A Preliminary Study of Hatchery Chinook Salmon Smolts Migrating in the Lower Fraser River, Determined by Radiotagging

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A PRELIMINARY STUDY OF HATCHERY CHINOOK SALMON SMOLTS MIGRATING IN THE LOWER FRASER RIVER, DETERMINED BY RADIOTAGGING

by

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ABSTRACT

Hvidsten, N.A., C.D Levings and J. Grout. 1996. A preliminary study of hatchery chinook salmon smolts migrating in the lower Fraser River, determined by radiotagging. Can. Tech. Rep. Fish. Aquat. Sci. 2085: 30 p.

The feasibility of using radiotags to determine the migration routes, patterns of movement, and migration speed of chinook salmon (*Oncorhynchus tshawytscha*) smolts was investigated in the lower Fraser River. Hatchery fish (14-19 g) appeared to show normal swimming behaviour when radiotransmitters (1.3 g) were attached externally. Mean net migration rate for 7 fish tracked in the mainstem river was 2.3 $km \cdot h^{-1}$. There was a positive, statistically significant relationship between river discharge and net migration rates, but tidal currents may have also influenced rates. Smolt behaviour in two restored embayment habitats in the lower river was also examined. The chinook released in these habitats held (or remained) for several hours before the tide changed and then moved into the mainstem river and migrated downstream. A smolt released in a slough chosen as a reference habitat exhibited similar movements.

RÉSUMÉ

Hvidsten, N.A., C.D Levings and J. Grout. 1996. A preliminary study of hatchery chinook salmon smolts migrating in the lower Fraser River, determined by radiotagging. Can. Tech. Rep. Fish. Aquat. Sci. 2085: 30 p.

Cette étude portait sur l'intérêt du radioétiquetage des smolts de saumon quinnat (*Oncorhynchus tshawytscha*) pour déterminer leurs voies migratoires et leurs habitudes et leur vitesse de déplacement dans le cours inférieur du fleuve Fraser. Les spécimens issus d'écloserie (14 g à 19 g) semblaient nager normalement lorsque les radioémetteurs (pesant 1,3 g) étaient posés sur les organes extérieurs. En l'occurrence, la vitesse moyenne nette de 7 spécimens observés dans le cours principal due fleuve était de 2,3 $km \cdot h^{-1}$. Une corrélation certaine et statistiquement importante a été observée entre le débit du fleuve et la vitesse nette de déplacement des smolts, mais il est possible que les courants de marée aient biaisé cette observation. D'autre part, on a observé le comportement des smolts dans deux échancrures profondes de la rive, qui avaient été remises en état, le saumon quinnat y est demeuré plusieurs heures, jusqu'au renversement de la marée, puis il a nagé jusqu'au cours principal et a repris son avalaison. Un smolt relâché dans un chenal choisi comme milieu de référence a montré les mêmes caractéristiques éthologiques.

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INTRODUCTION

In this study we investigated the feasibility of using radiotags to determine the migration routes, patterns of movement, and migration speed of chinook salmon (*Oncorhynchus tshawytscha*) smolts in the lower Fraser River, British Columbia. To our knowledge there has been only one previous study that examined chinook smolt migrations in rivers using this technique. Snelling et al. (1993) investigated migration of chinook smolts through impounded reaches of the Willamette River in Oregon using radiotags. Ultrasonic tags were used in a comprehensive study of coho smolt migrations in the Chehalis River estuary in Washington, U.S.A. (Moser et al. 1991). All other investigations on Pacific salmon smolt migrations through large rivers or estuaries have utilized recovery of batch marked fish as a technique to determine movements. Because single fish are not tracked with batch marking, the behaviour of individual animals cannot be determined with the latter method. There have been several studies with Atlantic salmon smolts in rivers (e.g. Spicer et al. 1995) and estuaries (e.g. Fried et al. 1978; Levings et al. 1994).

We also used radiotagging to specifically investigate the behaviour of chinook in two constructed embayments in the lower Fraser River. One embayment was on Annacis Channel and another was at Richmond Island on the North Arm. Batch marked chinook (Shreffler et al. 1990) and chum (Burger and Nishimura 1995) have been used to assess the fish use of restored habitat in Puget Sound and the Fraser estuary respectively. However, there are no previous studies using radiotagged fish to investigate behaviour or residency in these types of man-made habitats.

STUDY AREA

The study area was in the lower Fraser River between Mission and the mouth of the North Arm of the Fraser River (Fig. 1). Discharge decreased during the period of this study, July 7 to August 13, 1993, and ranged from 3000 to 4570 $m^3 \cdot s^{-1}$ (cms) at Mission (mean daily; Table 2) (Water Survey of Canada, unpublished). Tidal amplitude ranged from 3.6 m (above chart datum) at the estuary to about 1 m (Rood and Hamilton 1994) at the upstream part of the study area. Tide ranges for particular study dates are given below. Surface temperature at Mission in July and August usually ranges between 16 - 19°C (Northcote and Larkin 1989) and turbidity is usually > 1000 JTU (Clark et al. 1981). Predicted average surface currents (river and tide influenced) at Port Mann, in the lower part of the study area, are approximately 100 $cm \cdot s^{-1}$ in July and August (Seaconsult 1995). Current speed varies markedly over the tidal cycle and with location on the river. Currents at ebb tide would be expected to be higher at the upper reaches of the study area. The surface currents reverse on flood tides in the lower reaches of the study area and slow to near zero velocity in the upper reaches. Depths in the main channel ranged from 16 m in Plumper and Derby Reach to 0.4 m immediately above MacMillan Island (CHS Charts Nos. 3488, 3489) and were as low as 0.5 m in sloughs and embayments at low tide.

MATERIALS AND METHODS

1. FISH

Chinook smolts reared in the hatchery at the West Vancouver Laboratory were used in this experiment, specifically the red fleshed chinook stock from the Chilliwack River. The chinook smolts used ranged in fork length from 12-15 cm (Table 1) (mass 14.3 to 18.8 g, estimated from the length-weight relationship for this particular stock) and were selected from fish held in freshwater at the laboratory. The chinook were considered to be "smoltified" and hence ready for movement to the estuary.

2. RADIO TRACKING EQUIPMENT

Radiotransmitters, receiver, and antenna were supplied by Advanced Telemetry Systems Incorporated (ATS). Model 392 radiotransmitters with a wattage less than 5 milliwatts were used, fitted with antennae wire of 1 mm diameter stylon. Large (2.1 - 2.3 g; 20 cm antennae length), and small (1.3 g; 15 cm antennae length) radiotransmitters with frequencies ranging from 149.304 - 149.466 MHz were used. The range for the tags was tested at Mission in early July, with a tag held at the surface. These tests showed the range for both tag sizes was at least 300 m with full antennae length. To reduce drag on the fish, the antennae were reduced in length by about 5 cm.

A Fieldmaster 16 channel receiver was used to detect the signals and the frequency on each radiotransmitter matched up with one of the channels on the receiver. Earphones were used to detect the signal. A 4-element Yagi folding antennae was used. A Trimble Pathfinder Basic Global Positioning System (GPS) was used to determine positions on the river. The accuracy of the positioning system was estimated at approximately 25 m.

3. FIELD METHODS

Chinook smolts were removed from the holding tank at the laboratory and tagged either before they were transported to the Fraser River or about one hour prior to release to the river. The fish were held in the transport tank, with ice added to reduce activity prior to tagging. Two hollow needles (diameter 1 mm) were inserted through the dorsal muscle of the fish at the base of the dorsal fin rays about 6 mm apart. Stainless steel wires (est. 0.3 mm diameter), attached to the radiotransmitter tag, were passed through the hollow needles. The needles were removed and the wires were then knotted so that the tag was firmly attached on the right dorso-ventral side of the fish.

Fish were transported to the release site in a refrigerated (10 - 12°C) oxygenated tank in the back of a vehicle, then taken to the release site on an inflatable boat. The fish were submerged in a bucket set in shallow water for 30 - 45 minutes to acclimatize them to the river temperature. The elapsed time between when the fish were removed from the holding tank and released into the river was approximately 2 - 2.5 hours.

The fish were tracked in the Fraser River by steering the boat in the direction of the strongest radio signal. Earphones were used to estimate the signal strength. Positions were taken with the GPS approximately every 15 minutes at the location where the strongest signal from the fish was received. All times reported are in PDT. The fish were tracked until the signal was inaudible. The signal was often lost in reaches of the river that were characterized by interfering noise from boats, lumber mills, overhead power lines, or extensive log booms near the shore that prevented navigation of the boat close to where the fish moved.

RESULTS AND DISCUSSION

1. FISH BEHAVIOUR

The turbidity of the Fraser River precluded direct observations of the swimming ability of the smolts after tagging. However, it is likely that most of the fish behaved relatively normal and survived the tagging to move downstream. The transmitter mass accounted for < 13% of the estimated body weight of the fish, except for two smolts (B, C) where the tags were about 16 and 14%, respectively, of fish weight. There was no evidence that the migration of the latter two fish was significantly impaired. Their net migration rates were 4.0 and 4.3 $km \cdot h^{-1}$ (Table 2), which were among the highest observed in the study (see below). None of the tracking records suggested the fish died and sank to the bottom - this would have resulted in a constant location or very slow drift seaward (e.g. Spicer et al. 1995). Fish tagged with the lighter tags showed better swimming ability in a laboratory tank and therefore in future work the smallest possible tags should be used for smolt migration studies. It would be preferable to perform specific tests to compare behaviour of tagged and untagged fish as Moser et al. (1990) did for coho smolts.

2. ROUTES OF FISH RELEASED AT MISSION

Smolt A travelled along the north side of the main river channel for the entire tracking period. Net migration rate was 1.4 $km \cdot h^{-1}$ (Table 2), with the tide flooding (Fig. 1, 2). River discharge (daily mean) at Mission was 3490 cms. Contact was lost under a log boom along the north shore of the river after about 5.5 h of tracking.

Smolt B also travelled along the northern side of the river and moved at approximately the same speed as the river current. The tide was ebbing during the migration (Fig. 1, 3) and the net migration rate was 4.0 $km \cdot h^{-1}$. River discharge (daily mean) at Mission was 4570 cms.

Smolt C travelled along the north shore of the main river channel as it moved downstream and around the north side of Crescent Island. The fish remained mid channel while travelling past the north shore of MacMillan and Barnston Island. River discharge (daily mean) at Mission was 4390 cms. The fish moved south around Douglas Island and was lost approximately 100 m upstream of the Port Mann Bridge. The net migration rate was 4.3 $km \cdot h^{-1}$. The fish was released close to high tide, but the tide ebbed for the majority of the tracking period (Fig. 1, 4). Contact with the fish was lost about one hour after low tide.

3. ROUTES OF FISH RELEASED BETWEEN RUSKIN AND PORT MANN

Smolt D was released 1.5 km upstream of MacMillan Island, offshore of the seaplane base at Palmateer Creek. The smolt moved north around MacMillan Island in the middle of the main river channel, and followed the north shore through Derby reach. Contact was lost on the north shore of Bishops reach. The tide was high when the fish was released and ebbed during the tracking session. Low tide occurred approximately at the end of the track (Fig. 1, 5). River discharge (daily mean) at Mission was 3600 cms. The net migration rate of the fish was 2.8 $km \cdot h^{-1}$ (Table 2).

