Padilla Bay
National Estuarine Research Reserve

Technical Report No. 14

SWINOMISH CHANNEL AND PADILLA BAY: SURFACE CURRENTS DURING FLOOD TIDE AND WATER QUALITY

Douglas A. Bulthuis

Anne M. Conrad

October 1995

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WASHINGTON STATE DEPARTMENT OF ECOLOGY

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION NOAA U.S. DEPARTMENT OF COMMERCE

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ABSTRACT

Bulthuis, D.A. and A.M. Conrad. 1995. Swinomish Channel and Padilla Bay: surface currents during flood tide and water quality. Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 14, Mount Vernon, Washington. 99pp.

Water quality (total and volatile suspended solids, total coliform and fecal coliform bacteria, nitrate, nitrite, ammonium, soluble reactive phosphate, total dissolved phosphate, salinity and temperature) was measured in the Swinomish Channel near the entrance to Padilla Bay. Samples for analyses were collected hourly for twenty-eight hours, weekly for eight weeks and monthly for fifteen months near the time of low water slack tide. Surface currents during flooding tide were measured with drift sticks on four dates. Tidal currents and water height did not coincide at the Swinomish Channel entrance to Padilla Bay. North flowing currents predominated. Strong seasonal patterns were not evident for any of the water quality parameters except for temperature and nitrate, which was higher (15-25 μg-at of N/L) during December - April than during the rest of the year (4-15 μg-at of N/L). The concentrations of fecal coliform bacteria exceeded the Washington State standards for Class A marine water. The predominate movement of Swinomish Channel water in Padilla Bay is north and south with little movement of surface currents into the rest of Padilla Bay.

INTRODUCTION

The Swinomish Channel flows into the southwest corner of Padilla Bay and is one of several sources of water and pollutants for the bay. The channel connects Skagit Bay, (mean tidal range of about 3.5m) and Padilla Bay (mean tidal range of about 2.6m; U.S. Army Engineer District 1976; Fig. 1). Previous studies have noted a net northerly flow from Skagit Bay into Padilla Bay (Sylvester and Clogston 1958, McKinley et al. 1959, U.S. Army Engineer District 1976). As water moves north from Skagit Bay into Padilla Bay, it may transport pollutants and suspended solids from Skagit Bay, the town of La Conner, sloughs draining agricultural uplands, and other sources into Padilla Bay. Cassidy and McKeen (1986) measured water quality at 11 sites and sloughs in Padilla Bay including Swinomish Channel. Water quality in Swinomish Channel was usually poorer than water quality in the main basin of Padilla Bay, indicating that Swinomish Channel may be contributing pollutants to the bay.

Water movement in Swinomish Channel has been measured in relation to proposed outfalls in the vicinity of the channel including those for Texaco Refinery (Sylvester and Clogston 1958), and the Swinomish Marina (URS Consulting Co. 1985). These unpublished studies and that of Shannon Point Marine Lab (1991) have focused on flow in Swinomish Channel during ebb tide. Flow during flood tide has rarely been measured and remains poorly understood.

The objectives of this study were to determine water quality at the Padilla Bay mouth of the Swinomish Channel during 1992, determine surface currents from Swinomish Channel into Padilla Bay during flood tide, and to synthesize data on water quality and currents in the Padilla Bay portion of the Swinomish Channel collected in previous unpublished studies.

