstanding the potential holding of the tagged sockeye salmon in the inlet due to adverse migration conditions, their initial seaward movement is similar to that reported by other researchers. For example, this was observed for sockeye salmon in the Skeena River estuary by Groot et al. (1975), in chinook salmon in the Duwomish River estuary (Fujioka 1970) and the Columbia River estuary (Olson and Quinn 1993) and in Atlantic salmon in the Ribble River estuary, England (Priede and Cragg-Hine 1989). The researchers considered that this seaward movement was passive with the ebb tides and found corresponding inland movement with the flood tides. Priede and Cragg-Hine (1989) found that some salmon left the vertically mixed Ribble estuary on the ebb tides. Westerberg (1982) suggested that a high incidence of seaward movement by Atlantic salmon from the Lule estuary in Sweden was due to pollution from a steel works, a coke oven plant and silt from a dredging operation. Although a pulp mill discharges effluent at the head of Alberni Inlet into the freshwater lens of the highly vertically stratified estuary, prevailing density differences tend to keep the effluent in surface waters. Hence the likelihood of fish moving in response to the effluent discharged 15 km landward of their "holding area" seems remote. It is perhaps more likely that the fish moved seaward in response to unfavourable river water temperatures and low dissolved oxygen levels in sub-halocline waters which were at stressful levels (Birtwell et al. 1994).

In spite of the general seaward movement and holding of tagged fish in our study, three of them (9894, 9900 and 9906), subsequently moved inland towards the release location a net distance of 5, 3 and 10 km respectively in 24 h (days 5-6). It is possible that this movement indicated active migration to the Somass River. We cannot rule out, however the possibility of passive movement with the tides as observed by Priede and Cragg-Hine (1989).

## Depth

The three fish from which we received information were predominantly between 20 and 50 m depth. Only one fish was located at the surface (1 m, Figure 11) on one occasion (day 6) near Underwood Cove. Fish 9892 maintained a position at depth for several hours during flood and ebb tides. In the same inlet, Cooke (1989) found that sockeye salmon would remain at depths of 10-20 m for 4 h although the depth and duration were variable among fish and they also moved to occupy surface as well as deeper estuarine waters. Atlantic salmon in the Sheet Harbour Estuary in Nova Scotia kept a constant distance from the surface and associated with the halocline (Brawn 1982). Birtwell et al. (1983) captured higher numbers of coho, chinook and sockeye salmon between the surface and 2.5 m depth than in the deeper waters below the halocline near the head of Alberni Inlet. They concluded that depressed oxygen concentrations in the deeper waters effectively reduced habitat availability and restricted fish to shallower surface waters close to the mouth of the Somass River, above the most severely degraded habitat (Birtwell et al. 1983). Similarly, hydroacoustic surveys on July 31, 1994 (Canada, Department of Fisheries and Oceans 1994, unpublished report) suggested that most fish were distributed in the surface 3-5 m in the inner harbour but, further seaward, between Polly Point and China Creek, a larger proportion inhabited deeper water.

Dissolved oxygen, temperature and salinity were monitored three times per week during the summer of 1994, at stations between the mouth of the Somass River and 10 km seaward to China Creek, by MacMillan Bloedel Ltd., Alberni Pulp and Paper Division. These data were used to construct isopleths of temperature, oxygen and salinity down the inlet by Seaconsult Marine Research Ltd. (1995). We anticipated that the approximate dissolved oxygen, temperature and salinity of waters occupied by the salmon we were tracking would be deduced by reference to the data generated by the water quality monitoring program. Subsequently, assessments could be made of the conditions which salmon were exposed to and for how long. In addition, data collected from the temperature transmitters would provide information on the temperature of water which the fish chose to occupy. Unfortunately, the salmon we tagged moved seaward and generally outside the area encompassed by the water quality monitoring program hence comparisons with water quality data were limited.

Temperature, salinity and dissolved oxygen were measured from 0-50 m depth. An example of the structure of the water column at stations 5 and 10 km from the head of the inlet with respect to these variables is presented for August 3, 1994 in Table 10 and Figure 15. A thermocline and corresponding halocline occurred at the 4-6 m depth and dissolved oxygen levels decreased below this zone. The surface layer was characterized by lower salinity, higher temperature and higher dissolved oxygen than the deeper sea water (e.g. on August 3, 1994,

10 km station: surface 13.7‰ salinity, 20.1°C and 7.5 mg·L<sup>-1</sup> dissolved oxygen and in sea water at 45 m, 32.9‰ salinity, 9.0°C and 3 mg·L<sup>-1</sup> dissolved oxygen).

Depth and temperature data were collected from two fish (9894 and 9906 respectively) within the area for which water quality information is available. Fish 9894 was at 75 m (n = 1) on day 6 (August 4), 1 km north of the 10 km water quality station. Measurements taken at this station on August 3 at 45 m, show that salinity was 32.9‰, temperature was 9.0°C and dissolved oxygen concentration was 3 mg·L<sup>-1</sup>.

Some assumptions about the structure of the water column in the area of fish capture (outside of the water quality monitoring area) can be made from existing information. Tully's measurements (1949) extended throughout the inlet and he concluded that:

"There are three principal layers in the oceanographic structure of the water mass. The upper zone contains mixed fresh and sea water, and becomes progressively more saline from the head of the inlet to the mouth. This layer is clearly defined by an inflexion in the salinity-depth gradient, below which there is a middle zone containing circulatory sea water, whose salinity does not vary markedly within the length of the inlet. This zone was limited by the threshold, which acts as a weir, protecting the deep zone waters from all but frictional transfer of mass and velocity.

Sea water enters the middle zone during the flood tide and some is transferred to the upper zone by turbulence resulting from tidal velocity. During the ebb tide sea water leaves the inlet in both the upper and middle zones. The current in the middle zone is predominantly towards the head.

Fresh water entering the upper zone from land drainage remains in the zone and moves persistently seaward owing to isostatic head. The depth of this zone is constant in the length of the inlet owing to isostatic equilibrium, and the velocity accelerates downstream in proportion to the amount of sea water added from the middle zone."

Furthermore, "During the summer the temperature distribution closely follows the salinity structure, with minor modifications due to insolation, but in the winter the system becomes isothermal while the characteristic salinity distribution persists."

The surface brackish-water layer was 4-6 m deep during our study period (Seaconsult Marine Research Ltd. 1995). It appears that the properties of salinity and temperature of sea water in the inlet tend to be vertically uniform below the surface layers because they are continuously renewed from the Pacific Ocean (D. Hodgins, Vancouver, B.C., personal communication; Tully 1949). We consider it likely that low dissolved oxygen conditions associated with sea water in the water quality monitoring area also occurred where fish were located. We speculate that since all but one of the fish were located deeper than 6 m, that they

chose to occupy the colder, less oxygenated oceanic waters most of the time. During our study the waters within this zone were typically 9°C, 33‰ salinity and 3 mg·L<sup>-1</sup> dissolved oxygen (MacMillan Bloedel, Port Alberni, B.C. unpublished data). These results are consistent with the findings of our laboratory studies on the behaviour of adult sockeye salmon given a choice of occupying normoxic fresh water or hypoxic salt water (Birtwell et al. 1994).

### Temperature

Because of the required equilibration time it is probable that excursions by fish of less than 30 min duration through waters of different temperatures would not be rapidly, and therefore accurately, determined. The slow response time for the internal fish temperature to reach equilibrium with the external medium was also found by Berman and Quinn (1991). In their studies an internal tag in an adult (3 kg) chinook salmon took 28 min for equilibration from 8.6 to 17.9°C. They also observed that internal transmitters in larger fish were slower to respond. Despite this potential limitation, the data generated in our study revealed that most fish did not move rapidly and vertically in the water column during the day time, therefore the fish may not have encountered significant changes in water temperature over short periods of time. Accordingly the internal fish temperature data we obtained probably reflected the ambient conditions. Data for all fish with temperature transmitters revealed the occupancy of waters with a narrow temperature range (9.3-10.1°C).

Two fish were detected within the pulp mill's water quality monitoring area thus permitting comparisons between their internal temperature and ambient water conditions (and hence depth selection). On August 3, (day 5) the internal temperature of fish 9906 was 9.6°C (n=5) and on the following day the temperature was 10.0-10.1°C (n=4). Based on the information from the monitoring program at the 5 km station, this fish was in the less oxygenated sea water at 7-15 m depth where temperatures were 9.6-10.1°C, salinity 31-32‰, and dissolved oxygen 3-4 mg·L<sup>-1</sup>. A second fish (9894) occupied waters near the 10 km water quality monitoring station at 75 m depth (n=1, Figure 15). At this location, waters above the halocline were 19.7-20.1°C, 14-16‰ salinity and 7 mg·L<sup>-1</sup> dissolved oxygen while those in deeper sea water were 9.0-10.7°C, 31-33‰ salinity and 3-4 mg·L<sup>-1</sup> dissolved oxygen. In that all of the tagged fish in this study had internal temperatures within the range 9.3-10.8°C we concluded that they were occupying the deeper, less oxygenated sea water ( $\leq 4$  mg·L<sup>-1</sup> dissolved oxygen).

Sockeye salmon, in laboratory experiments which simulated conditions in Alberni Inlet, spent the majority of time in hypoxic sea water (3-4 mg·L<sup>-1</sup> dissolved oxygen) but made very transient excursions through a thermocline to normoxic fresh water (Birtwell et al. 1994; Piercey et al. 1993). Hyatt (Canada,

Department of Fisheries and Oceans, Nanaimo, B.C., personal communication) concluded from hydroacoustic surveys that a higher proportion of sockeye salmon occupy shallower water as they move towards the mouth of the Somass River. A result which Birtwell et al. (1983) determined in 1975/76 using fish capture and in-situ experimental techniques. Sockeye salmon in coastal waters off British Columbia remained at or below the thermocline in stratified waters (Quinn et al. 1989) and with their obvious fidelity to waters with temperatures of 9-10°C, the occupancy of deeper sea water in unpolluted inlets would not pose a risk to finite energy reserves. Because of the hypoxic conditions in the deeper waters of Alberni Inlet close to the Somass estuary, salmon delayed on their migration will experience additional energy demands to compensate for the ambient sub-optimal conditions. Prolonged occupancy of such waters has been shown to be detrimental (Stucchi et al. 1990). A seemingly species-specific behaviour contrasting with that of sockeye salmon was exhibited by chinook salmon which swam in surface waters of the Columbia River estuary where temperature and salinity gradients were large (Olson and Quinn 1993). Chum salmon in coastal waters off Japan either resided near the thermocline (Soeda et al. 1987) or remained near the surface and seldom dove through the thermocline (Ichihara and Nakamura 1982). Atlantic salmon in the Sheet Harbour estuary avoided fresh or salt water and occupied the halocline at 5-20‰ salinity (Brawn 1982). Such behaviour may well be displayed by adult sockeye salmon closer to the mouth of the Somass River where a well-defined halocline is present in the vertically-stratified estuary (Birtwell et al. 1983).