Smolt E was released 0.5 km above the downstream end of Crescent Island on the north shore. The fish moved to the middle of the main channel upon release and then to the south shoreline near the mouth of Nathan Creek. The fish moved along the south shore and continued downstream on the north side of MacMillan Island along the island's shoreline. The fish stopped under a log boom from 1612 - 1712 h, which was close to high tide (Fig. 1, 6). The smolt resumed moving in the middle of the channel when the tide began to ebb, but the signal was lost at Haney. The net migration rate of the fish was 1.9 $km \cdot h^{-1}$ (Table 2). River discharge (daily mean) at Mission was 3380 cms.

Smolt F was released along the north shore of the main river approximately 1.3 km upstream of Barnston Island. Low tide was at approximately 1110 h, one hour before the fish was released (Fig. 1, 7). River discharge at Mission was 3330 cms. The fish moved downstream quickly between 1230 to 1340 h, around the north end of Barnston Island and passed around the north shoreline of Douglas Island. The fish entered the Pitt River at 1554 h, and a strong flood tide seemed to push the smolt up the middle of this tributary. The smolt was lost a few hundred metres upstream of the Highway 7 Bridge (Fig. 8), in mid channel. The net migration rate was 2.6 $km \cdot h^{-1}$ (Table 2).

Smolt J was released at 1714 h slightly north of mid channel 1 km downstream of the Port Mann Bridge. The fish was tracked moving along the north side of the Sapperton V-dyke where the signal was subsequently lost at 1832 h. A large log barge was being dumped in this area which hampered efforts to relocate the fish. The net migration rate of the fish was 1.3 $km \cdot h^{-1}$ (Table 2). The tide was flooding into the estuary while the fish was being tracked (Fig. 1, 9). River discharge at Mission was 3690 cms.

Smolt L was released in Parsons Channel across from Mann Point on Barnston Island at about 1710 h. The fish moved downstream in Parsons Channel, entered the main stem of the Fraser River, and moved along the south shore, and then travelled into the main channel on the south side of Douglas Island. The fish moved very slowly through the south channel between about 2220 and 0000 h. High tide occurred at 2305 h (Fig. 1, 10) and river discharge at Mission (mean daily) was 3370 cms. Downstream movement began at 0008 h, after the tide began to ebb, and fish contact was lost at 0050 h. The net migration rate for this smolt was 1.3 $km \cdot h^{-1}$.

Smolt M was released 800 m upstream of Douglas Island in mid channel at about 1715 h. River discharge at Mission was 3870 cms (mean daily). The fish moved down river along the south side of Douglas Island, but migration stopped at 1947 h. Shortly thereafter the fish began moving upstream around the north side of Douglas Island and into the Pitt River. The migration stopped close to high tide (about 2105 h) (Fig. 1, 11) and then continued up the Pitt River until the signal from the fish was lost under a log boom at about 0000 h. The net migration rate was 1.7 $km \cdot h^{-1}$ (Table 2).

4. ROUTES OF FISH RELEASED BELOW NEW WESTMINSTER

Smolt G was released at 1559 h in a compensatory habitat constructed by excavation of an embayment at the south end of Patrick Island. This site was immediately upstream (south bank) of the Highway 91 (Annacis Island) Bridge over Annacis Channel. A strong flood tide was observed at 1620 h and high tide was at 1840 h (Fig. 12, 13). River discharge at Mission was 3720 cms (mean daily). The fish remained inside the embayment for about 5 hours until 2100 h when it moved out of the embayment and started moving downstream in Annacis Channel. The net migration rate was 2.0 km•h^{-1} (Table 2). Movement out of the embayment coincided with change to an ebb tide. The fish migrated downstream in mid channel and contact was lost 1.5 km downstream.

Smolt H was released in Tilbury Slough about 400 m upstream of the mouth, during a flood tide (Fig. 14, 15). High tide was at 2015 h. Between 1705 h and 1945 h the fish moved to the mouth of the slough. The fish remained at the mouth of the slough between about 2100 h and 0030 h. The tide began to ebb at 2045 h. The fish migrated downstream and out of the slough, along the south side of the mainstream Fraser River, beginning at 0038 h. Net rate of migration was 0.3 km•h^{-1} (Table 2) until contact was lost at about 0145. River discharge at Mission was 3650 cms.

Smolt K was released in a compensatory habitat constructed by excavation of an embayment on the southeast end of Richmond Island, in the North Arm of the Fraser River. The tide was flooding at the time the fish was released (Fig. 16, 17) at 1845 h. River discharge at Mission was 3500 cms. The fish moved upstream into Richmond slough. The fish began to move downstream out of the channel as the tide began to flood, but the signal was lost at 2016 h. Net migration rate was 0.3 km•h^{-1} (Table 2). A salt wedge is known to be present in the lower reaches of the North Arm (Carey 1990) which may have hindered reception of the radio signal.

5. TIDAL AND RIVER CURRENT EFFECTS

It appears that the tide has a major effect on the net migration rates of smolts in the Fraser River, but the number of smolts tracked was too small to make any firm conclusions. Table 3 shows the net migration rates for 9 smolts which mainly migrated in the main stem river, distributed according to whether the tide was ebbing or flooding for most of the migration or whether it was turning (+ or - 30 min) from ebb to flow or flow to ebb. The five smolts migrating during the ebb slack or maximum ebb tides showed higher migration rates (mean 3.33 and 3.74 km•h^{-1}, respectively) than smolts migrating during flood slack or maximum flood (1.33 and 1.43 km•h^{-1}, respectively). A Wilcoxin two-sample test showed that the migration rates during maximum flood were significantly different ($p<0.05$) than that during ebb slack or maximum ebb. Smolts migrating during a changing tide were affected differently. Smolts F and M moved back upstream into the Pitt River with the incoming tide and, as a result, their migration rates were higher than those of smolts migrating on the mainstem river during a flood tide. Smolt K migrated upstream in Richmond Island slough with the flood tide and downstream as the tide ebbed. This upstream movement may explain the extremely slow net migration rate of this smolt. Smolt H began migrating 3.5 hours after the tide turned, perhaps reflecting slow currents at that time.

River currents interact with the tidal effects and may also have directly influenced migration rates of the chinook smolts. It appeared that most smolts migrated in mid channel (Fig. 1) where the current may be strongest, but more data are required to investigate this further. There was a significant correlation between net migration rate and mean daily discharge at Mission ($p < 0.05$) for the 7 smolts that were released into and stayed within the main stem reaches of the river. Mean migration rate for these smolts was 2.3 $km \cdot h^{-1}$, considerably slower than that reported by Snelling et al. (1993) for radiotagged chinook smolts (mean 3.5 $km \cdot h^{-1}$) in the Willamette River. However, the impounded reach of the Willamette River where Snelling et al. (1993) tracked smolts was not influenced by tidal effects.

6. FISH BEHAVIOUR IN EMBAYMENTS AND SLOUGHS

Smolts G and K were released into embayments constructed as compensatory habitat. Smolt G remained inside Patrick Bay on Annacis Channel or at the mouth of the bay until the tide began to ebb, at which point it began to migrate out of the bay and downstream. Smolt K moved out of the Richmond Island embayment immediately, but remained in the adjacent slough until the tide began to ebb. In general, the behaviour of these two smolts was somewhat similar to that shown by the fish released into Tilbury Slough (Smolt H), which was chosen as a reference habitat. This slough is a relatively natural channel that has been blocked at its upstream end by industrial activity. Smolt migration from these habitats suggested that the fish may behave in response to tidal changes, but other identified factors such as diurnal rhythms in migration may also be responsible.

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Table 1. Length, estimated mass, transmitter mass, release date, and release location for 12 chinook smolts tracked in the lower Fraser River in July and August 1993.

Smolt	Length (cm)	Estimated Mass (g)	Date Released (1993)	Transmitter Mass	Release Point
A	14.0	17.4	July 27	1.3 g	Upstream tip of Matsqui Island - main channel
B	12.0	14.3	July 6	2.1 - 2.3 g	Upstream tip of Matsqui Island - main channel
C	12.7	15.5	July 7	2.1 - 2.3 g	Upstream tip of Matsqui Island - main channel
D	14.2	17.7	July 29	2.1 - 2.3 g	Seaplane Base 1.5 km upstream of MacMillan Island
E	15.2	19.1	August 12	2.1 - 2.3 g	Crescent Island
F	13.9	17.3	August 13	1.3 - 2.3[1] g	Upstream of Barnston Island
G	14.7	18.4	July 30	1.3 g	Patrick Bay (constructed embayment)
H	12.9	15.8	August 2	1.3 g	Tilbury Slough
J	14.5	18.1	August 5	2.1 - 2.3 g	Downstream of the Port Mann Bridge
K	12-15 cm (est.)	14.3-18.8	August 6	1.3 - 2.3[1] g	Richmond Island (constructed embayment)
L	12-15 cm (est.)	14.3-18.8	August 9	1.3 - 2.3[1] g	Parsons Channel
M	14.2	17.7	August 4	2.1 - 2.3 g	Upstream of Douglas Island

1 Mass of transmitter not available.

Table 2. Migration times, distances and net migration rates for 12 chinook smolts tracked in the lower Fraser River and estuary in July and August 1993. River discharge at Mission is also shown.

Smolt	Release Time	Time when Signal was Lost	Migration Time (hours)	Migration Distance (km)	Net Migration Rate ($km \cdot h^{-1}$)	Discharge at Mission (mean daily cms)
A	1833	2350	5.3	7.55	1.4	3490
B	1343	1516	1.6	6.21	4.0	4570
C	2037	0520	8.7	37.77	4.3	4390
D	1744	2236	4.9	13.65	2.8	3600
E	1227	1927	7.0	13.55	1.9	3380
F	1204	1710	5.1	13.45	2.6	3330
G	1559[1]	2147	0.8	1.51	2.0	3720
H	1705[2]	0142	1.1	0.27	0.3	3560
J	1714	1832	1.3	1.64	1.3	3690
K	1845	2016	1.5	0.48	0.3	3500
L	1711	0050	7.7	9.56	1.3	3370
M	1717	2357	6.7	11.5	1.7	3870

1 Migration began at 2100 h

2 Migration began at 0038 h on August 3, 1993

Table 3. Net migration rates for 9 chinook smolts on ebb, slack and flood tides during the study period. Data are only for smolts which mainly migrated through the mainstem Fraser River.

	Tide Type and Migration Rate ($km \cdot h^{-1}$)			
Smolt	**Maximum Flood**	**Ebb Slack**	**Maximum Ebb**	**Flood Slack**
A	1.01	3.52	-	-
B	-	3.43	-	-
C	-	5.52	4.02	4.42
D	-	3.81	2.01	-
E	3.95	-	2.06	1.54
F	2.35	-	-	-
J	1.16	-	-	-
L	1.72	-	-	0.76
M	2.78	-	-	-
MEAN	2.16	4.08	2.69	2.24

Figure 1. Migration tracks in the Fraser River for smolts released at Mission (Smolts A, B and C) and between Ruskin and Port Mann (Smolts D, E, F, J, L and M).