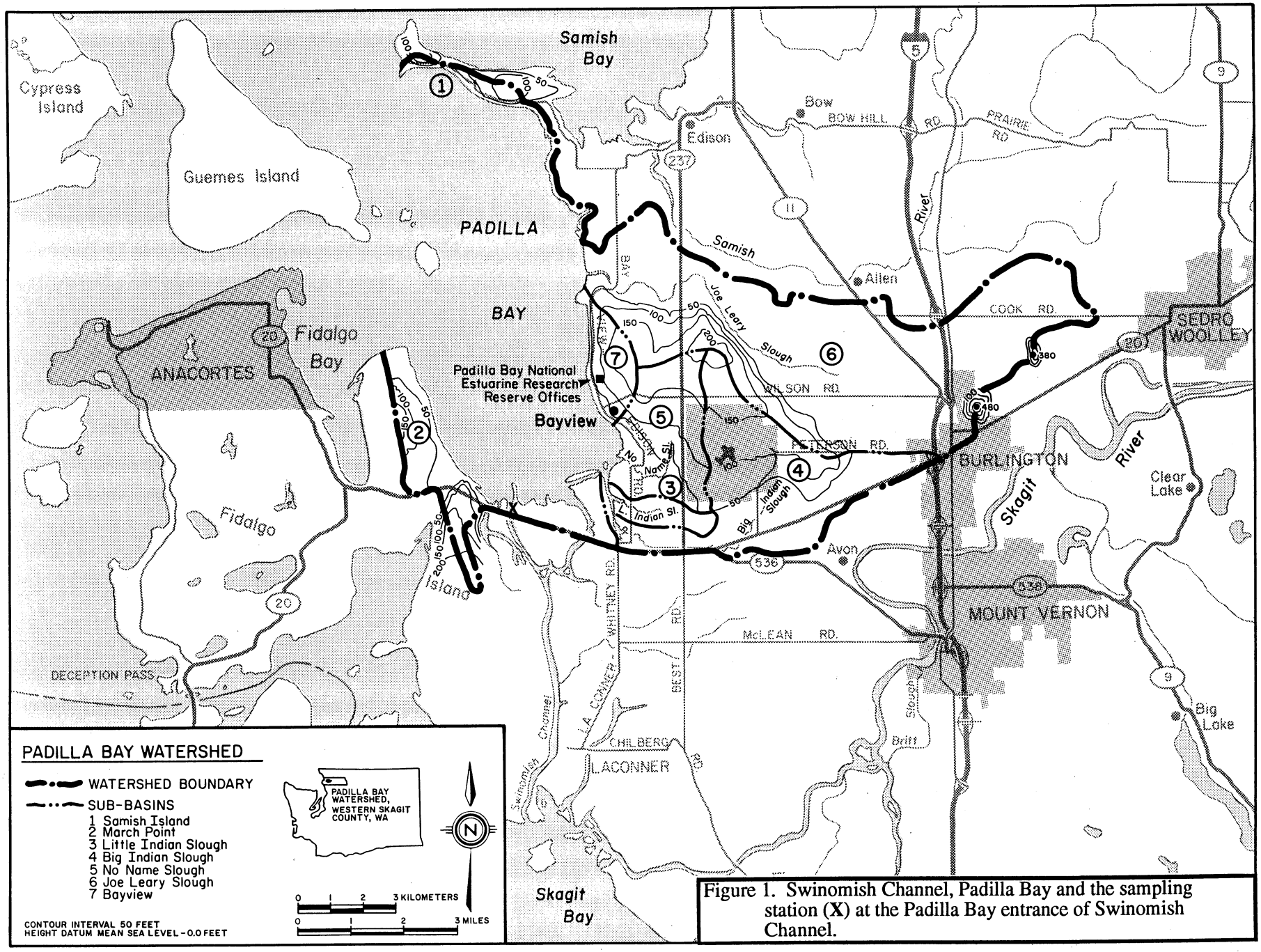

Figure 1. Swinomish Channel, Padilla Bay and the sampling station (X) at the Padilla Bay entrance of Swinomish Channel.