Although tagged sockeye salmon in this study moved seaward on release, tended to hold within an area 6-10 km from the release site, and three fish moved inland on the final (sixth) day of study, we cannot fully explain the basis for this movement. This behaviour could be associated with low river flows, high river temperatures, sub-optimal dissolved oxygen conditions in waters the fish chose to occupy, handling stress, tidal currents etc. If the overriding contributing factor is the need for the salmon to be in cold sea water, then they would have been in hypoxic conditions, some of which could have been lethal over time Chapman (1940). The salmon we tagged with depth and temperature transmitters were predominantly in colder sea water of low oxygen content at depth. The metabolic demands of occupying such hypoxic waters will be higher than in fish occupying similar but normoxic waters. For non-feeding adult salmon on their spawning migration increased energy expenditures required to mitigate or compensate for these conditions could ultimately lead to a reduction in reproductive success, or a failure to migrate, as recorded in 1990 (Stucchi et al. 1990). With an anticipated increase in global temperatures, migration delays could be more prevalent. It would be prudent, therefore, to continue to improve the conditions of this inlet for the benefit of aquatic resources. The provincial and federal governments and MacMillan Bloedel Ltd. are co-operating towards this objective.

### ACKNOWLEDGEMENTS

This work was undertaken with the co-operation of many individuals. George Kruzynski (Canada, Department of Fisheries and Oceans, West Vancouver Laboratory) demonstrated transmitter attachment techniques. Jim Morrison (Fisheries and Oceans Canada, South Coast Division (SCD) provided a rigid-hulled inflatable boat, logistical assistance and liaison with officials in Port Alberni. Jim Mitchell (SCD) authorized use of a commercial seiner *Viking Spirit* from the test fishery for fish capture. Tom Bird (Canada, Department of Fisheries and Oceans, Recreational Fisheries Division) supplied the 25 ft. boat *Shimano* for tracking support which was operated by Terry Gjernes. John Candy (Canada, Department of Fisheries and Oceans, Pacific Biological Station) provided telemetry equipment and gave advice on tracking procedures. Laurie Gordon, (Canada, Department of Fisheries and Oceans, area/species co-ordinator) arranged an extension of the support vessel *Marila* and assistance with the advertising of a reward for recapture of salmon. Hank Buitendyk provided and operated the 48 ft. support vessel *Marila*. Margaret Wright (SCD) made water quality information available and assisted in the field work. Ron Fink (Global Fisheries Consultants Ltd.) provided valuable comments on the manuscript. Bruce Nidle drafted the figures, Derek Nishimura assisted with graph preparation and Donna Mawson assisted with the word processing. The co-operation and support of MacMillan Bloedel Ltd. is appreciated.

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Table 1.. Type and identification number of transmitters inserted into adult sockeye salmon on July 29, 1994.

Type	No.	Frequency (kHz)	ID Code	Fish Length (cm)
temperature	9903	67.30		61
	9904	71.04		62
	9906	76.80		60
pressure (depth)	9892	50.00	350	58
	9894	60.00	450	70
	9897	67.30	600	63
	9900	73.50	750	64

Table 2. Fish 9892 location & depth data,  
Alberni Inlet.

DAY	1994	TIME	DEPTH (m)
0	29-Jul	10:39	*
1	30-Jul	15:14	*
2	31-Jul	11:10	*
2	31-Jul	11:20	*
3	1-Aug	18:25	*
3	1-Aug	19:10	19
4	2-Aug	18:15	18
5	3-Aug	14:10	20
6	4-Aug	10:30	21
6	4-Aug	10:45	21
6	4-Aug	11:10	19
6	4-Aug	12:05	21
6	4-Aug	12:10	21
6	4-Aug	12:15	21
6	4-Aug	12:15	20
6	4-Aug	12:30	21
6	4-Aug	12:40	20
6	4-Aug	12:45	20
6	4-Aug	12:50	22
6	4-Aug	13:10	20
6	4-Aug	13:15	21
6	4-Aug	13:20	20
		mean depth	20
		SD	1
		min	18
		max	22
		n	17

\* Location only

Table 3. Fish 9894 location and depth data, Alberni Inlet.

DAY	1994	TIME	DEPTH (m)
0	29-Jul	10:18	*
1	30-Jul	15:32	*
1	30-Jul	17:20	*
2	31-Jul	07:42	*
2	31-Jul	08:54	*
2	31-Jul	09:00	*
2	31-Jul	10:50	*
2	31-Jul	12:30	*
3	1-Aug	19:40	*
4	2-Aug	14:00	*
4	2-Aug	14:36	*
4	2-Aug	14:42	*
4	2-Aug	14:49	*
4	2-Aug	15:31	21
5	3-Aug	14:30	*
6	4-Aug	12:59	75
mean depth			48
SD			38
n			2
min			21
max			75

\* Location only

Table 4. Fish 9897 location &amp; depth data, Alberni Inlet.

DAY	1994	TIME	DEPTH (m)
0	29-Jul	10:31	*
1	30-Jul	15:32	37
1	30-Jul	17:30	*
3	1-Aug	18:10	*
3	1-Aug	18:35	*
3	1-Aug	19:10	11
3	1-Aug	19:35	*
4	2-Aug	14:00	*
4	2-Aug	15:02	8
4	2-Aug	15:19	9
4	2-Aug	15:24	*
4	2-Aug	15:27	*
4	2-Aug	19:50	8
4	2-Aug	19:55	10
4	2-Aug	20:00	8
5	3-Aug	11:02	45
5	3-Aug	11:19	67
5	3-Aug	11:28	54
5	3-Aug	11:30	59
5	3-Aug	11:43	54
5	3-Aug	12:15	58
5	3-Aug	12:24	58
5	3-Aug	12:31	55
5	3-Aug	12:40	57
5	3-Aug	12:48	59
5	3-Aug	15:35	48
5	3-Aug	15:45	40
5	3-Aug	16:05	38
5	3-Aug	16:10	36
5	3-Aug	16:15	32
5	3-Aug	16:20	35
5	3-Aug	16:25	34
5	3-Aug	16:30	33
5	3-Aug	16:40	32
6	4-Aug	11:15	1
		mean depth	37
		SD	20
		n	26
		min	1
		max	67

\* Location only

Table 5. Fish 9900 location data, Alberni Inlet.

DAY	1994	TIME	DEPTH (m)
0	29-Jul	10:35	*
3	1-Aug	16:06	*
3	1-Aug	16:34	*
3	1-Aug	16:49	*
3	1-Aug	17:10	*
3	1-Aug	17:13	*
3	1-Aug	17:50	*
3	1-Aug	18:05	*
3	1-Aug	18:05	*
4	2-Aug	14:00	*
4	2-Aug	15:32	*
4	2-Aug	15:45	*
4	2-Aug	15:56	*
5	3-Aug	15:57	*
6	4-Aug	12:59	*

\* Location only

Table 6. Response time of internal temperature transmitter to ambient temperature changes.

CONDITION	ELAPSED TIME (min)	TEMPERATURE (°C)		
		INTERNAL	WATER	MEAN ± SD
Calibration	-	11.9	12.0	
Warming	0	12.7	18.3	
	5	13.7	18.3	
	10	15.3	18.4	
	15	16.6	18.6	
	20	17.9	18.6	
	25	18.2	18.6	
	30	18.6	18.6	
	45	18.9	18.8	
	60	19.0	18.8	
	75	19.0	18.9	
				18.6 ± 0.2
Cooling	0	19.1	18.3	
	5	19.1	18.1	
	10	18.8	17.6	
	15	18.6	17.2	
	20	18.0	16.6	
	25	17.8	16.4	
	30	17.1	16.1	
	35	17.0	15.8	
	40	16.5	15.6	
	45	16.3	15.4	
60	15.7	14.7		
				16.5 ± 1.2

Table 7. Fish 9903 Location &amp; temperature data, Alberni Inlet.

DAY	1994	TIME	TEMP (°C)
0	29-Jul	09:45	*
3	1-Aug	18:10	*
3	1-Aug	18:25	*
3	1-Aug	18:35	9.8
3	1-Aug	18:55	9.8
3	1-Aug	19:15	10.0
4	2-Aug	15:00	10.3
5	3-Aug	14:20	9.8
5	3-Aug	14:30	10.3
5	3-Aug	16:30	9.6
5	3-Aug	16:37	9.5
5	3-Aug	16:40	9.7
5	3-Aug	16:47	9.3
5	3-Aug	16:58	9.6
5	3-Aug	17:05	9.7
5	3-Aug	17:13	9.6
5	3-Aug	17:17	9.7
5	3-Aug	17:23	9.6
5	3-Aug	17:27	9.5
6	4-Aug	10:45	9.3
6	4-Aug	11:40	10.8
6	4-Aug	12:05	9.3
6	4-Aug	12:30	10.5
6	4-Aug	12:40	10.0
6	4-Aug	13:15	9.8
mean depth			9.8
SD			0.4
min			9.3
max			10.8
n			22

\* Location only

Table 8. Fish 9904 location & temperature data,  
Alberni Inlet.

DAY	1994	TIME	TEMPERATURE (°C)
0	29-Jul	09:54	*
4	2-Aug	19:10	10.1
4	2-Aug	14:59	*
5	3-Aug	14:00	9.7
		mean temperature	9.9
		SD	0.3
		min	9.7
		max	10.1
		n	2

\* Location only

Table 9. Fish 9906 location & temperature data,  
Alberni Inlet.