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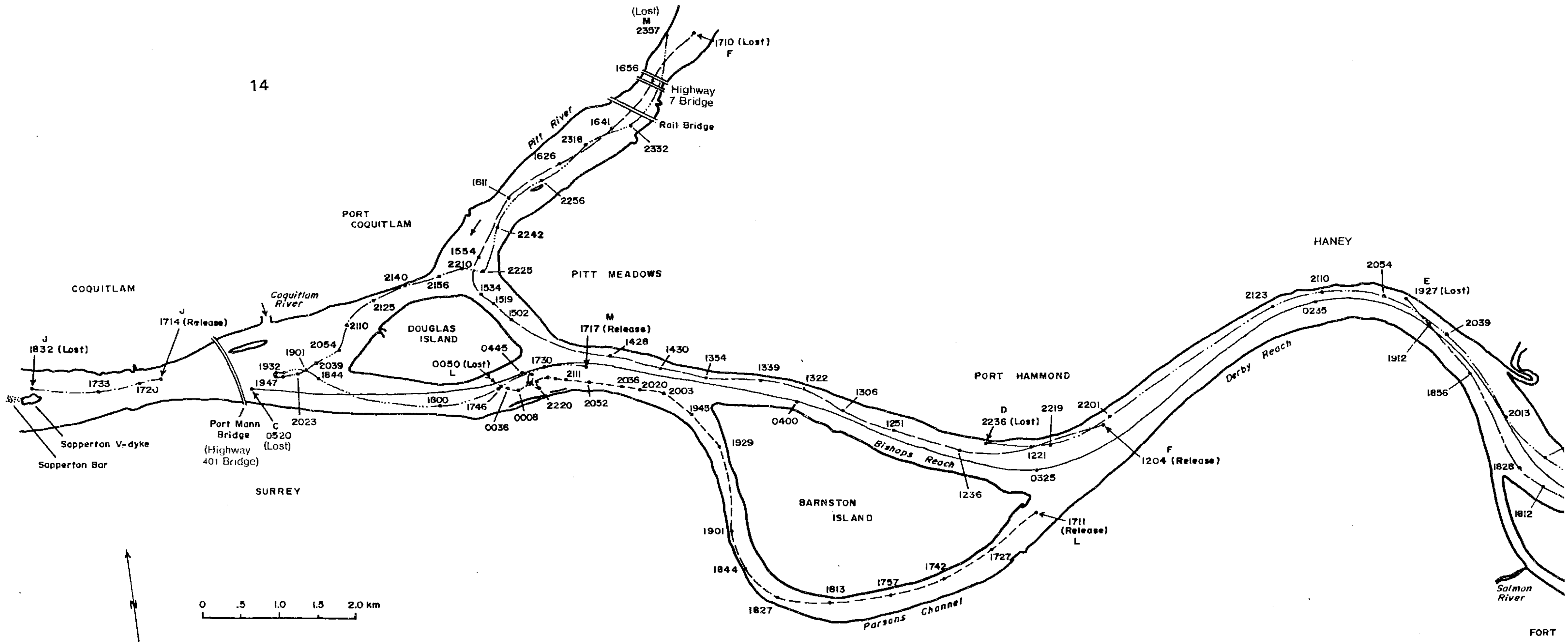

PORT COQUITLAM
COQUITLAM
PITT MEADOWS
DOUGLAS ISLAND
Pitt River
Coquitlam River
Highway 7 Bridge
Rail Bridge
Port Mann Bridge (Highway 401 Bridge)
Sapperton V-dyke
Sapperton Bar
SURREY
BARNSTON ISLAND
PORT HAMMOND
HANEY
Bishops Reach
Derby Reach
Parsons Channel
Salmon River
FORT
J 1832 (Lost)
J 1714 (Release)
M 1717 (Release)
(Lost) M 2357
1710 (Lost) F
C 0520 (Lost)
0050 (Lost) L
D 2236 (Lost)
F 1204 (Release)
E 1927 (Lost)
1711 (Release) L
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N

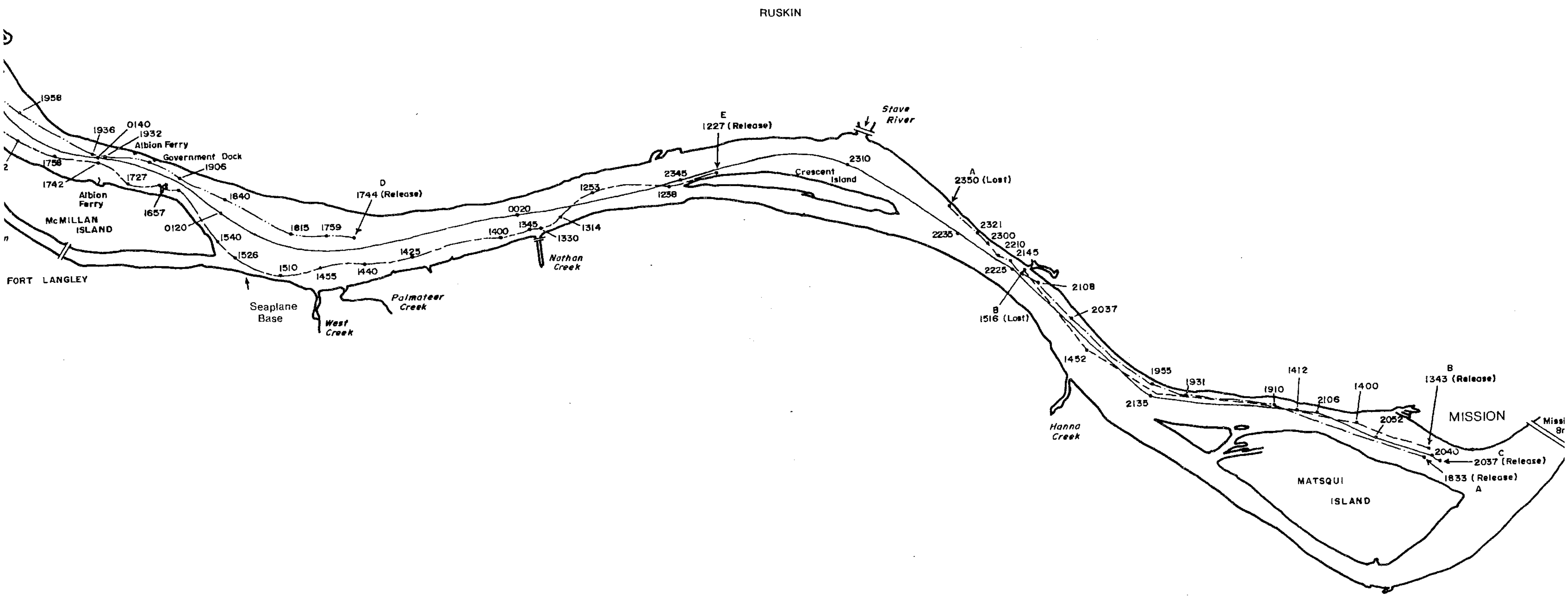
RUSKIN
Stave River
E
1227 (Release)
Crescent Island
2310
2345
1238
1253
1314
1330
1345
1400
0020
A
2350 (Lost)
2321
2300
2210
2145
2235
2225
2108
2037
B
1516 (Lost)
1452
Hanna Creek
1955
1931
2135
1412
1910
2106
1400
2052
B
1343 (Release)
2040
C
2037 (Release)
1833 (Release)
A
MISSION
MATSQUI
ISLAND
1958
1936
0140
1932
Albion Ferry
Government Dock
1906
1758
1742
1727
Albion Ferry
1657
McMILLAN
ISLAND
0120
1840
1815
1759
D
1744 (Release)
1540
1526
1510
1455
1440
1425
FORT LANGLEY
Seaplane Base
West Creek
Palmateer Creek
Nathan Creek

Figure 2. Changes in tide height (m) at New Westminster during tracking of Smolt A on July 27, 1993.

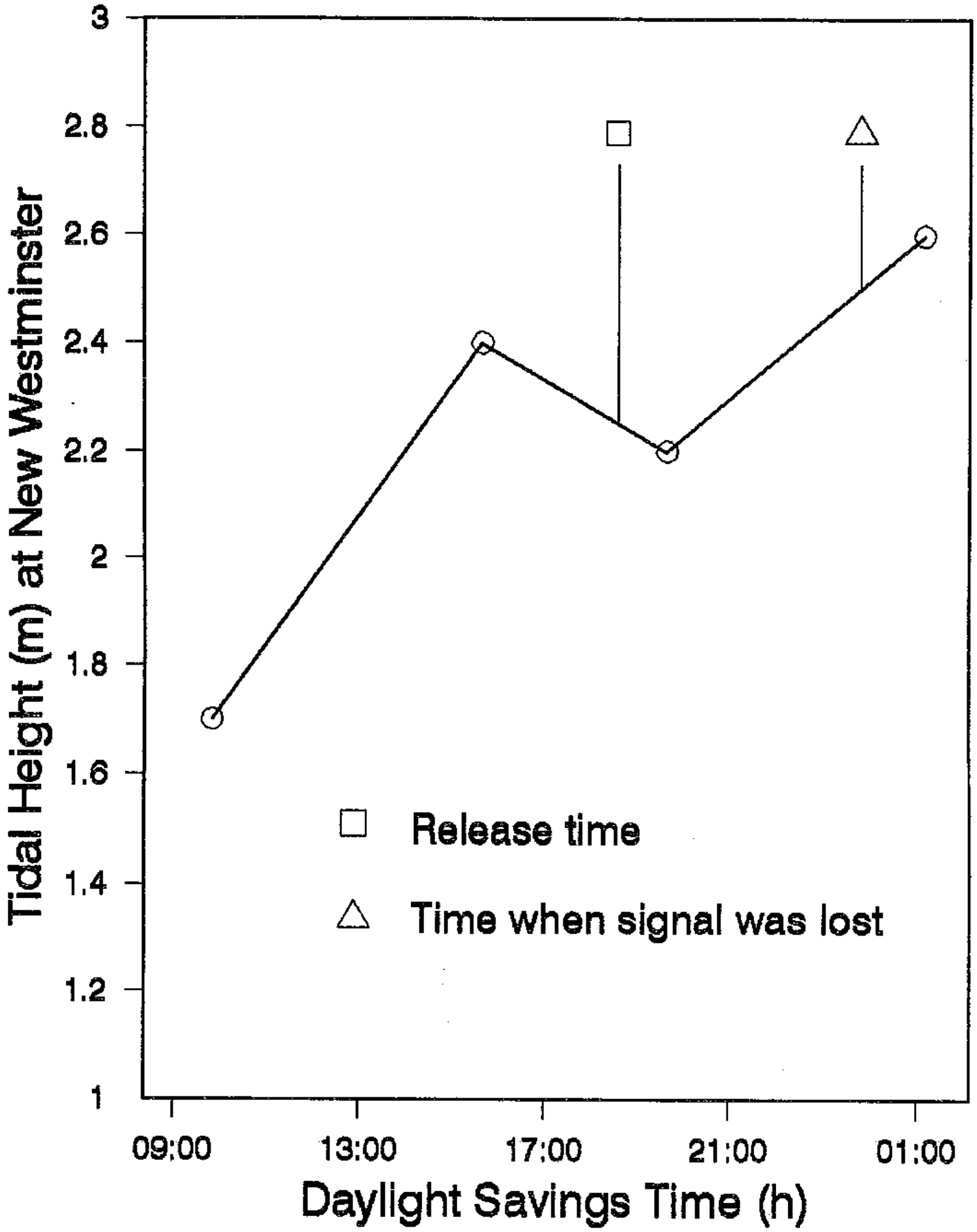

Figure 3. Changes in tide height (m) at New Westminster during tracking of Smolt B on July 6, 1993.