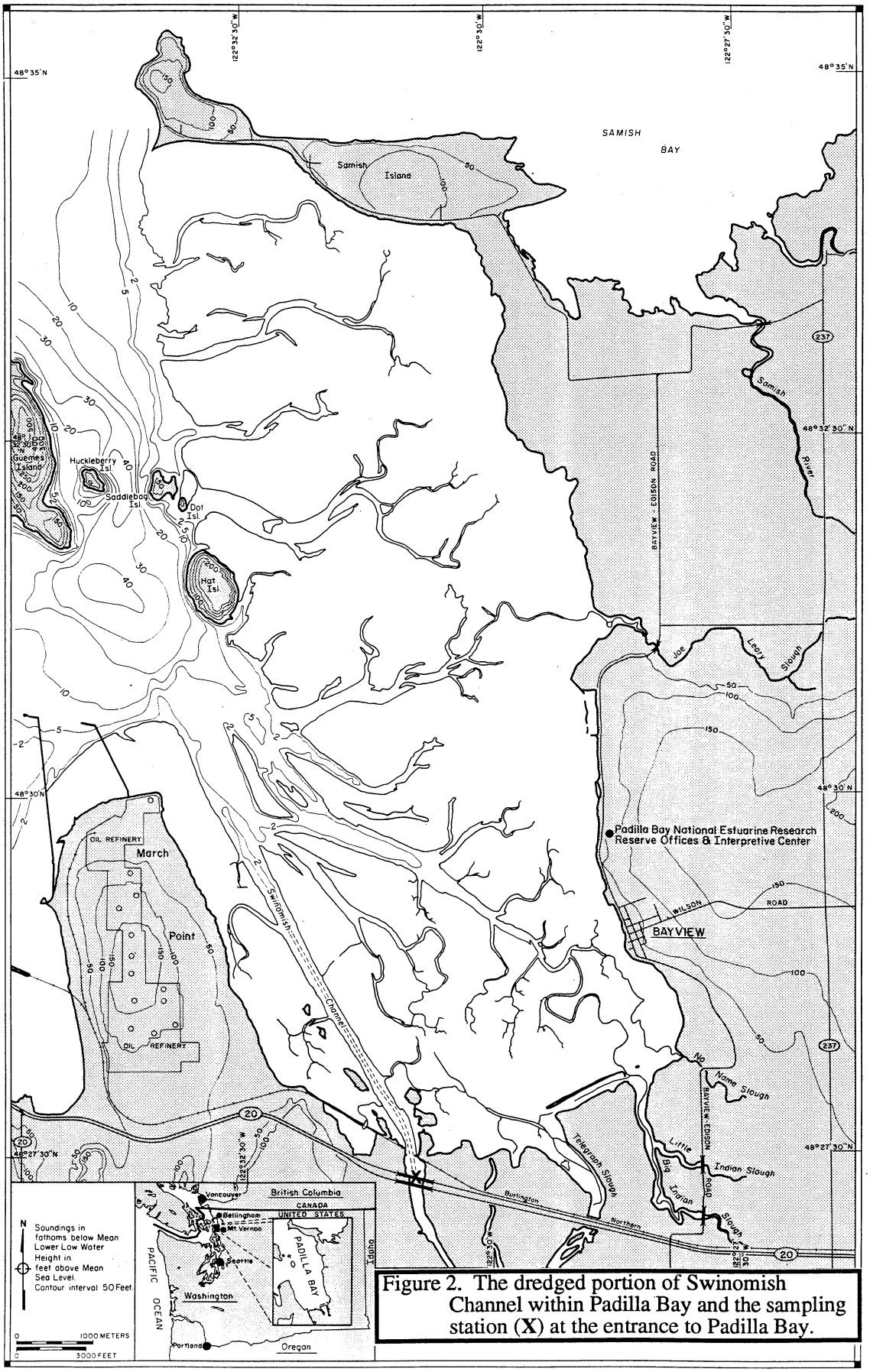

Figure 2. The dredged portion of Swinomish Channel within Padilla Bay and the sampling station (**X**) at the entrance to Padilla Bay.

METHODS

In the present study, water quality in Swinomish Channel was measured with hourly sampling for 28 hours on one occasion, weekly sampling for two months, and monthly sampling for sixteen months at the Padilla Bay entrance of the Swinomish Channel. Flow was measured hourly for 28 hours at the Padilla Bay entrance of the Swinomish Channel, and currents were measured with drift sticks deployed at various locations during flood tide on four dates. Unpublished studies and reports were reviewed for any data on currents or water quality in Swinomish Channel.

Water quality parameters that were measured in the present study included temperature, salinity, total suspended solids (TSS), total volatile suspended solids (TVSS), total and fecal coliform bacteria, dissolved ammonium, nitrate, nitrite, reactive phosphate, and total dissolved phosphate. Samples for analyses were collected at 0.5 m depth (unless otherwise reported) with a La Motte water sampler and placed immediately in sample containers. Samples were taken beneath the Highway 20 bridge over the Swinomish Channel in mid channel (Figs. 1 & 2) at the time of predicted low water. Temperature, salinity, TSS, TVSS, and total and fecal coliform bacteria were measured weekly from January to March 1992 and monthly from March 1992 through May 1993. Dissolved nutrients (ammonium, nitrate and nitrite, nitrite, reactive phosphate, total phosphate) were measured monthly from March 1992 through May 1993. On May 20-21, 1992, temperature, salinity, TSS, TVSS, water height and rate of water flow at the surface were determined hourly for 28 hours.