DAY	1994	TIME	TEMPERATURE (°C)
0	29-Jul	10:05	*
1	30-Jul	17:50	*
1	30-Jul	18:00	*
3	1-Aug	18:25	*
5	3-Aug	13:10	9.6
5	3-Aug	13:13	9.6
5	3-Aug	13:20	9.6
5	3-Aug	13:25	9.6
5	3-Aug	13:30	9.6
5	3-Aug	14:40	*
5	3-Aug	14:50	*
5	3-Aug	14:55	*
6	4-Aug	11:08	10.0
6	4-Aug	11:33	10.1
6	4-Aug	11:37	10.1
6	4-Aug	12:20	*
6	4-Aug	12:27	10.0
mean temperature			9.8
SD			0.2
min			9.6
max			10.1
n			9

\* Location only

Table 10. Dissolved oxygen, salinity and temperature at 1,5 and 10 km from the head of Alberni Inlet on August 3, 1994

Depth (m)	Dissolved Oxygen (mg·L <sup>-1</sup> )			Dissolved Oxygen % Saturation			Salinity (‰)			Temperature (°C)		
	1 km	5 km	10 km	1 km	5 km	10 km	1 km	5 km	10 km	1 km	5 km	10 km
0	7.9	7.8	7.5	94	92	90	5.1	8.0	13.7	22.7	21.0	20.1
1	7.8	7.6	7.4	93	90	88	5.3	8.3	13.7	22.6	21.1	20.1
2	7.6	7.3	7.3	90	86	87	6.7	9.1	14.2	21.9	20.9	20.1
3	6.9	7.1	7.1	83	85	86	12.3	12.3	16.4	20.7	20.5	19.7
4	6.6	6.9	7.2	79	83	87	13.4	14.7	17.8	20.2	20.0	19.2
5	2.8	2.4	5.5	32	28	64	21.8	23.1	22.4	16.0	15.7	16.4
6	2.7	3.9	4.2	30	43	47	29.3	30.4	30.7	11.8	10.8	11.4
7	2.4	2.3	4.3	26	25	47	30.4	31.3	30.8	10.3	10.1	10.7
8	2.5	3.3	4.3	27	36	47	30.9	31.9	30.8	10.4	10.1	10.6
9	2.5	2.1	4.2	27	23	46	31.2	31.9	31.2	9.9	9.9	10.1
10	2.0	3.0	4.1	22	32	44	31.3	32.1	31.2	9.8	9.8	10.0
12	1.2	3.0	4.0	13	32	43	31.5	32.4	31.5	9.6	9.7	9.9
15	1.0	2.5	3.3	11	27	35	32.0	32.5	31.9	9.5	9.6	9.5
20	-	1.6	2.9	-	17	31	-	32.5	32.3	-	9.3	9.4
25	-	0.8	2.4	-	9	26	-	32.8	32.7	-	9.1	9.1
30	-	1.9	2.7	-	20	29	-	32.7	32.8	-	9.1	9.1
35	-	2.2	2.9	-	24	31	-	32.8	32.7	-	9.1	9.1
40	-	2.3	2.9	-	25	31	-	32.8	32.8	-	9.1	9.1
45	-	2.6	3.0	-	28	32	-	32.8	32.9	-	9.1	9.0
50	-	2.6	-	-	28	-	-	32.9	-	-	9.0	-

Figure 1. Map of the Somass River drainage and Alberni inlet.

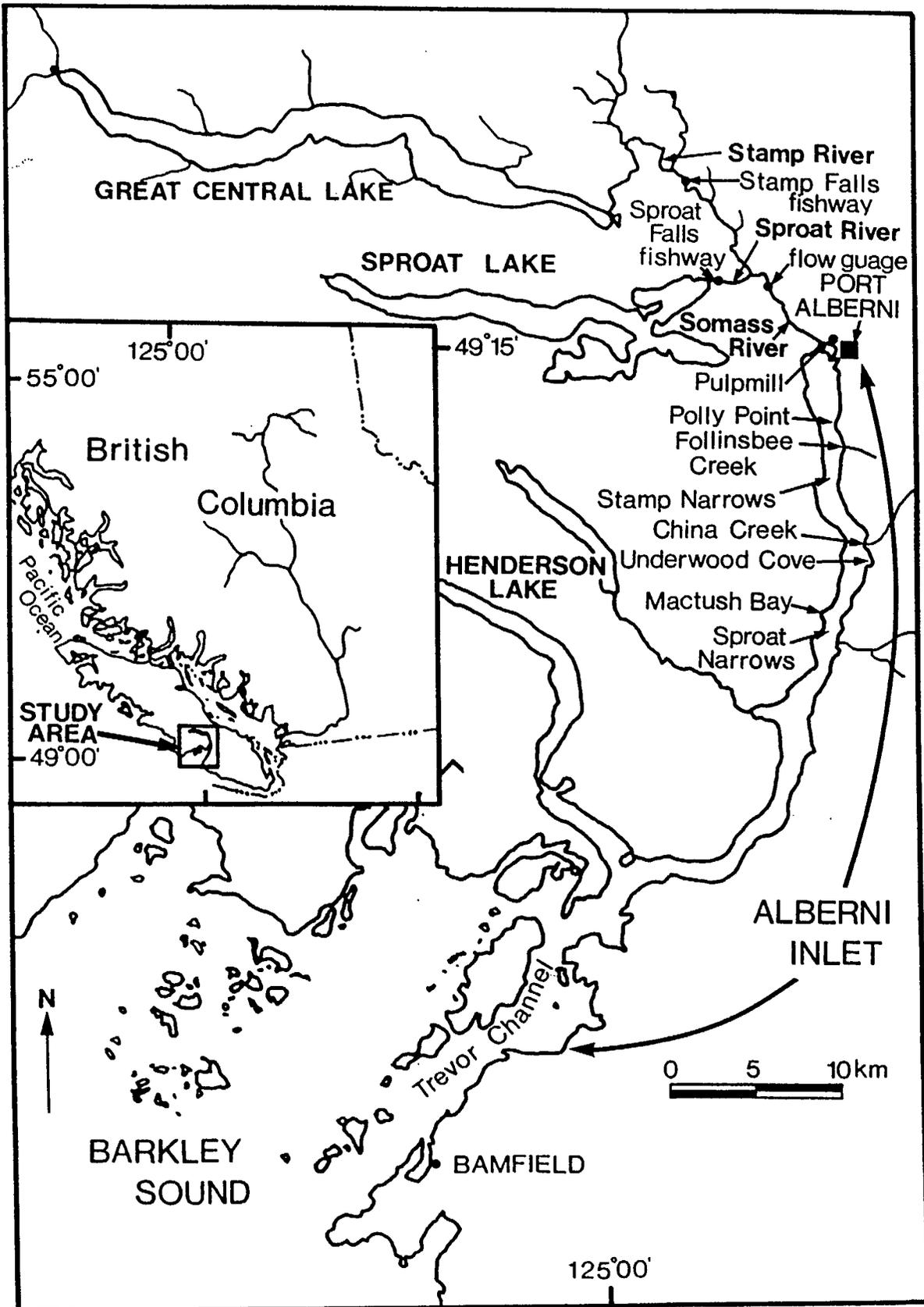


Figure 2. Study area in Alberni Inlet (★ water quality monitoring stations 1,5 and 10 km from the head of the inlet).

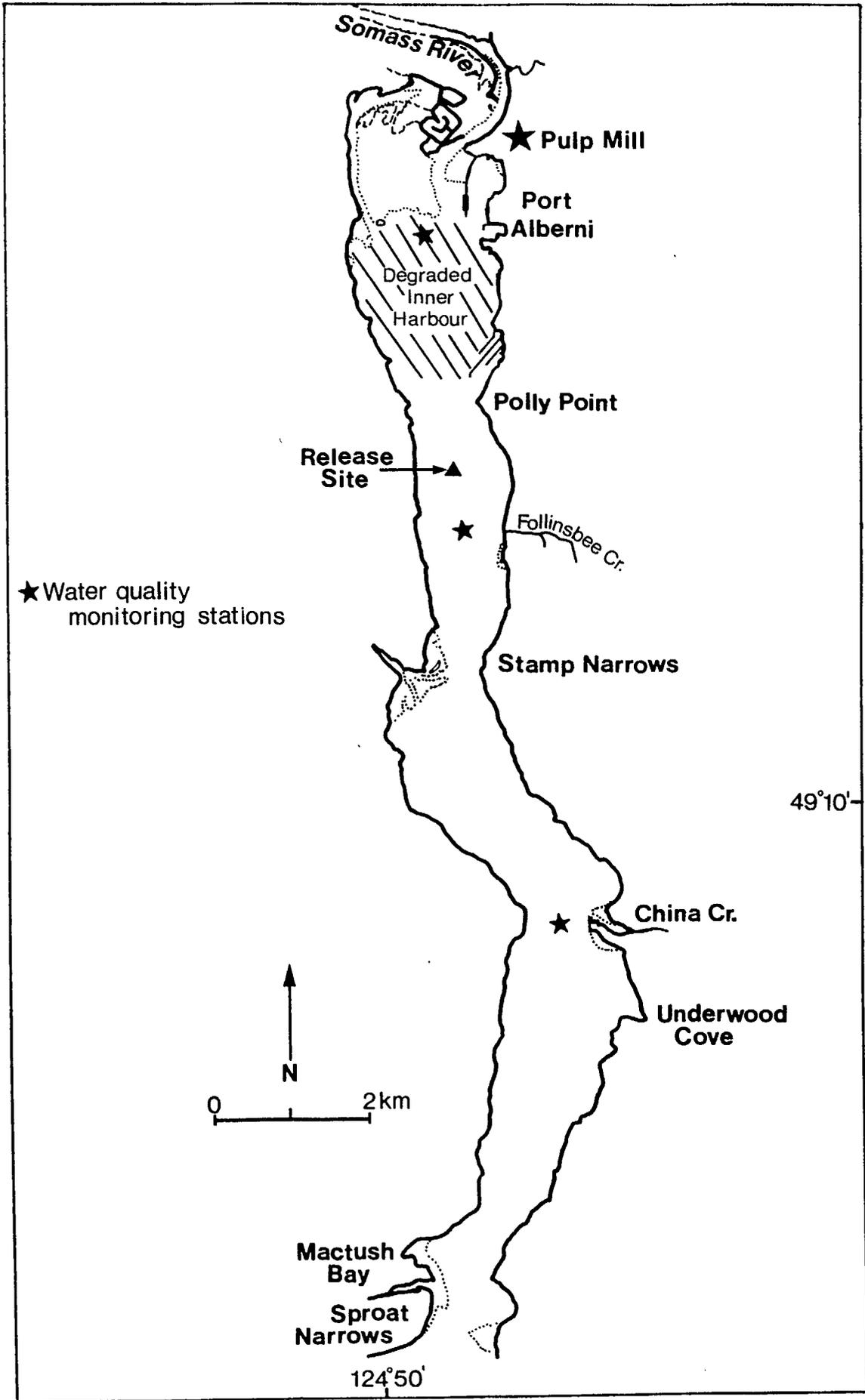


Figure 3. Net horizontal movement of fish 9892.