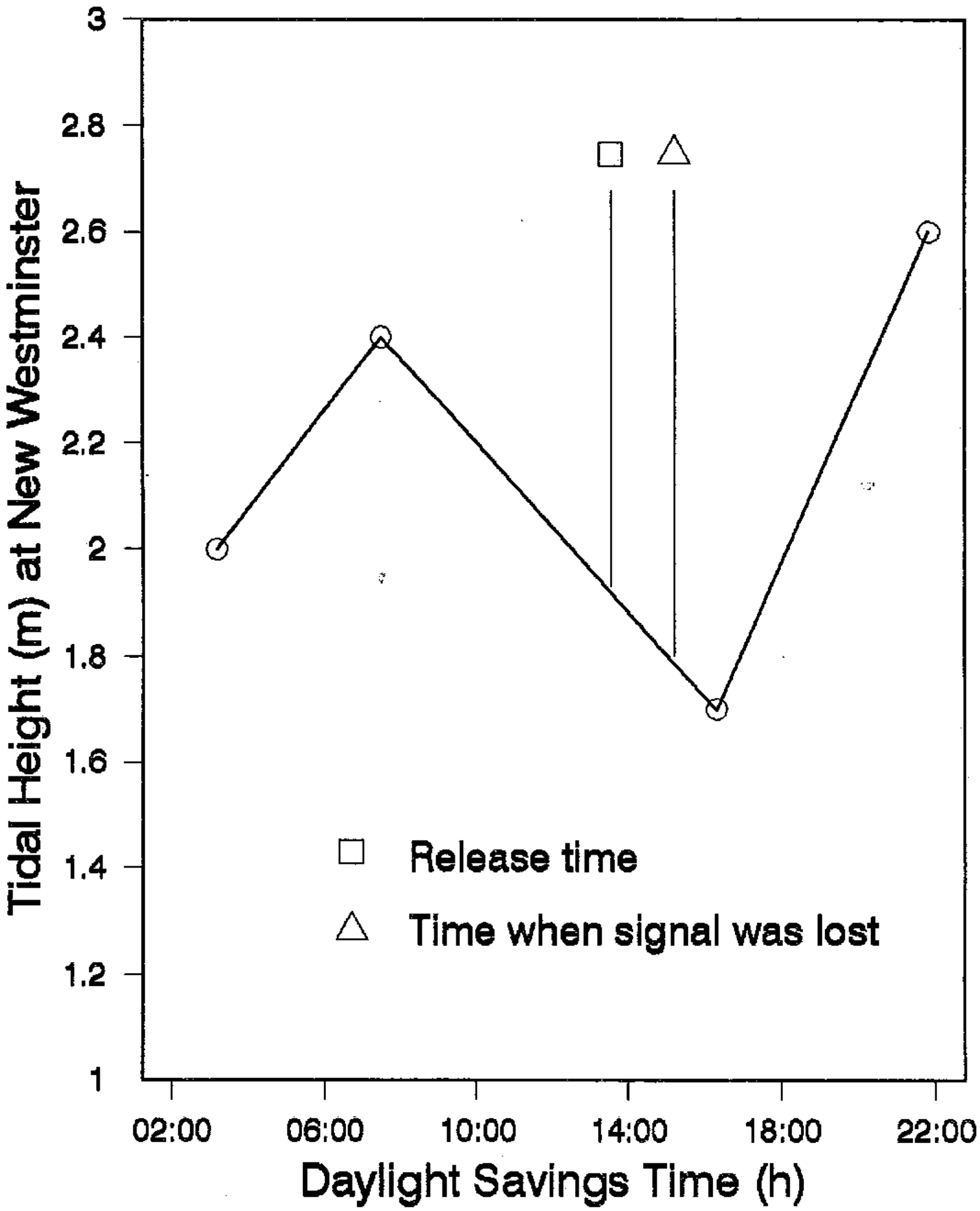

Figure 4. Changes in tide height (m) at New Westminster during tracking of Smolt C on July 7, 1993.

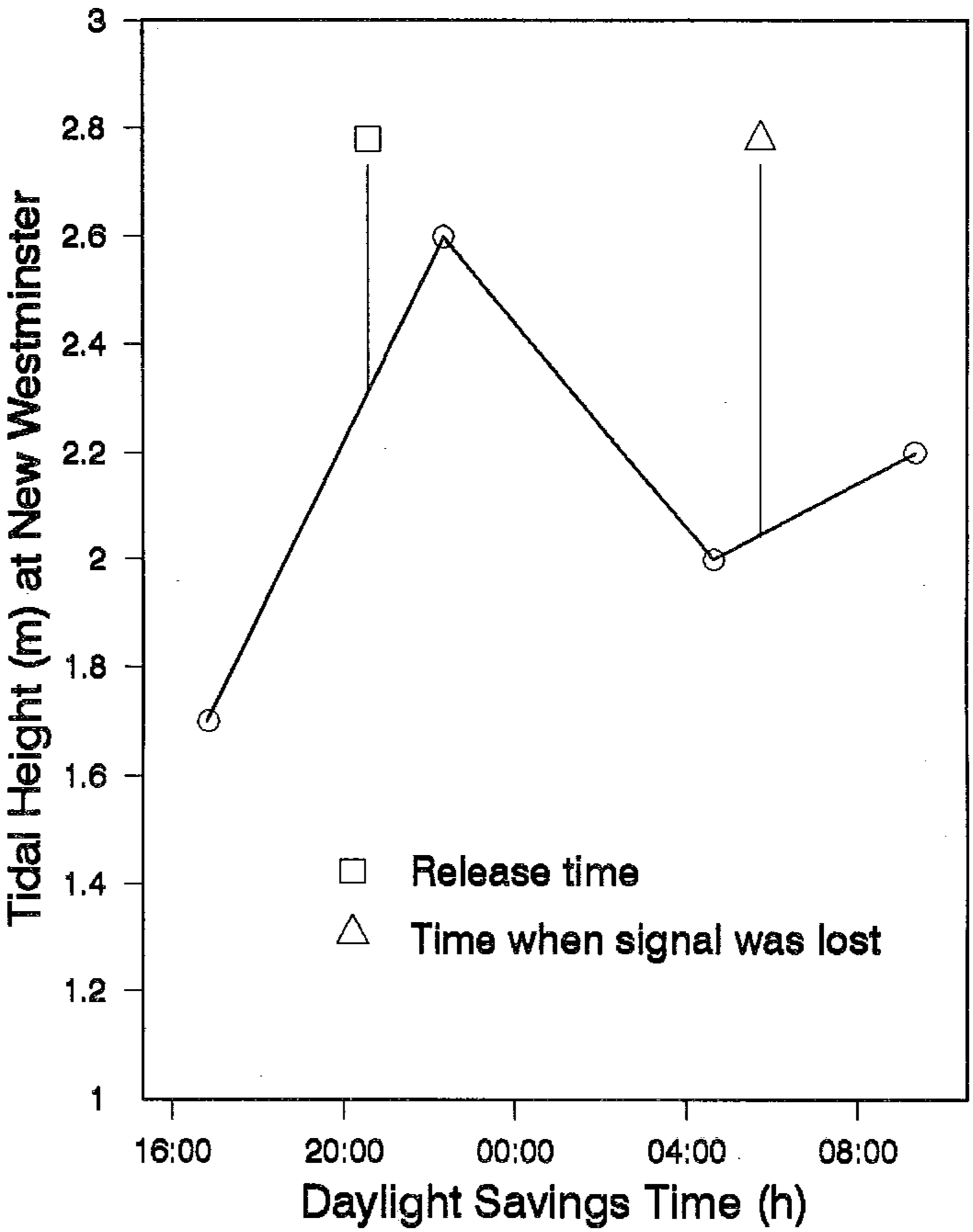

Figure 5. Changes in tide height (m) at New Westminster during tracking of Smolt D on July 29, 1993.

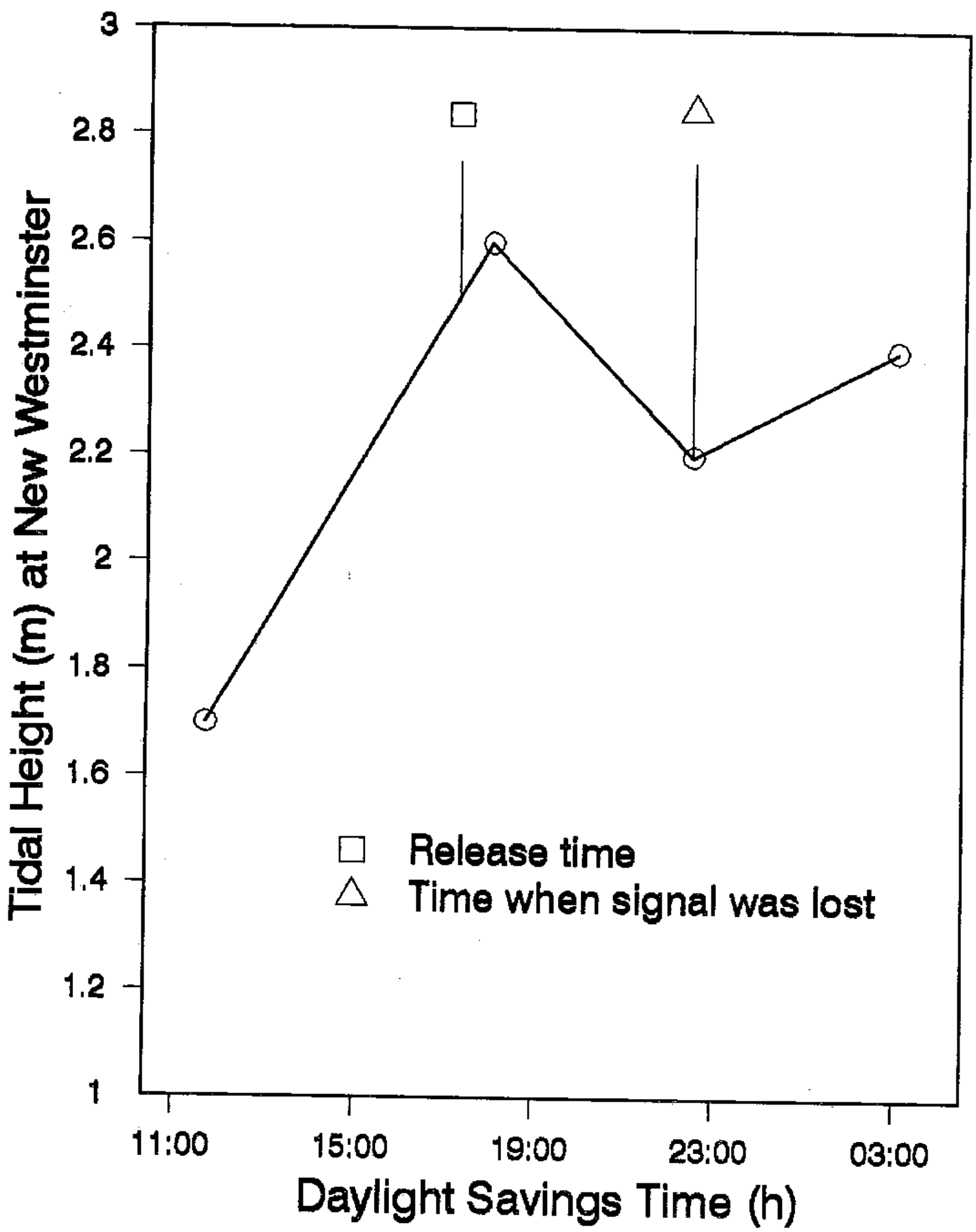

Figure 6. Changes in tide height (m) at New Westminster during tracking of Smolt E on August 12, 1993.