Temperature and salinity were measured <u>in situ</u> with a YSI model 33 SCT field meter. The YSI 33 was calibrated per the manufacturer's instructions. The manufacturer's reported accuracy's are up to $\pm$ 0.9°C and up to $\pm$ 1.5‰. Sampling, preservation, and

analytical methods for other parameters were conducted according to Puget Sound Protocols (Puget Sound Estuary Program 1986).

Samples for TSS and TVSS were stored in cleaned, tap water rinsed, sample water rinsed plastic sample containers, kept cool in the field and stored at 4°C until analysis within seven days. Water samples were filtered through Whatman glass fiber filters (934 AH) that had been previously washed, ashed and weighed. Filters were dried for three hours at 105°C, weighed three times with one hour drying time between weighings, heated to 550°C for one hour and weighed again. Filters were kept in a desiccator when not in the oven or being weighed. Replicate samples were taken at each sample time and location.

Samples for total and fecal coliform bacteria were collected in sample bottles provided by Skagit County Health Department, kept cool, and delivered to Skagit County Health Department, Mount Vernon within 24 hours of sampling. Skagit County Health Department estimated bacterial numbers using the membrane filter method (Standard Methods for the Examination of Water and Wastewater). Replicate samples were taken of all samples.

Samples for dissolved nutrients were placed immediately in sample bottles provided by Am Test [Am Test Analytical Laboratories, 14603 NE 87th Street, Redmond, WA 98052], kept cool, and sent to Am Test for analysis within 48 hours of sample collection. Am Test used the U.S.E.P.A. methods (350.1, 353.2, 354.1, 365.1, 365.2) with the quality assurance and quality control procedures required by the State of Washington, Department of Ecology to measure dissolved ammonium, dissolved nitrate and nitrite, dissolved nitrite, dissolved reactive phosphate and total dissolved phosphate.

The rate of surface water flow beneath the Highway 20 bridge was measured hourly for 28 hours on May 20-21, 1992. Two marks were placed on the bridge pilings 75 feet apart. Oranges were tossed in the water upstream of the bridge. The time it took an orange to travel from the first to the second mark was measured with a stopwatch; at least three measurements were made each time.

Surface currents during flood tides were measured with drift sticks on four dates: July 31, August 4, August 31, and September 13, 1993 and surface currents during ebb tide was measured on one date: October 5, 1992. Drift sticks, two inches by two inches by two feet were constructed from wood and individually weighted with lead at one end to attain a buoyancy that kept the sticks oriented vertically with the top six inches (painted bright orange with black numbering) above the water surface. Fifteen to thirty drift sticks were deployed and followed each date. Six to ten drift sticks were set out at predicted low tide at predetermined sites. About one hour, two hours, and three hours after predicted low tide, subsequent sets of drift sticks were deployed at the same sites. The time and location of each drift stick was determined about every half hour until predicted high water when the drift sticks were recovered. Location and time of each drift stick was measured by pulling the vessel alongside the stick and recording time and latitude/longitude with on board GPS (Magellan with a stated accuracy of about 100 m). On days when surface currents carried the sticks in divergent directions, the time between readings increased to greater than every 30 minutes. On most days, most of the sticks were recovered, but a few sticks were lost. On August 4, 1993, one half of the drift sticks were flagged with two foot lengths of thin bamboo stakes with orange flagging tape attached to the top of the bamboo stakes. Drift sticks were flagged in an attempt to increase visibility. However, flagged drift sticks were more strongly affected by the wind, and drift sticks were not flagged on subsequent dates.

Unpublished reports, project studies, and environmental impact statements were reviewed for data that may have been collected on the Swinomish Channel in Padilla Bay. Relevant data sets were extracted from such reports, presented, and summarized.