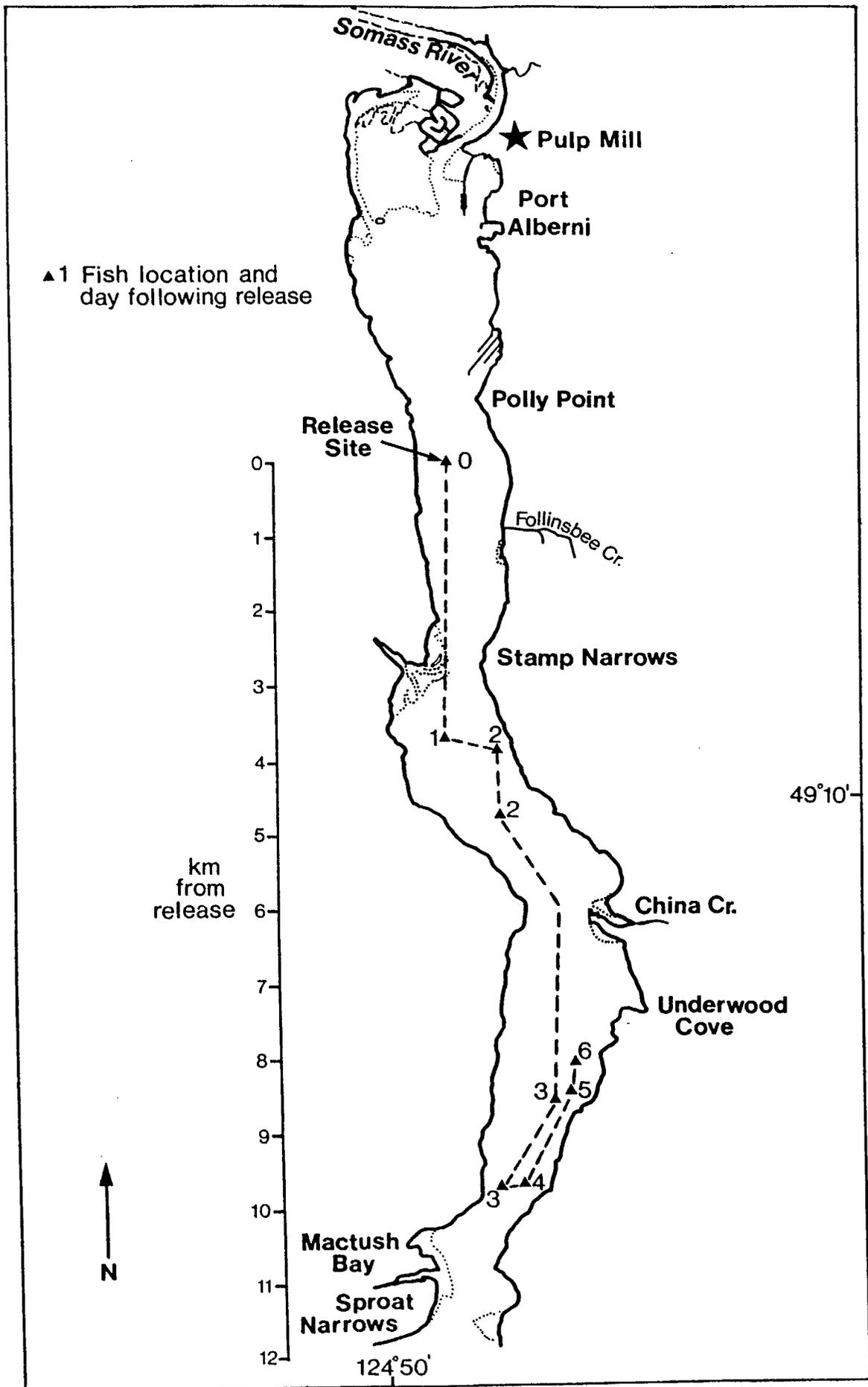


Figure 4. Net horizontal movement of fish 9894.

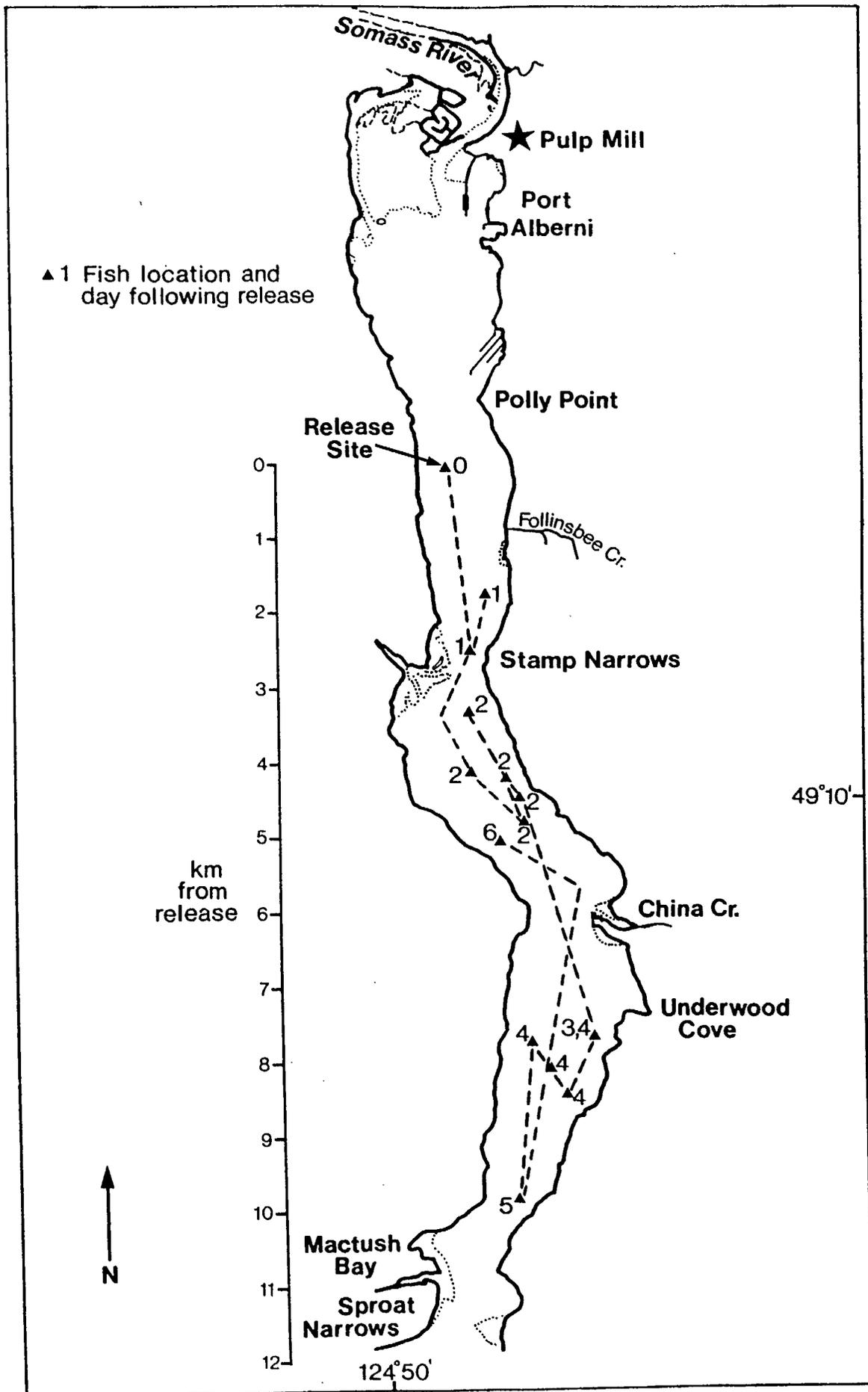


Figure 5. Net horizontal movement of fish 9897.



Figure 6. Net horizontal movement of fish 9900.