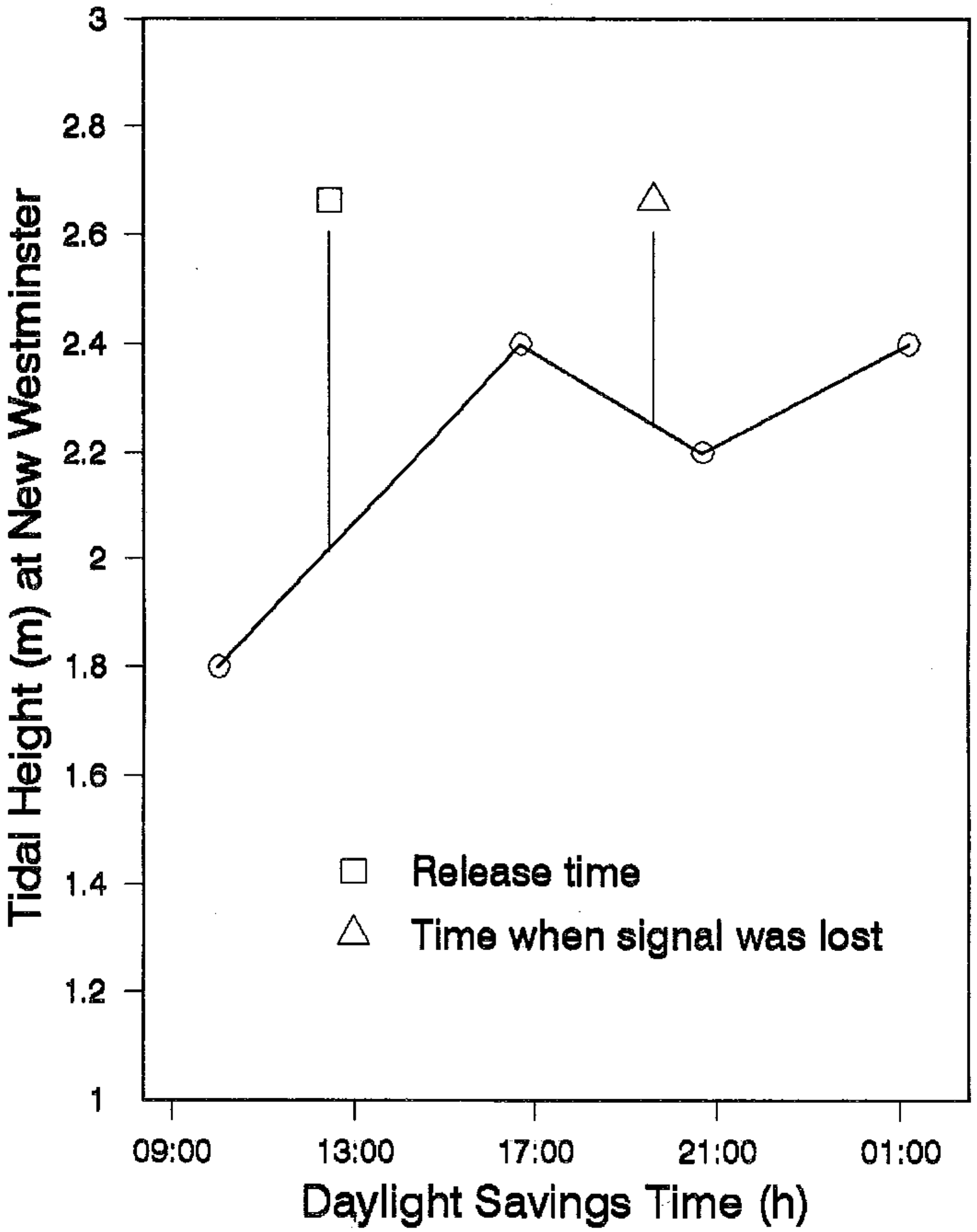

Figure 7. Changes in tide height (m) at New Westminster during tracking of Smolt F on August 13, 1993.

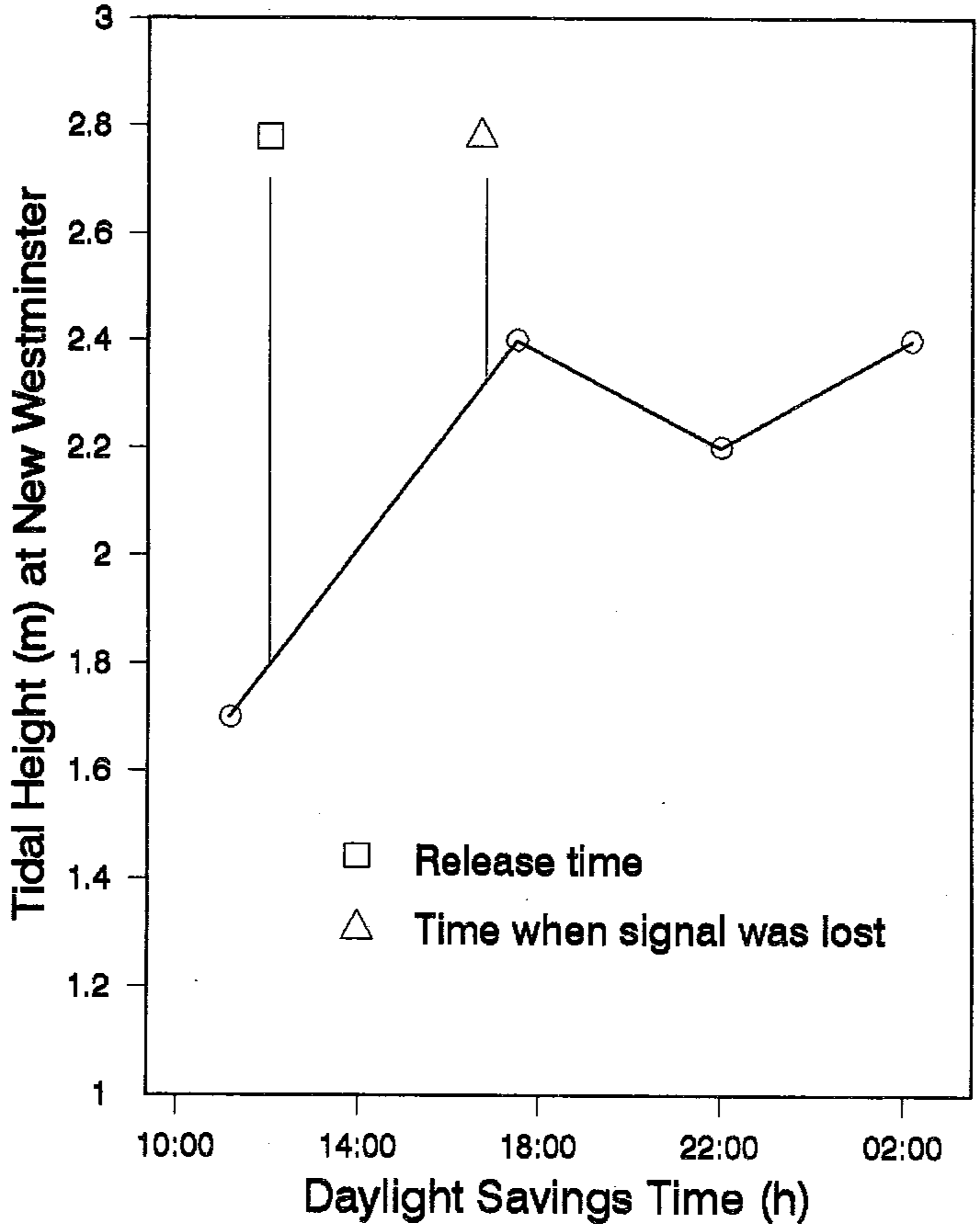

Figure 8. Migration tracks for Smolts F and M in the Pitt River.