RESULTS

Tidal cycle

Hourly measurements of flow and water height for 29 hours during a spring tide on May 20-21, 1993, indicated that tidal flow and water height do not coincide at the Padilla Bay entrance of the Swinomish Channel (Fig. 3). Maximum southerly surface flow was measured about two hours after low water at 1400, maximum northerly flow occurred about one hour before high water at 2200, but about three hours after the high water at 0700 (Fig. 3). Similarly, slack water (current speed equals 0) occurred about an hour before the low water at 1400, but about three hours before the high water at 2200. Temperature did not change much over the 29 hour sampling period (Fig. 4). However, salinity varied from 18 to 26‰ and was at minimum near the end of the north flowing tidal flows(Fig. 4). Total suspended solids varied from 2.6 to 9.6 mg l^{-1} with a pronounced peak at about 1600, coinciding with maximum southerly current speeds (Fig. 4). Organic suspended particulate matter did not vary over the 29 hour sampling period as much as the total suspended particulate matter. Data sheets for all of the data collected in the 29 hour study are presented in Appendix A.

Seasonal changes in water quality

Seasonal changes in temperature fluctuated from lows of about 7-8°C during late winter to a high of 15° in September (Fig. 5). In contrast, salinity did not vary obviously with the season; the lowest values of salinity were recorded in January, February, May,

November, 1992 and April, 1993 (Fig. 5, Appendix B). Similarly, suspended particulate matter did not vary clearly with the season (Fig. 5). Organic suspended particulate matter ranged from 8% to 32% of the total suspended particulate matter. Although organic suspended particulate matter increased as total suspended particulate matter increased, it decreased as a percentage of the total suspended particulate matter (Figs. 5 and 6).

The concentration of total and fecal coliform bacteria at the Swinomish Channel entrance fluctuated widely over the seventeen month sampling period with no evidence of a seasonal pattern (Table 1). Replicate samples taken at the same time varied widely.

Nitrate plus nitrite at the channel entrance was higher during the winter and lower during the summer (Fig. 7). The concentration of ammonium, total dissolved phosphate, and reactive dissolved phosphate did not indicate seasonal trends, but fluctuated below 0.10 μM ammonium and phosphate (Fig. 7, Appendix B).

Surface current studies

Initial surface current studies (drogue trail 1) focused on the Swinomish Channel during times of northward flow (cf Fig. 3). Drift sticks released about one hour after high water in the Swinomish Channel (when northward flow was beginning) on October 5, 1992, moved northward along the dredged shipping channel (Fig. 8). A few drift sticks moved into the shallows and became stranded by the receding tide. Such drift sticks (which were picked up and moved to the center of the channel at the same latitude) resumed their northward movement when returned to the channel. The time and location of each drift stick was noted about every half hour or when located (Fig. 8). About four hours after northward flow had started under the Highway 20 bridge and drift sticks had been released, the drift sticks that had traveled the farthest were east of

and relatively stationary (Fig. 8, Fig. 9). None of the drift sticks moved into Padilla Bay although a few were in the mouths of the channels.

Because of these results the next set of surface current studies (drogue trial 2) focused on movement during flood tide from the dredged portion of Swinomish Channel in Padilla Bay. The drift sticks were deployed near the time of low water slack from the southern part of the dredged channel to midway between March Point and Hat Island (Fig. 10). The general movement of the drift sticks was south in the dredged channel. The movement of drift sticks #12 and #14 illustrate this pattern of movement (Fig. 11). Some drift sticks were sighted and located once or twice during the day and not seen again. A few drift sticks moved out of the area of the dredged channel (to the east or west); the rate of movement of such sticks decreased markedly (Fig. 12). Drift sticks 1-14 moved south in the dredged portion of the Swinomish Channel and were generally retrieved or last seen as they were about to leave Padilla Bay down the Swinomish Channel (Fig.'s 13, 14, and 15 Appendix C). [Location and time data for all drift sticks in drogue trials 2, 3, and 4 are presented in tabular form in Appendix C.] Drift sticks 15-22, which were deployed near the north end of March Point moved less distance than sticks 1-14 and initially moved very little before moving south in the channel (Fig. 16). Four drift sticks deployed between March Point and Hat Island drifted very little during the first 1.5 hours and were not found again during the day (Fig. 17).