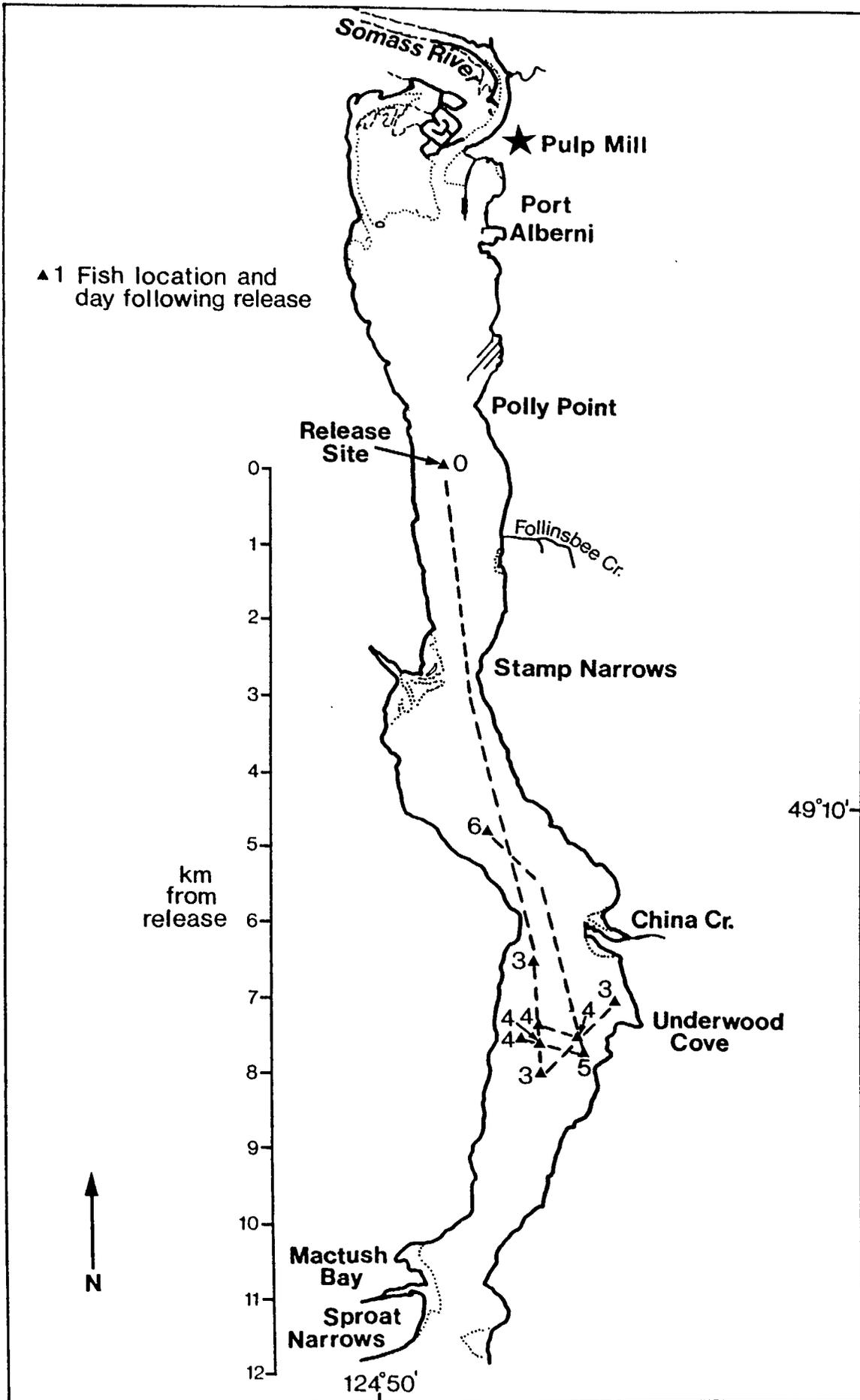


Figure 7. Net horizontal movement of fish 9903.

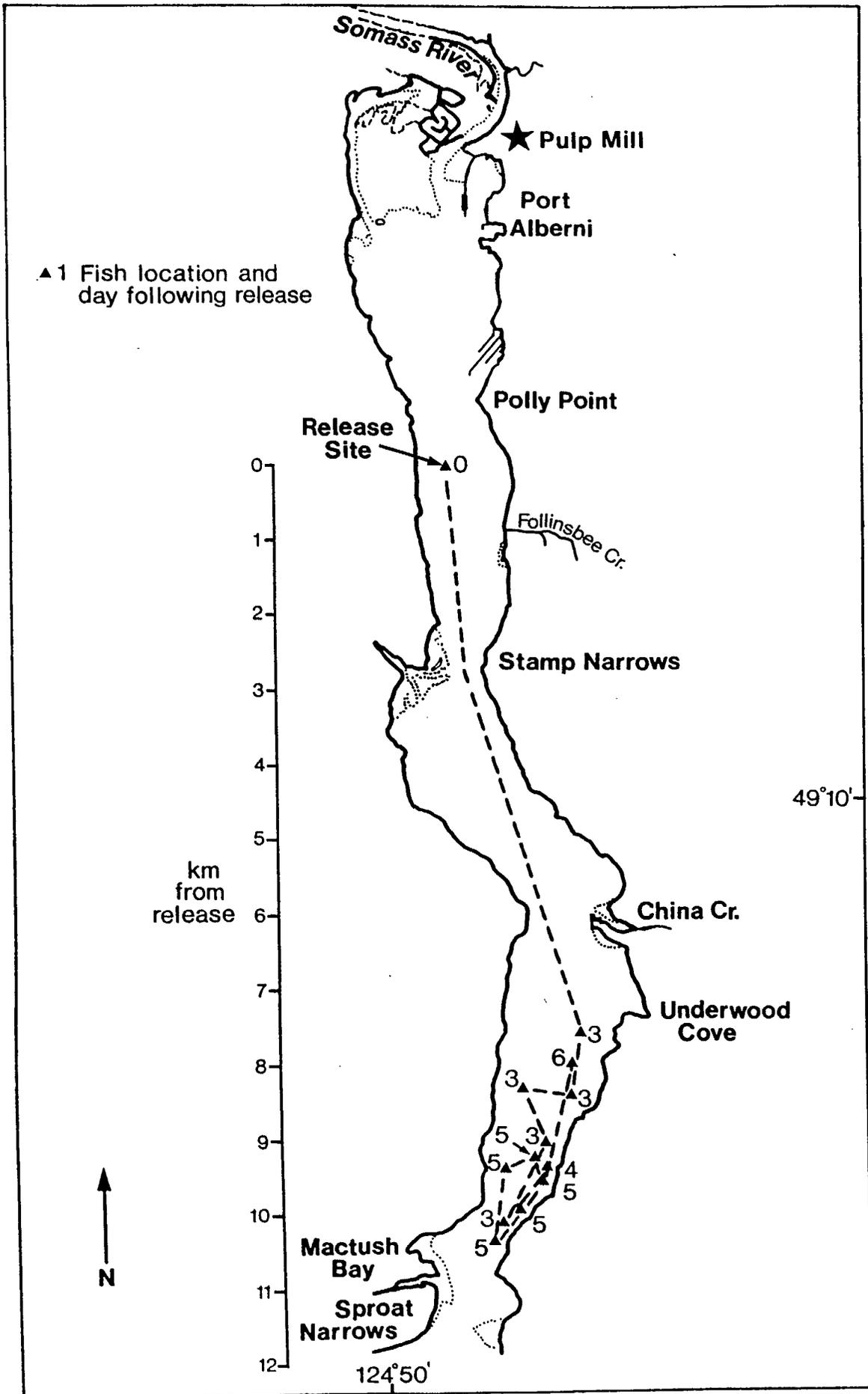


Figure 8. Net horizontal movement of fish 9904.

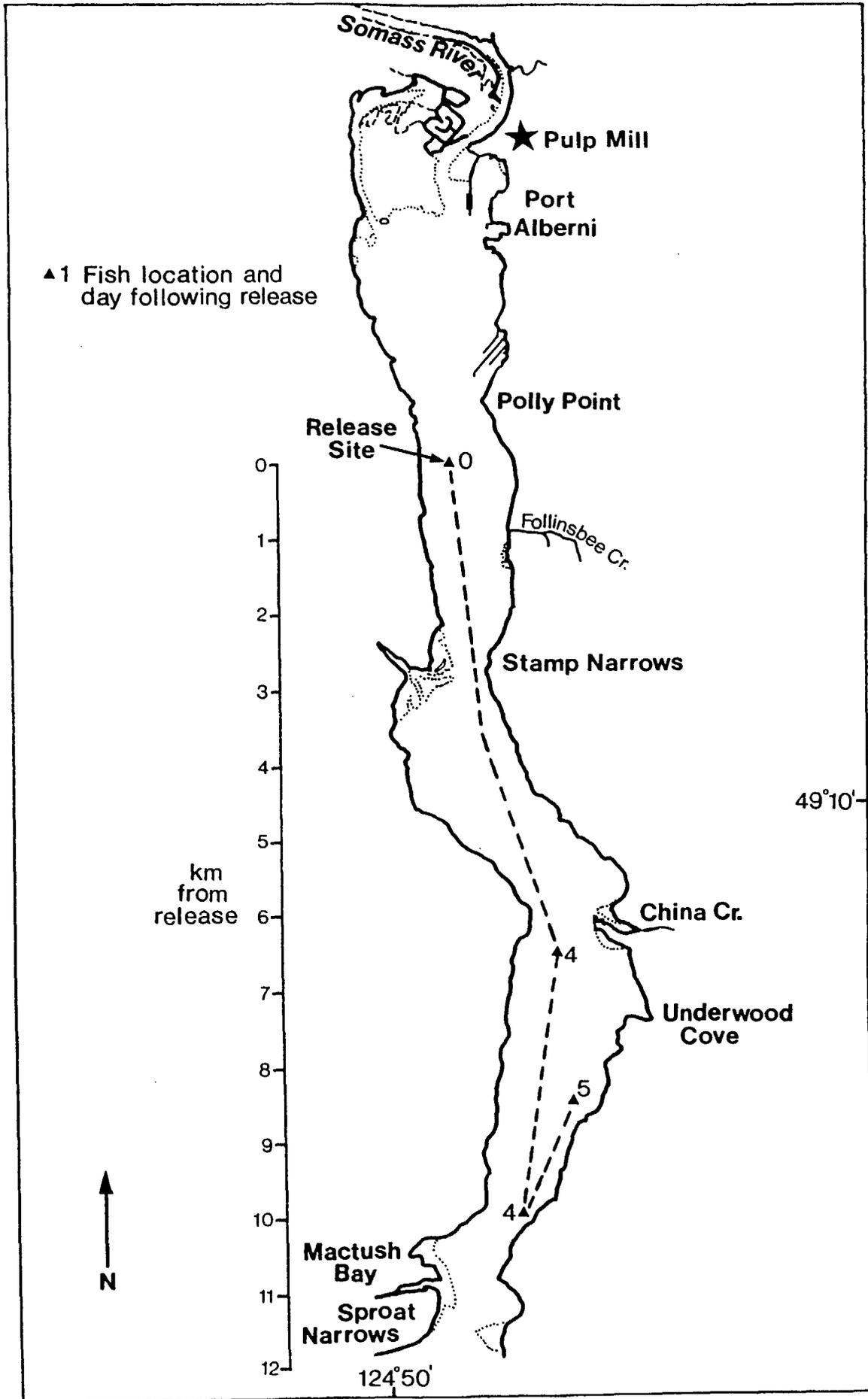
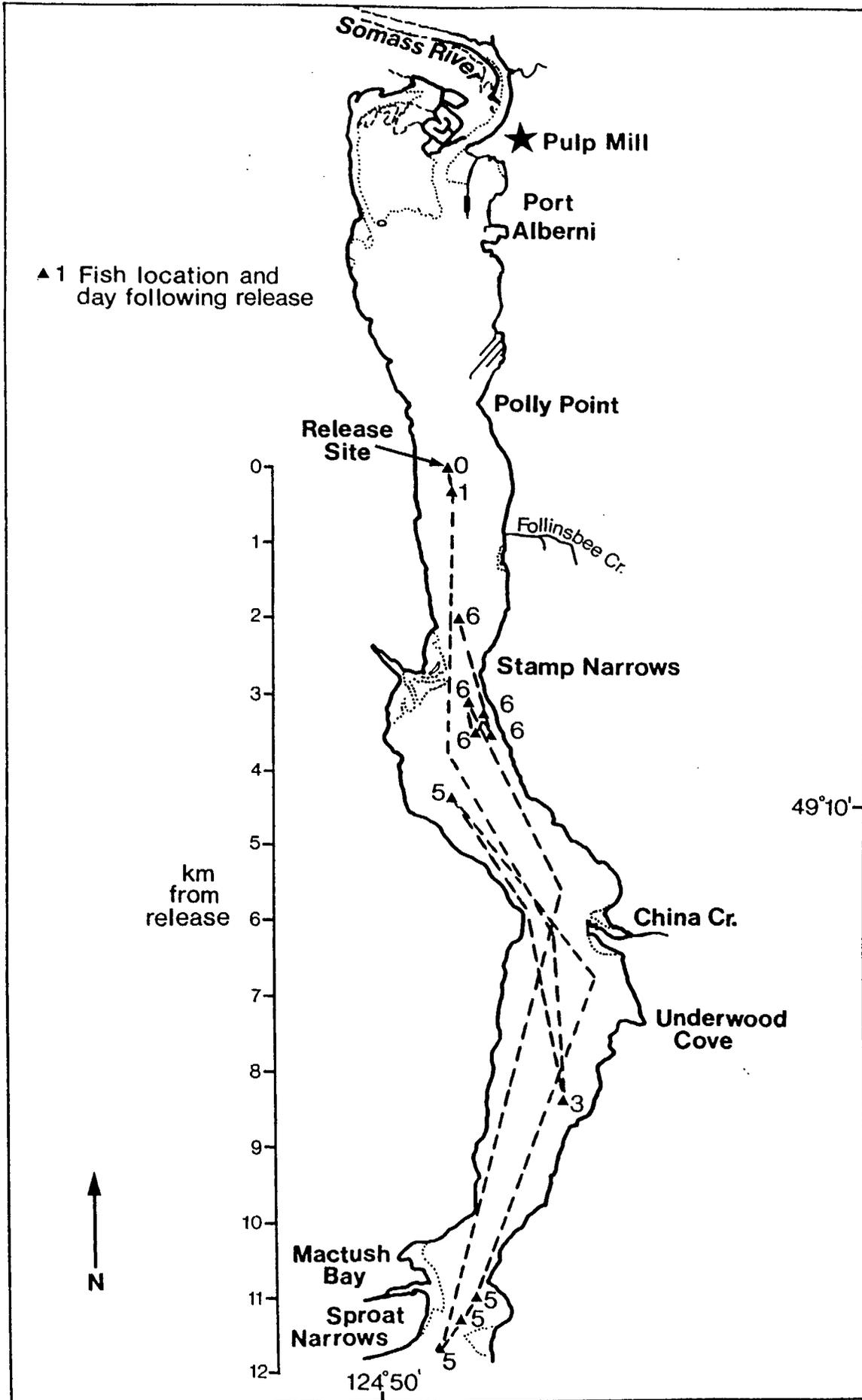