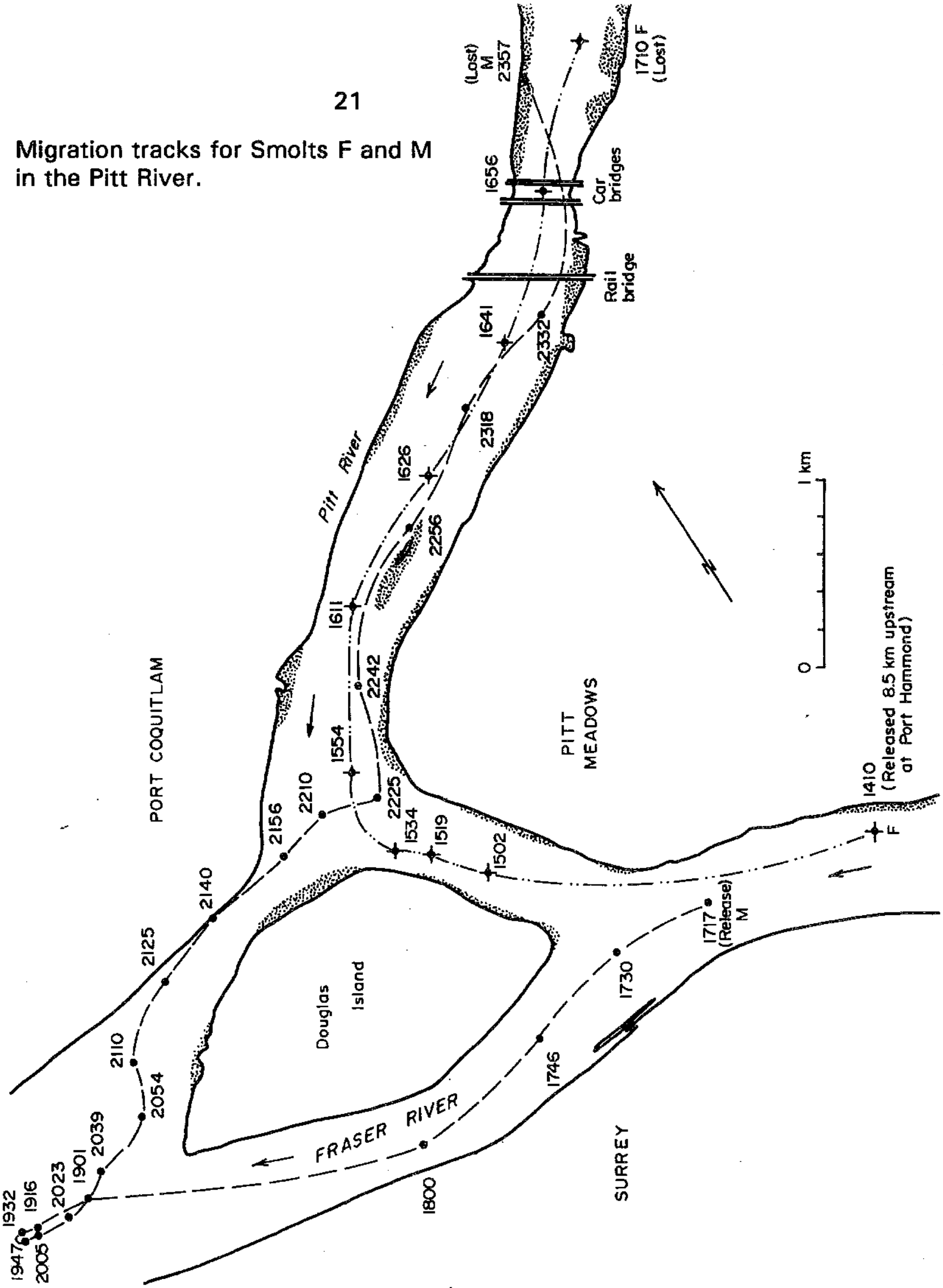

Figure 9. Changes in tide height (m) at New Westminster during tracking of Smolt J on August 5, 1993.

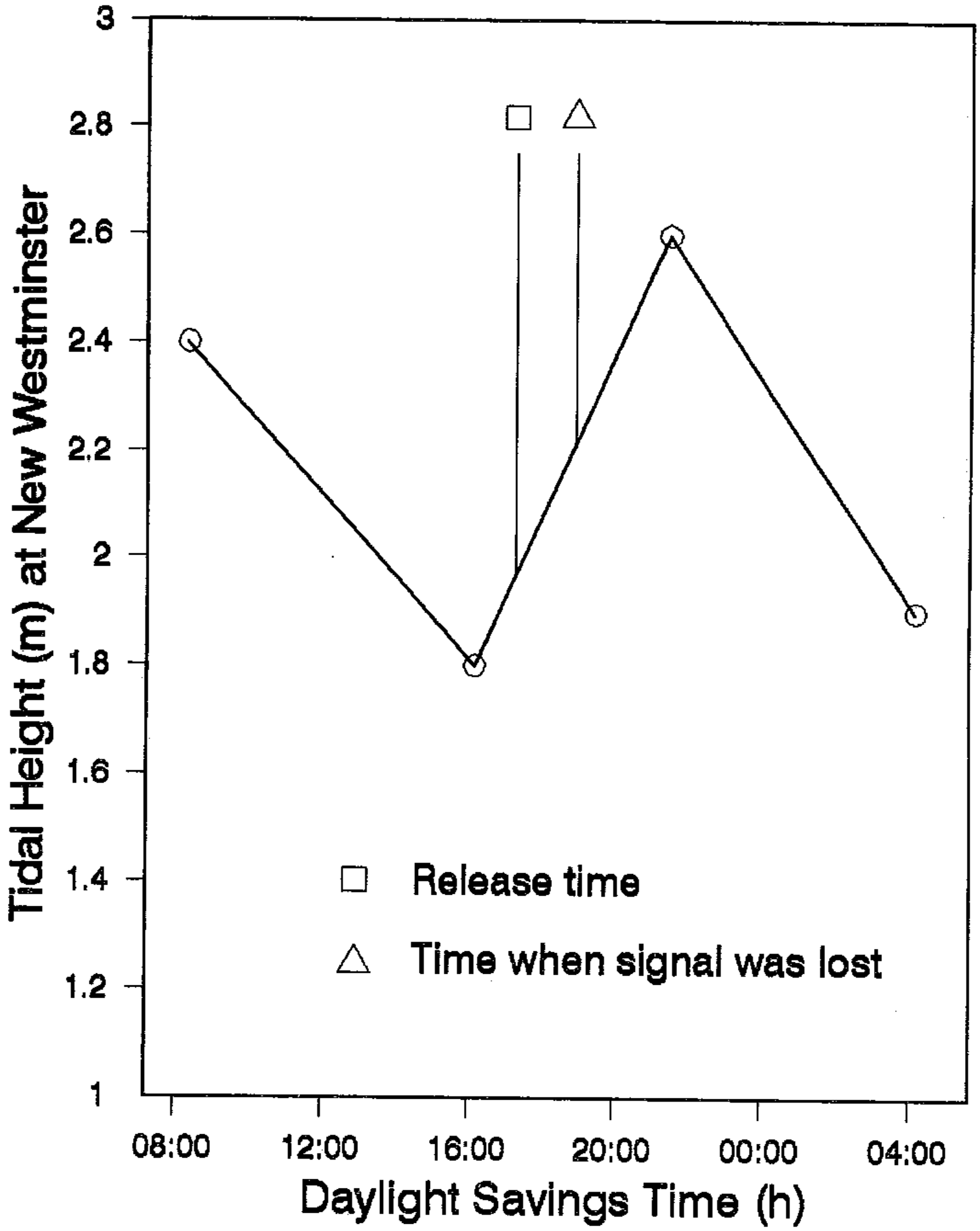

Figure 10. Changes in tide height (m) at New Westminster during tracking of Smolt L on August 9, 1993.

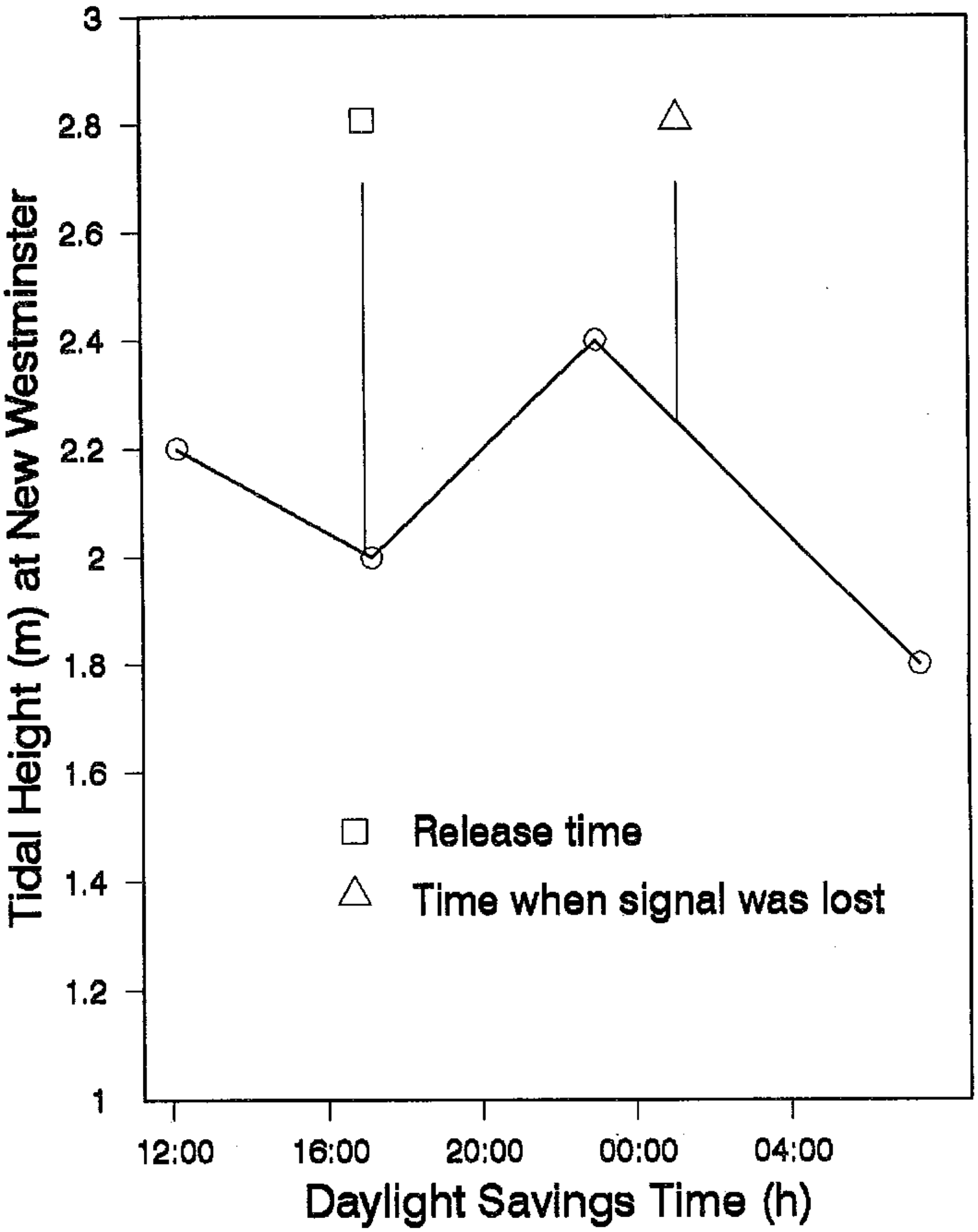

Figure 11. Changes in tide height (m) at New Westminster during tracking of Smolt M on August 4, 1993.