Because drift sticks deployed in the southern part of the dredged channel in Padilla Bay left the bay during flood tide, and because several drift sticks near March Point 'disappeared' during drogue trial 2, the next drogue trial (3) focused on movement of drift sticks that were deployed at the northern end of the Swinomish Channel in Padilla Bay (Fig. 18). The drift sticks were deployed between 12:07 and 12:13 p.m.; predicted low water in Swinomish Channel was 1:00 p.m. Between deployment and 1:00 p.m. the

sticks drifted only short distances west and then south (Fig. 19). After LLW, the drift sticks moved south, either in the Swinomish Channel or onto the intertidal flats between the Swinomish Channel and March Point (Fig. 20). One drift stick (#39) moved west and then north into the Guemes Channel (Fig. 21). Stick #39 was not seen after 3:00 p.m. This movement was a contrast to that of the drift stick (#30) deployed just south of stick #39 (Fig. 21). Stick #30 moved west for the first hour, then moved south for the next five hours over the intertidal area between the Swinomish Channel and March Point and finally moved into the Swinomish Channel near the time of predicted HHW (7:46 p.m., Fig. 21). The pattern of movement of drift stick #30 was typical for almost all of the drift sticks deployed in Experiment #2 near March Point (Figs. 19 & 20). One stick moved farther south than the others and by 6:46 (one hour before predicted HHW) was west of the sand islands between Swinomish Channel and March Point (Fig. 20).

A final trial (#4) with drift sticks in Swinomish Channel focused on movement during the last part of flood tide. On September 13, 1993, the predicted low tide in Swinomish Channel was at 9:31 a.m. and high tide at 4:28 p.m. The results from May 20-21, 1992 current measurements indicated that slack water in the Swinomish Channel would be about three hours after predicted LLW (Fig. 2); that is about 12:30 p.m. on September 13, 1993. Drift sticks were deployed at five locations at about 1:00, 2:00, 3:00, and 4:00 p.m. (Fig. 22). Drift sticks deployed at 1:00 p.m. moved south in the Swinomish Channel until about 3:00 p.m. and then moved into Padilla Bay (Figs. 23 & 24). The drift stick initially deployed the farthest south of those released about 1:00 p.m. (#21) began moving into Padilla Bay about 30 minutes before the other drift sticks (Fig. 25).

The second set of drift sticks in trial #4, released about 2:00 p.m., moved south in Swinomish Channel for about an hour. Two of the five sticks then moved east into

Padilla, two moved west toward March Point, and one moved north in Swinomish Channel (Figs. 26, 27, & 28). The drift sticks released at about 3:00 and 4:00 p.m. moved in all directions as the water in the channel became slack and then reversed directions (Figs. 29 & 30). Between 4:05 and 4:41 p.m. drift stick #35 moved north in the channel while drift stick #39 moved south (Fig. 30). After 4:41, drift stick #39 also moved north.

The movement of drift sticks during drogue trial #4 indicated that during flood tide the water in the portion of the Swinomish Channel that is in Padilla Bay continues to move south until about 1.5 hours before predicted high water when water moved from the channel into Padilla Bay near the sand dredge spoil islands near the entrance of the Swinomish Channel to Padilla Bay.

Previous studies

Cassidy and McKeen (1986) measured water quality weekly for one year at twelve sites in and around Padilla Bay, including one site at the entrance of the Swinomish Channel to Padilla Bay. In that study, temperature fluctuated seasonally from 18° during summer to 4°C during winter (Fig. 31). Salinity, however, fluctuated week to week from 20 to 30‰ with a couple of very low salinities (12‰ and 15‰) in November and January (Fig. 31), but no strong seasonal trends. Similarly, the dissolved oxygen, pH, and turbidity values reported by Cassidy and McKeen did not show a strong seasonal pattern (Fig. 32). The concentration of nitrate indicated a two-season pattern: values between 20-30 μM from October to April, and values below 15 μM May to September (Fig. 33.) Because the concentration of ammonium was less than 8 μM and without a strong seasonal trend, the total inorganic nitrogen pattern was similar to that for nitrate (Fig. 33). Total and soluble phosphate did not vary with the season (Fig. 33).

There have been few studies on water flow and circulation in and around Padilla Bay and the Swinomish Channel. Parker and Bruce (1980) in their survey of historical tidal and current data in Puget Sound report the existence of tidal measurements at the Swinomish Slough entrance to Padilla Bay and current measurements north of March Point. In 1957 and 1958, Texaco conducted a series of current studies in Guemes Channel, Swinomish Channel, and off William Point (Sylvester and Clogston 1958, Appendix D-1). They concluded that:

> "on the greater ebb, Guemes Channel passes from two to three times the volume of water that lies in the entire tidal prism of Fidalgo and Padilla Bays. During a flood tide, the discharge through Guemes Channel is only slightly greater than the intertidal volume in Fidalgo and Padilla Bays. Current studies also indicate that over half of the ebb tide outflow into Padilla Bay from Swinomish Channel comes from Skagit Bay while on a flood tide, only a small portion of Swinomish Channel water passes into Skagit Bay."