Figure 9. Net horizontal movement of fish 9906.



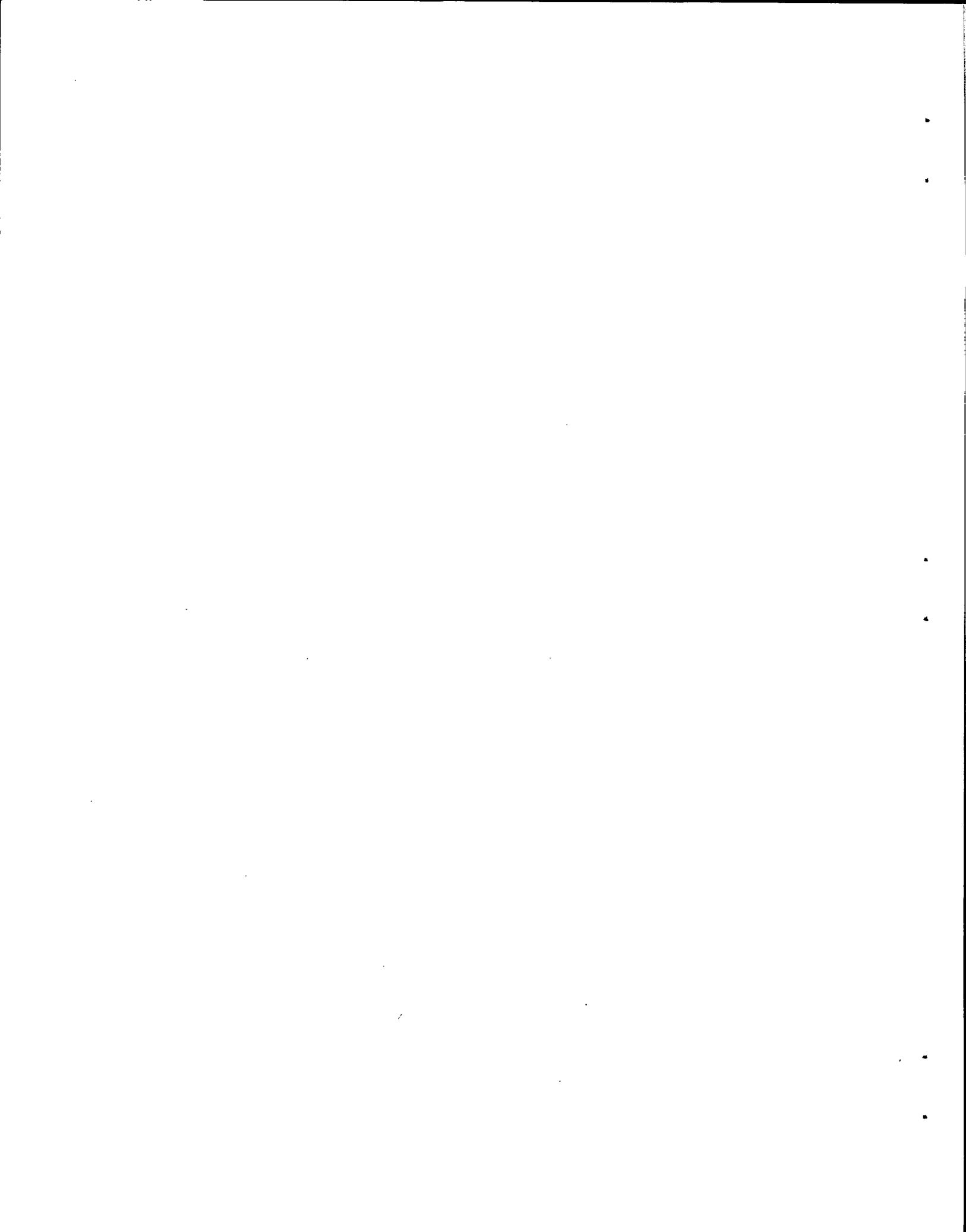


Figure 10. Vertical movement of fish 9892.