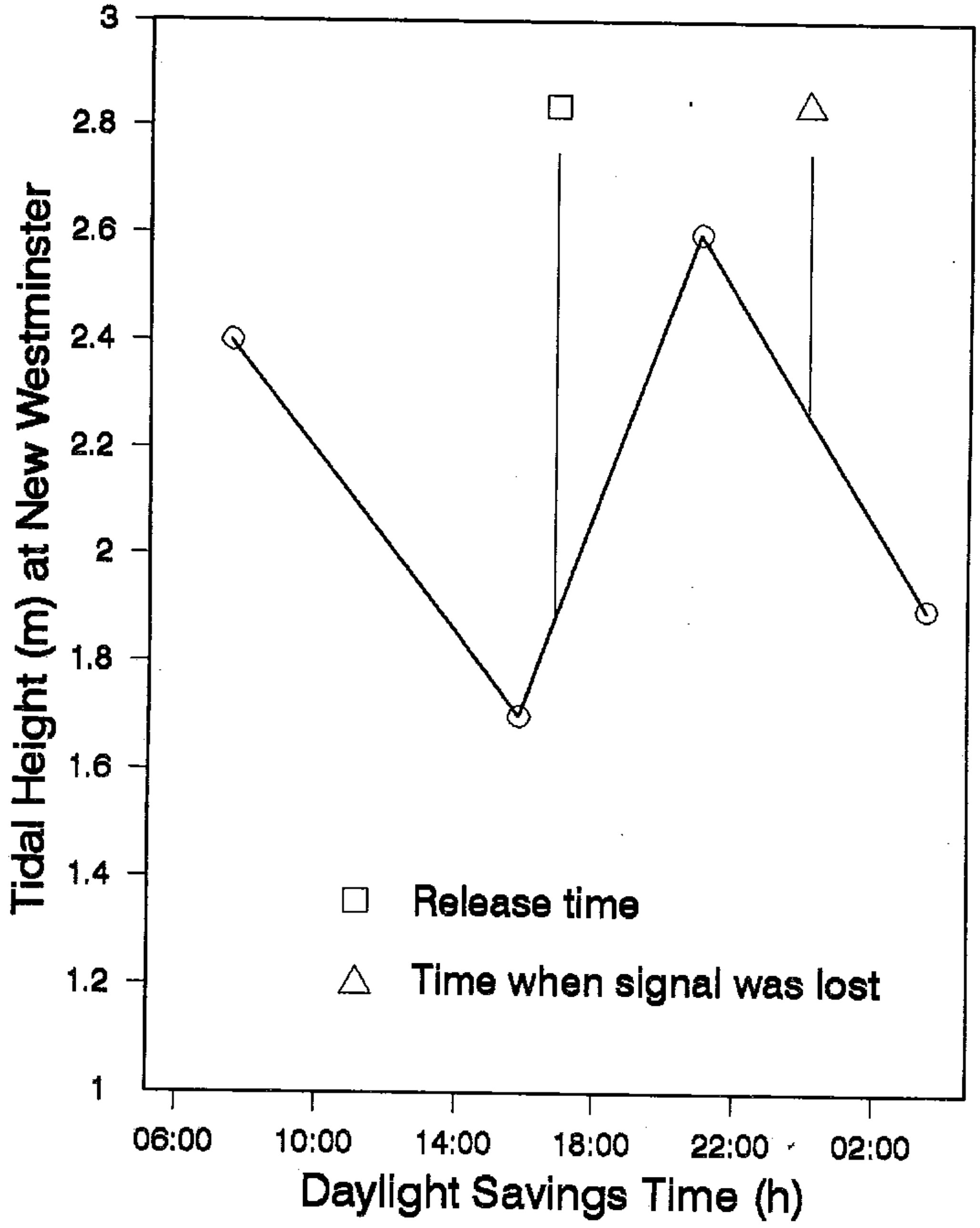

Figure 12. Migration track for Smolt G, released into a constructed embayment (Patrick Bay) on Annacis Channel.

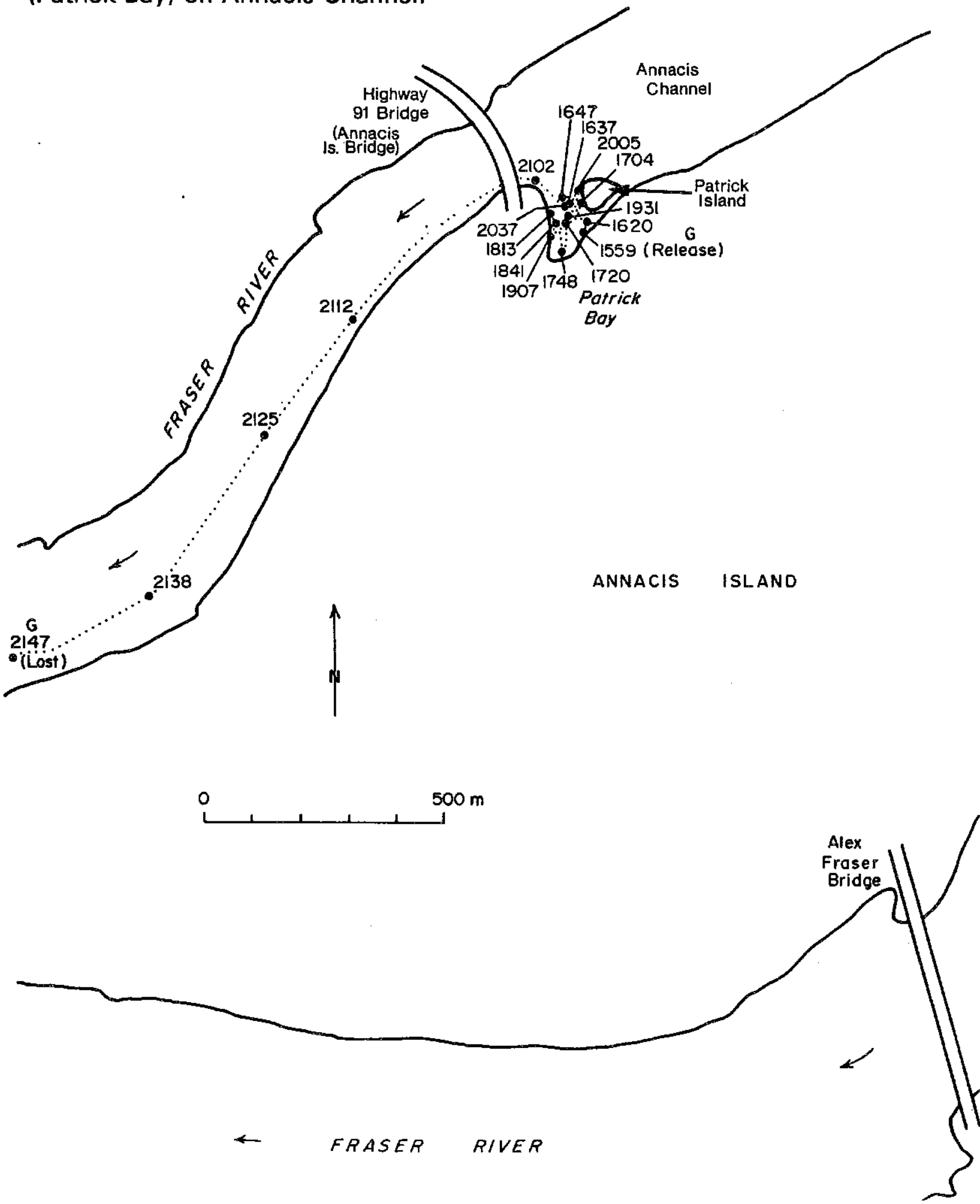

Figure 13. Changes in tide height (m) at New Westminster during tracking of Smolt G on July 30, 1993.

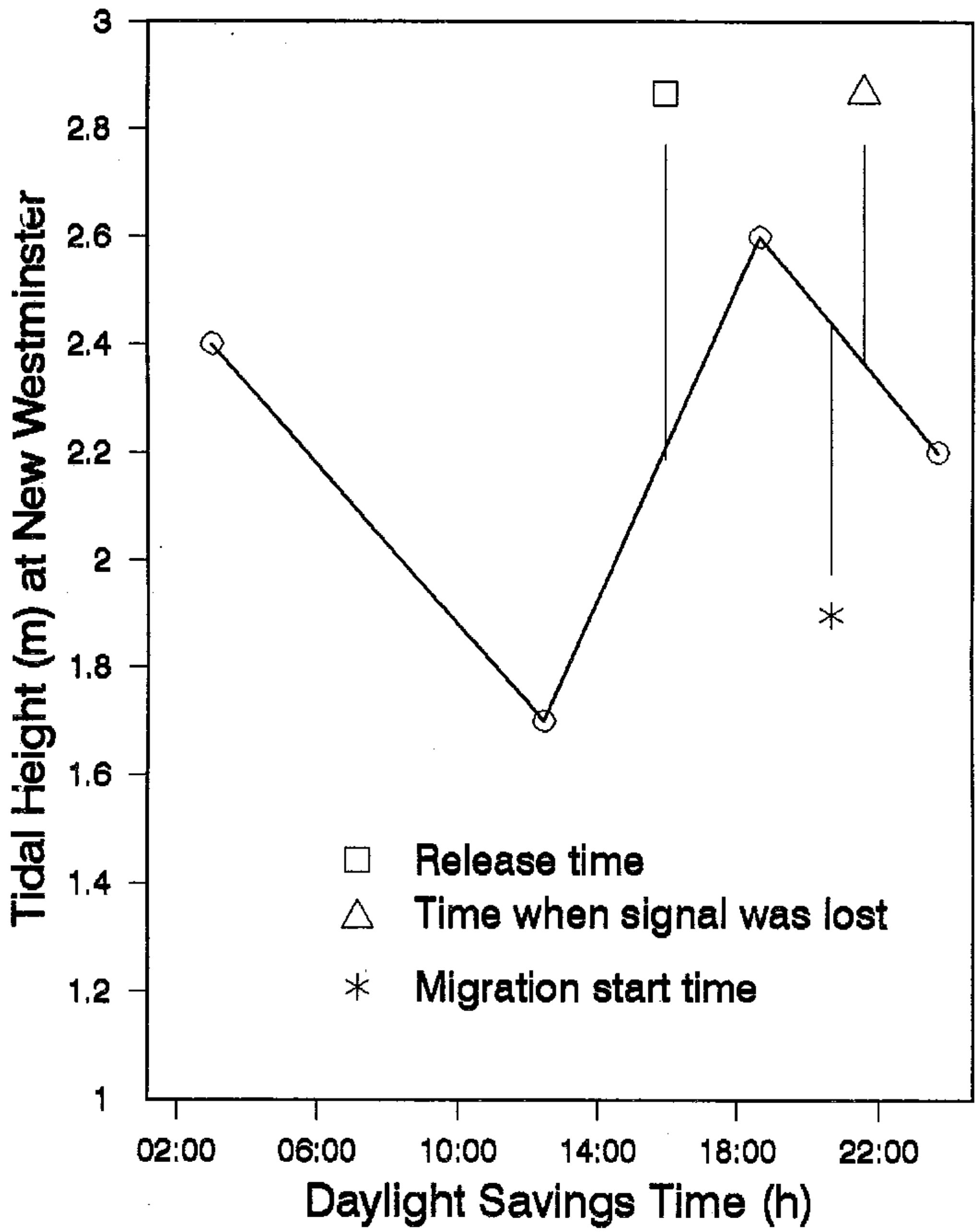

Figure 14. Migration track for Smolt H, released in Tilbury Slough.