Two drogues that Sylvester and Clogston (1958) released in the Swinomish Channel in Padilla Bay during ebb water moved north in Swinomish Channel (Appendix D-1).

The Draft Environmental Impact Statement for the Swinomish Marina summarized drift sheet studies conducted near the site of the proposed marina (URS Corporation 1985). Drift sheets released on ebb tides near the entrance of Swinomish Channel moved north into Guemes Channel. Drift sheets released at the northern end of the Swinomish Channel moved toward Hat Island during ebb tide and into Padilla Bay as flood tide began (Appendix D-3).

Shannon Point Marine Laboratory (1991) released drogues at the north end of Swinomish Channel (east of March Point) and followed them for about 30 minutes on a flood tide and ebb tide (Appendix D-2). During flood tide the drogue moved southeast down the dredged Swinomish Channel, and during ebb tide the drogue moved toward Hat Island (Appendix D-2).

DISCUSSION

The twenty-eight hour flow data indicated a net northerly flow of water from Skagit Bay into Padilla Bay through the Swinomish Channel. This is consistent with previous studies which noted the greater water height in Skagit Bay than in Padilla Bay (Fig. 34). Sylvester and Clogston (1958) calculated that over half of the volume of water flowing from Swinomish Channel into Padilla Bay on an ebb tide comes from Skagit Bay while only a small portion of Swinomish Channel water passes into Skagit Bay on a flood tide. The lower salinity observed near the end of the ebb tide (Fig. 4) supports this explanation. Sylvester and Clogston estimated the volume of water ebbing from Swinomish Channel to be 3% of the volume of Padilla and Fidalgo Bays while McKinley et al. (1959) estimated this flow to be 10% of the volume of Padilla Bay south of a line from March Point to Joe Leary Slough. These studies and estimates indicate both a net northerly flow in Swinomish Channel and that Swinomish Channel is not a major source of water to Padilla Bay.

Suspended solids, nutrients and coliform bacteria were measured near the end of ebb tide in the Swinomish Channel to indicate water quality of the Skagit Bay water that may be entering Padilla Bay. Nitrogen concentrations in the Swinomish Channel were somewhat lower in 1992-93 as measured in this study compared to the concentrations

reported by Cassidy and McKeen (1986) for 1985-86 (cf. Figs. 7 and 33). This was true despite the fact that in 1992-93 sampling was always conducted near the end of the ebb tide when Skagit Bay water would be expected to predominate, while sampling was conducted during all tide phases in 1985-86. Even more striking is the strong seasonal pattern in concentration of nitrate in 1985-86 with highs during the higher rainfall months of November to April (Fig. 33). In 1992-93, concentration of nitrate was only slightly higher during December to March than other months (Fig. 7). Total and soluble phosphate concentrations were similar both years and there was no indication of seasonal differences (Figs. 7, 33).

The concentrations of suspended solids and nutrients measured in the Swinomish Channel in this study were of a similar order of magnitude to concentrations reported throughout Padilla Bay in previous studies (Figs. 6 and 7, Cassidy and McKeen 1986, Bulthuis unpublished data). N:P ratios of dissolved inorganic nutrients averaged about nine (Table 2) which, as a source of nutrients to Padilla Bay, would indicate slight nitrogen limitation of phytoplankton growth (Ryther and Dunstan 1971). Bernhard (1993) reported nitrogen limited growth of phytoplankton in Padilla Bay during summer. As a whole, these data indicate that Swinomish Channel is not a major source of nutrients or suspended solids to Padilla Bay.

The counts of total and fecal coliform bacteria in the Swinomish Channel (Table 1) indicate that Washington State Water Quality Standards are not being met. No data have been reported for fecal coliform bacteria throughout Padilla Bay, but these data indicate that the channel may be a source of such contamination to Padilla Bay.