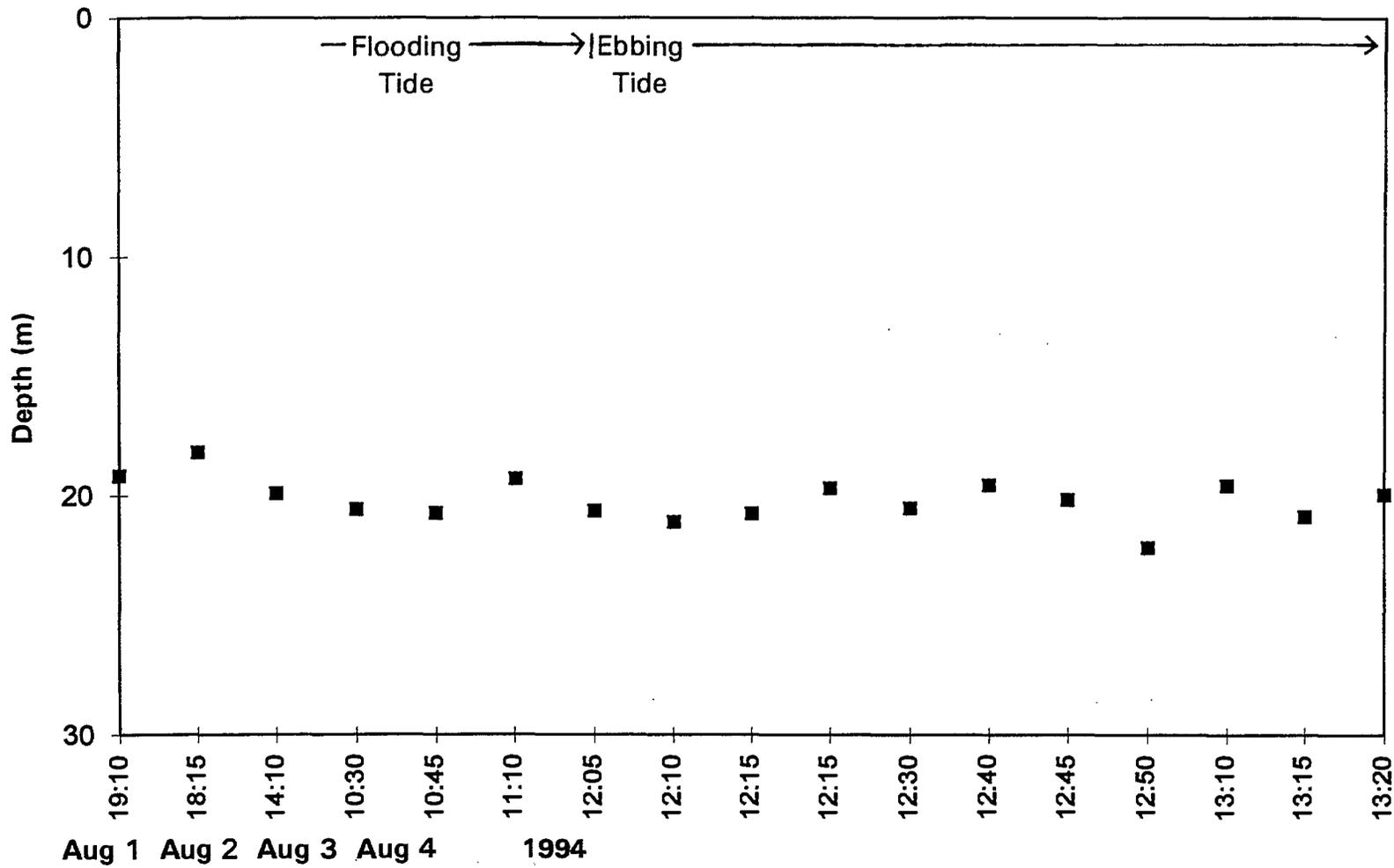
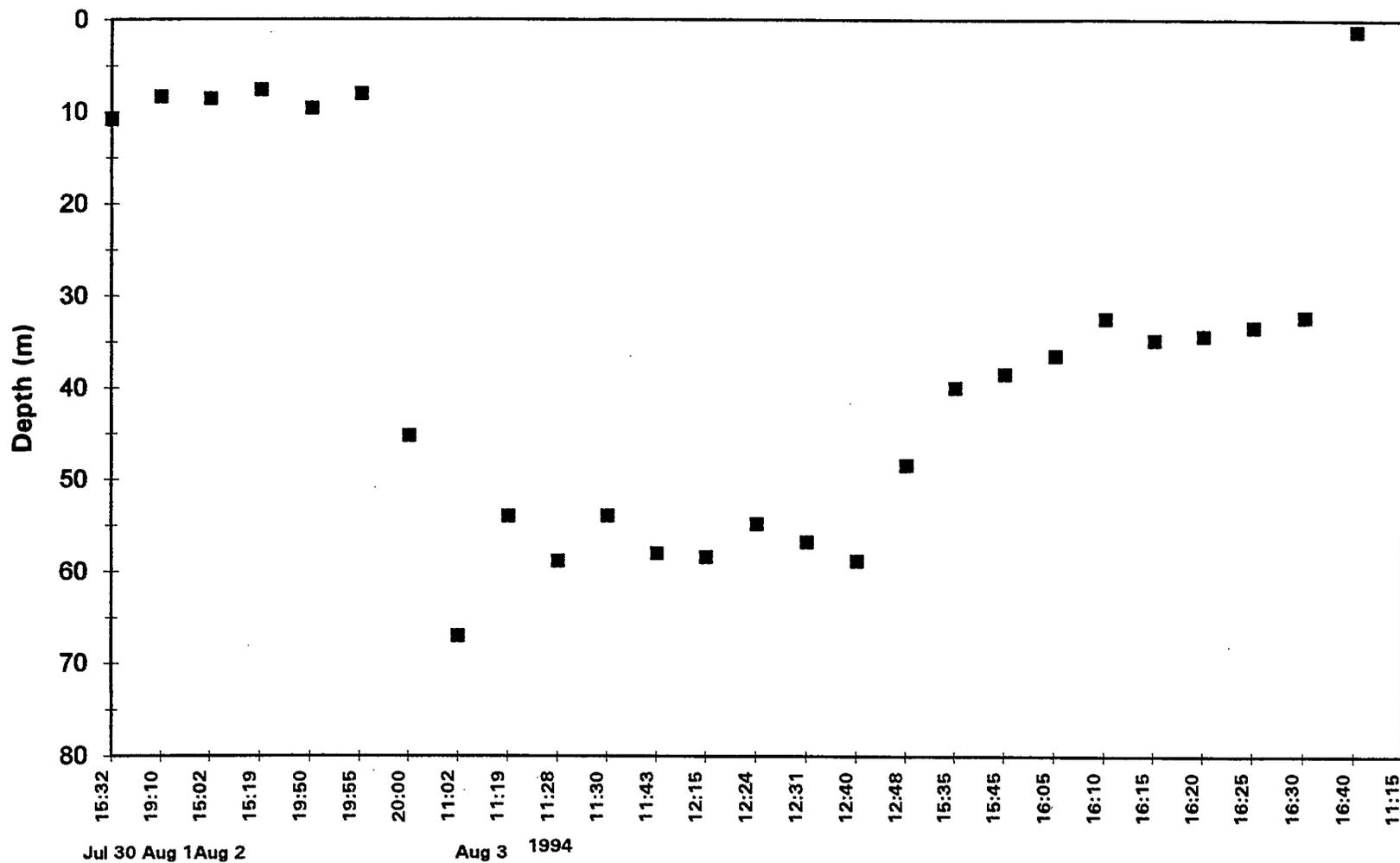


Figure 11. Vertical movement of fish 9897.



**Figure 12. Response time of internal temperature transmitter to ambient temperature changes.**

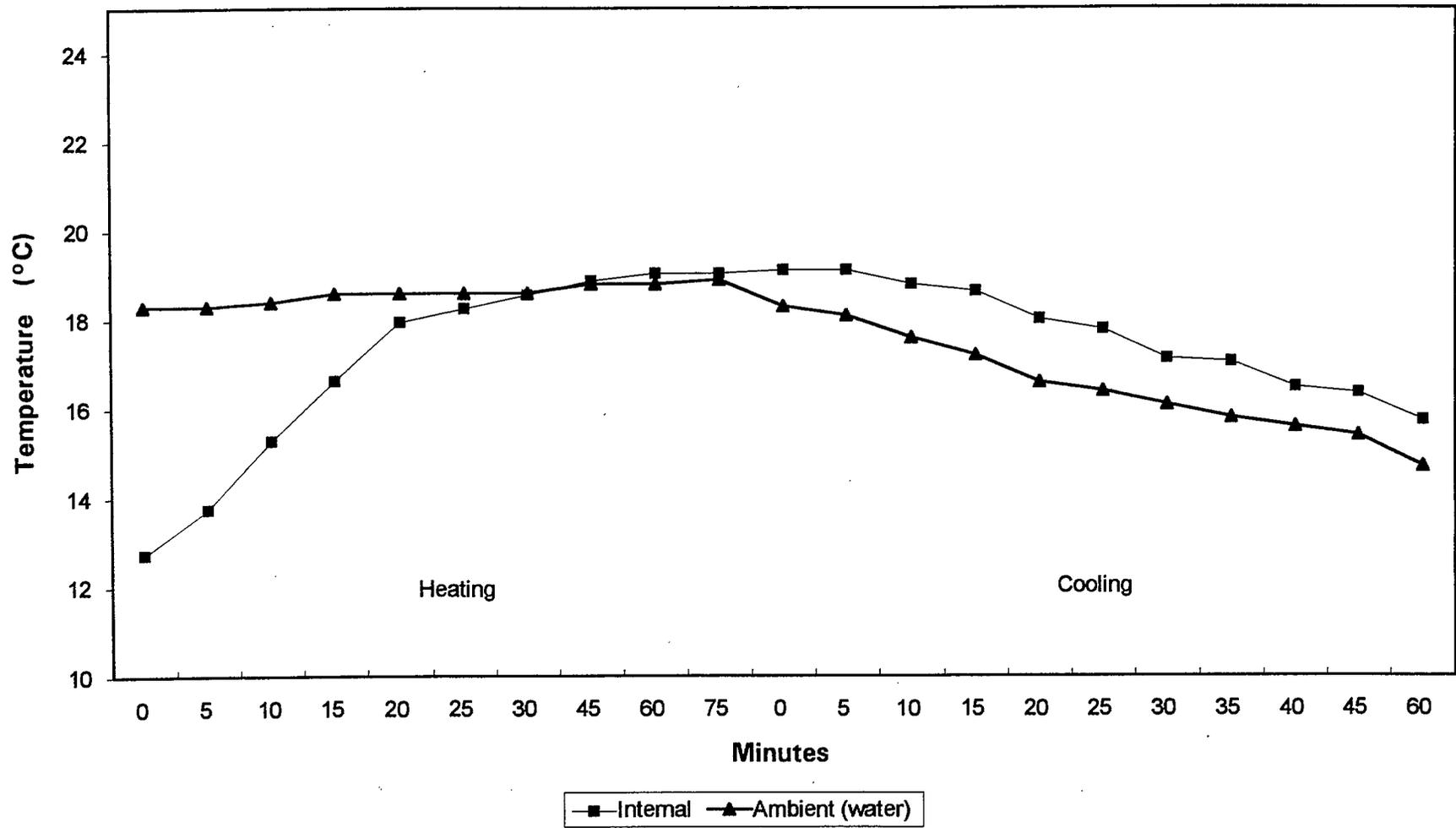
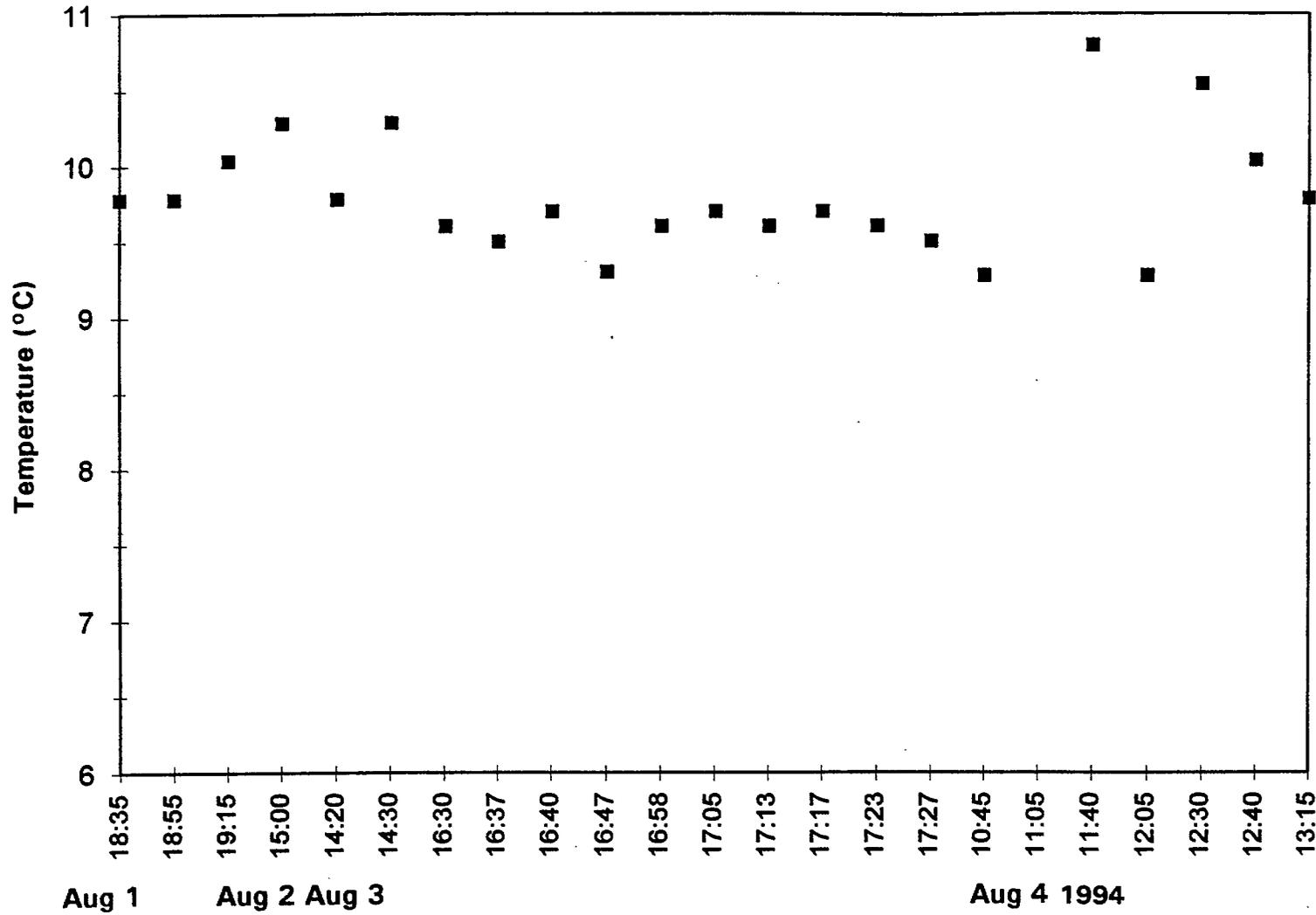