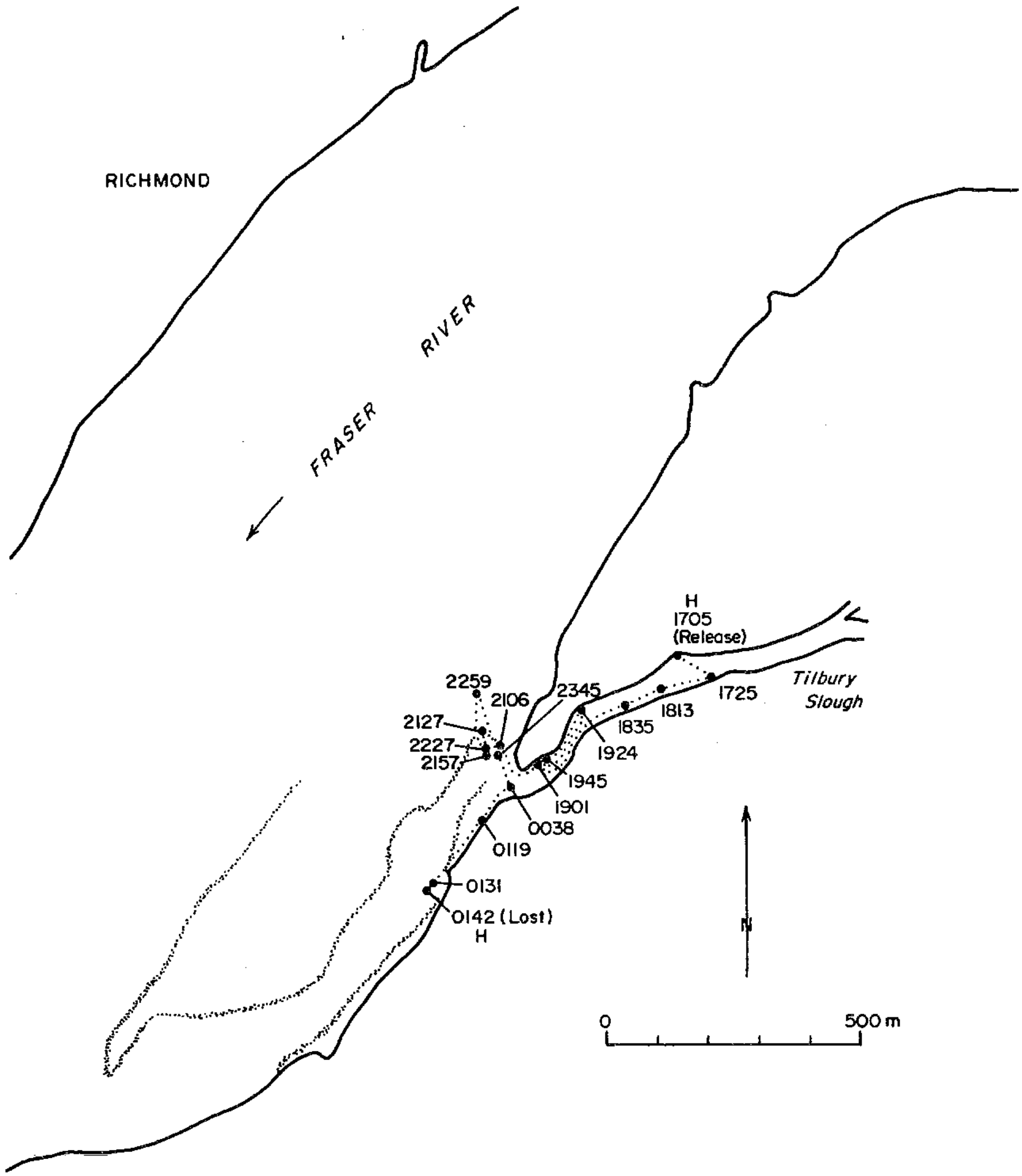

Figure 15. Changes in tide height (m) at New Westminster during tracking of Smolt H on August 2, 1993.

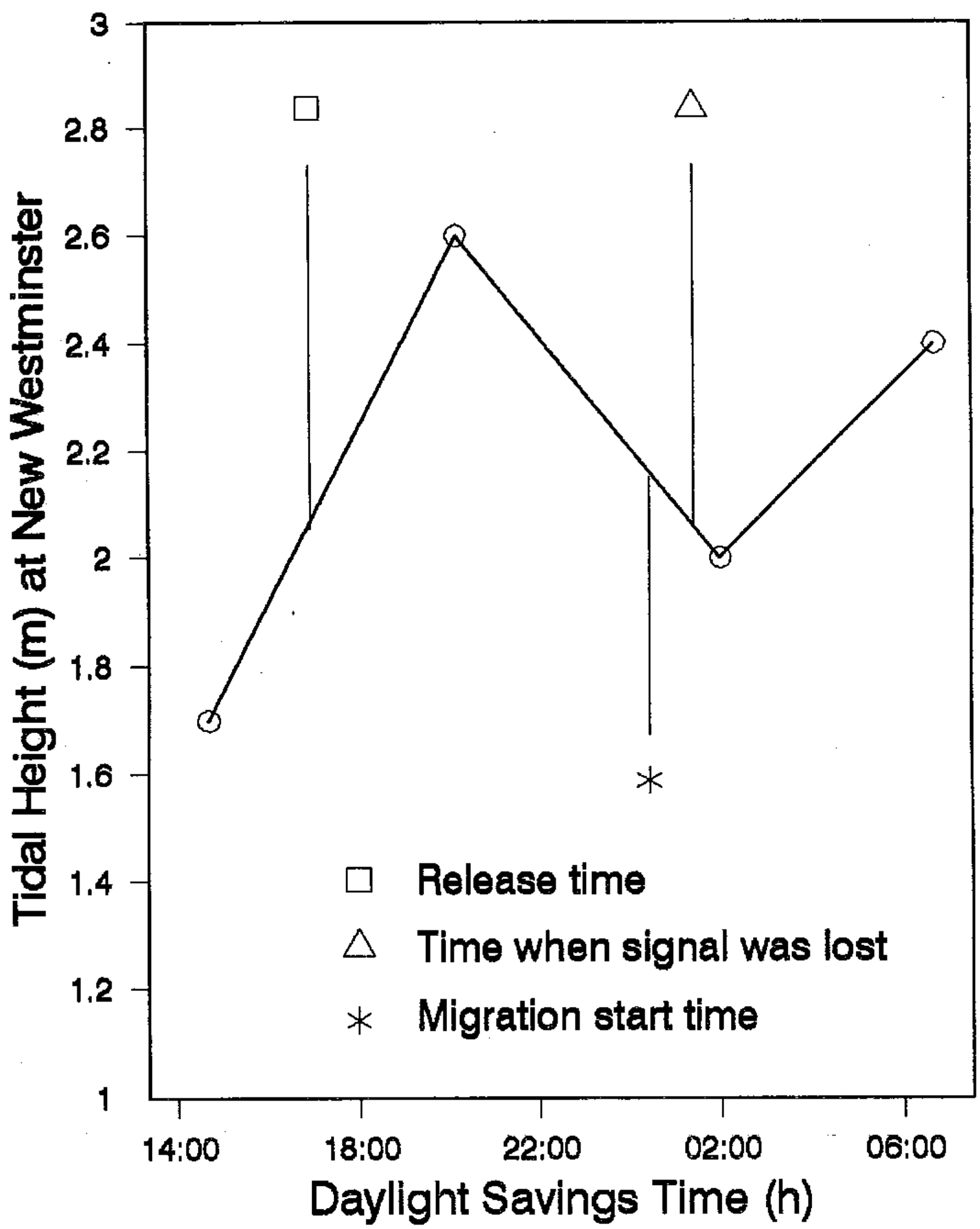

Figure 16. Migration track for Smolt K, released into a constructed embayment on Richmond Island, North Arm of the Fraser River.

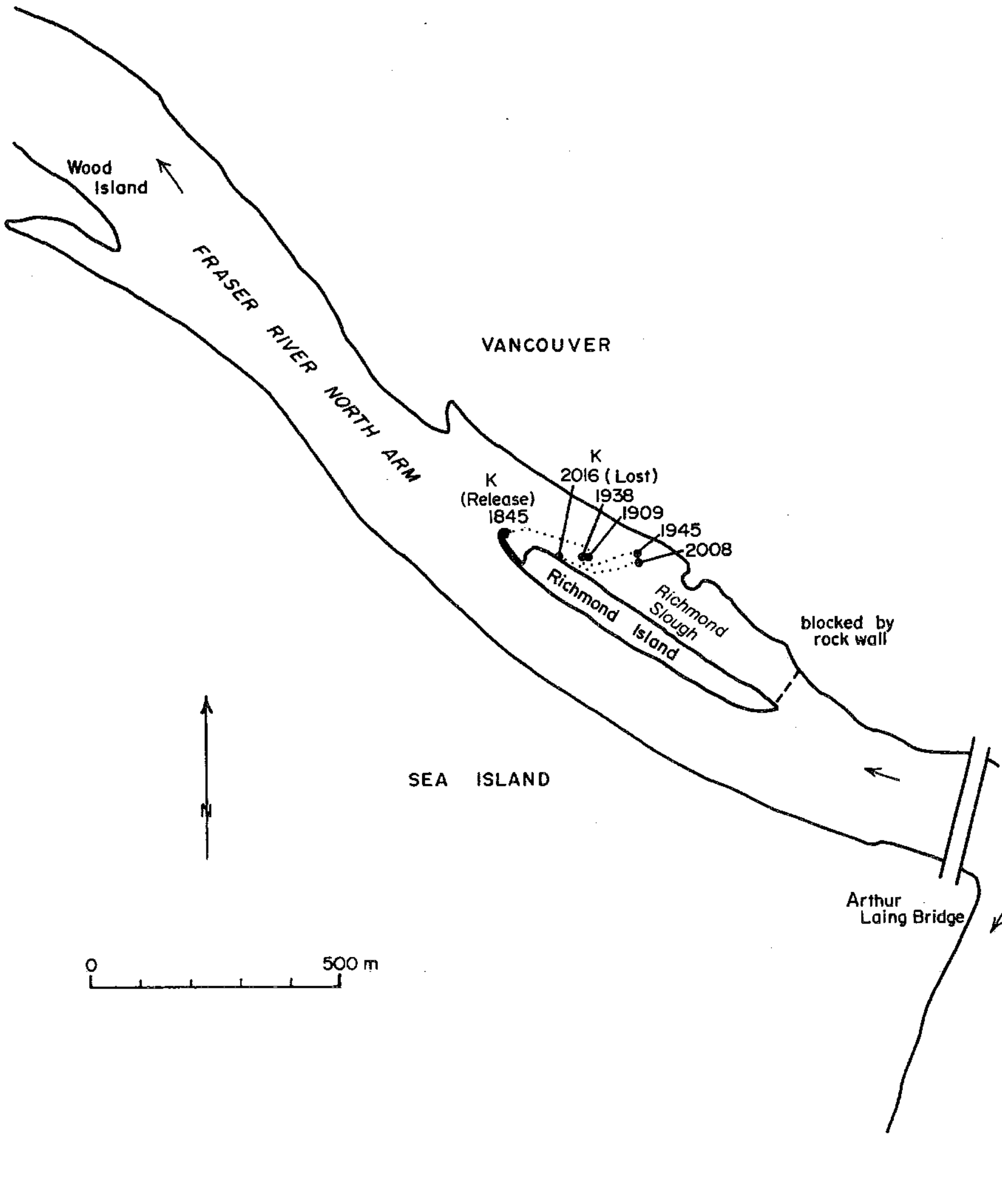

Figure 17. Changes in tide height (m) at New Westminster during tracking of Smolt K on August 6, 1993.