Figure 13. Temperature data from fish 9903.



**Figure 14. Temperature data from fish 9906.**

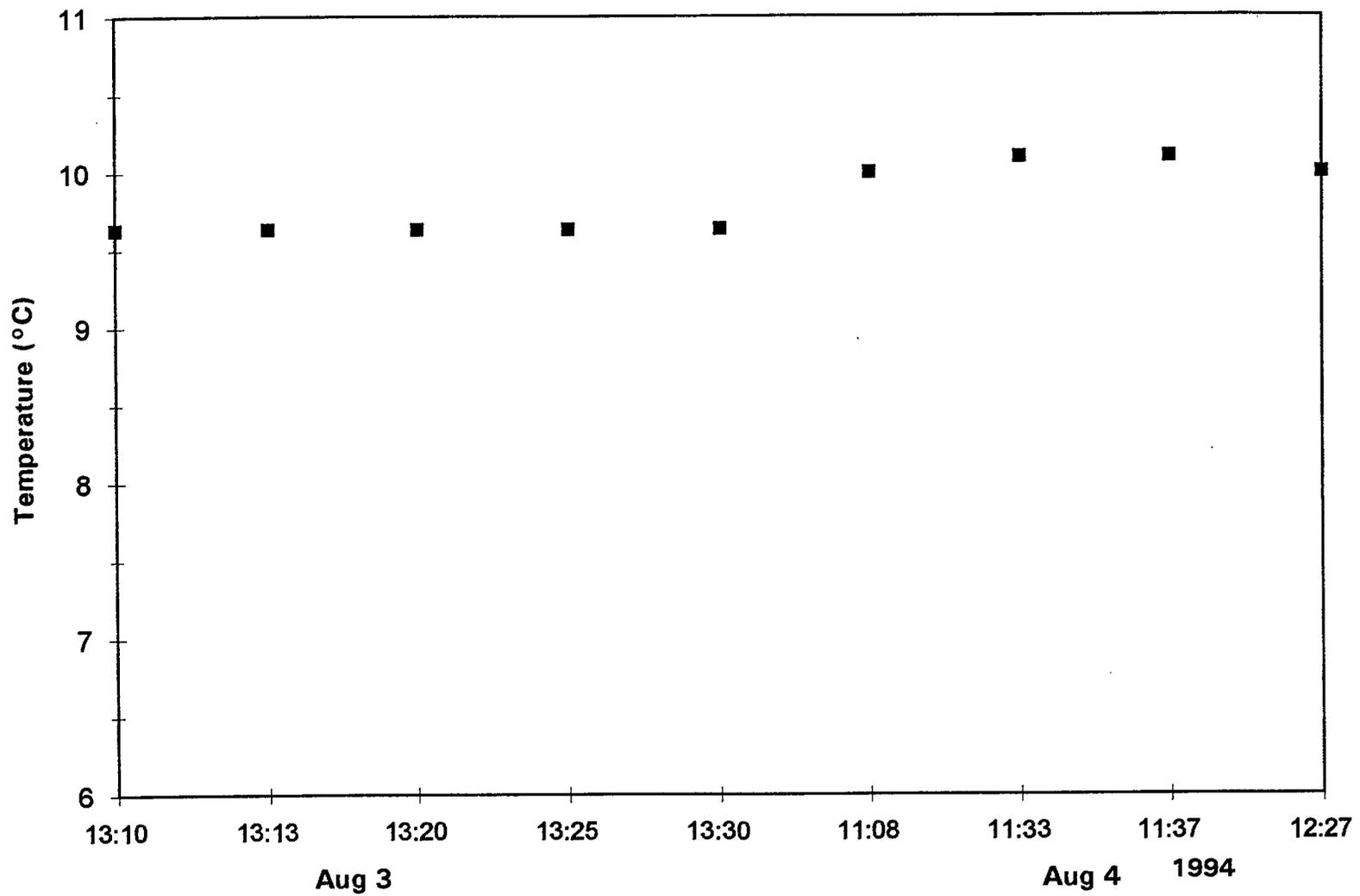
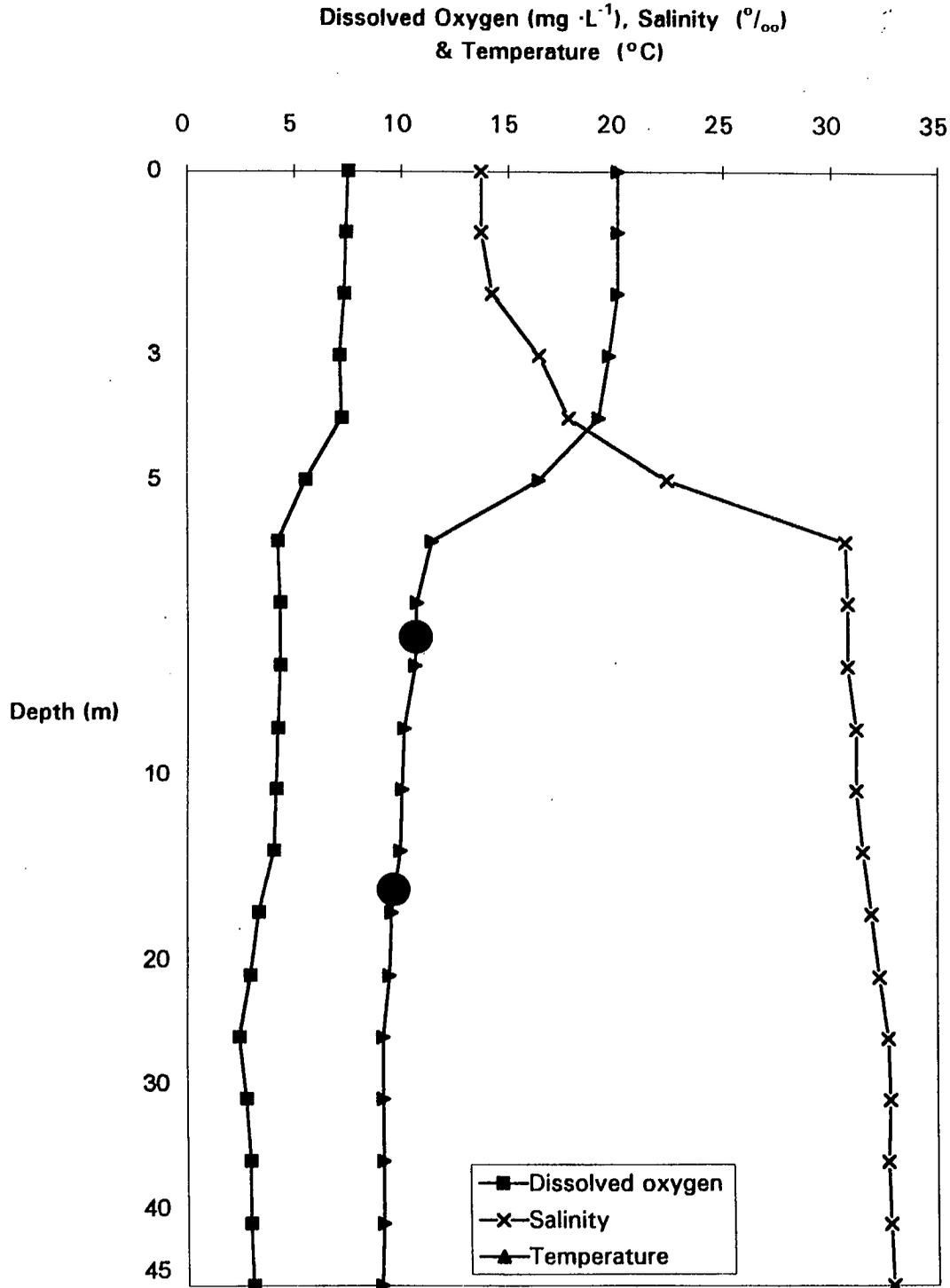


Figure 15. Dissolved Oxygen, Salinity & Temperature, 10 km from the Head of Alberni Inlet, August 3, 1994.



● Internal temperature of fish 9906 on day 5-6

SH 223 F55 no.2355

Spohn, S.

Preliminary studies on the  
movement of adult sockeye...

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