The drift stick experiments were conducted during ebb flow, early flood, late flood, and at both ends of the Padilla Bay portion of the Swinomish Channel. As a whole, the

results of these experiments indicate a strong pattern of water movement between Swinomish Channel and Guemes Channel with little movement to or from the rest of Padilla Bay. In particular, the drift sticks deployed at about low water slack near March Point light in drogue trial #3 (Fig. 18) all moved down Swinomish Channel rather than into Padilla Bay (Fig. 20). Only during the later stages of flood tide did any drift sticks move into Padilla Bay (Figs. 24, 28, 29). When they did, the rate of movement was much slower than movement in the channel; and the sticks moved only into areas adjacent to the channel. After high water slack, this water would begin ebbing from Padilla Bay. Thus, water from Swinomish Channel appears to primarily flow out Guemes Channel toward Rosario Strait with only a small proportion moving into Padilla Bay and mixing with water from other sources. The limited drogue and drift card studies that have been conducted previously, similarly indicated most movement in the Padilla Bay portion of the Swinomish Channel is north and south rather than into Padilla Bay (URS Corporation 1985, Shannon Point Marine Laboratory 1991, Sylvester and Clogston 1958).

Surface currents measured in the present study were those associated with spring tides, because such tides were considered the most likely to produce movement of Swinomish Channel water into Padilla Bay. It is possible, however, that during neap tides there may be greater movement of Swinomish Channel water into Padilla Bay because Guemes Channel ebb currents would not be as strong. Also, the present study concentrated on movement of water during a single tidal cycle. Over several tidal cycles, Swinomish Channel water may be mixed with water from other sources and subsequently flushed into Padilla Bay.

In conclusion, the present study indicates that the concentration of available nitrogen and phosphorus and suspended solids in Swinomish Channel is similar to

concentrations throughout Padilla Bay; that total and fecal coliform bacteria are high and fecal coliform bacteria exceed Washington State standards; that there is a net northerly flow of water in Swinomish Channel, and that the predominant movement of water in the Padilla Bay portion of the Swinomish Channel is north and south with little admixture into the rest of Padilla Bay.

Table 1. Total and fecal coliform bacteria in surface water from the Swinomish Channel near the entrance to Padilla Bay at the time of low tide. Units are number of colony forming bacteria per 100 mls. Washington State water quality standards for Class A marine waters state that the geometric mean for fecal coliforms shall be less than 14 and that not more than 10% of the samples shall be > 43.

Date	Total coliform	Fecal coliform
21-Jan-92	1100	9.1
21-Jan-92	460	3.
27-Jan-92	240	15.
27-Jan-92	240	15.
3-Feb-92	210	43.
3-Feb-92	64	3.6
11-Feb-92	150	23.
11-Feb-92	93	9.1
17-Feb-92	39	3.6
17-Feb-92	39	9.1
24-Feb-92	43	23.
24-Feb-92	210	64.
1-Mar-92	43	3.1
1-Mar-92	75	9.1
21-Apr-92	23	15.
21-Apr-92	460	43.
21-May-92	8	2.
21-May-92	5	2.
17-Jun-92	2	2.
17-Jun-92	2	2.
15-Jul-92	20	10.
15-Jul-92	22	2.
26-Aug-92	40	15.
26-Aug-92	40	12.
9-Sep-92	110	30.
9-Sep-92	160	20.
9-Oct-92	150	81.
9-Oct-92	120	119.
8-Nov-92	80	10.
8-Nov-92	100	28.
8-Dec-92	460	93.
2-Feb-93	12	9.
2-Feb-93	18	5.
30-Mar-93	2	2.
30-Mar-93	4	14.
27-Apr-93	51	62.
27-Apr-93	44	46.
20-May-93	13	4.
20-May-93	7	7.
Geometric mean		11.4
Percent > 43		15%

Table 2. Total inorganic nitrogen and phosphorus and N:P ratios in the Swinomish Slough where it flows beneath the Highway 20 bridge from March 1992 to May 1993.

Date	Total inorganic nitrogen (µg-at N/L)	Total dissolved phosphorus (µg-at P/L)	N:P
23-Mar-92	14.6	1.7	8.4
21-Apr-92	16.5	1.8	9.0
21-May-92	7.4	1.2	6.2
17-Jun-92	16.1	2.1	7.7
15-Jul-92	7.9	1.8	4.5
26-Aug-92	12.9	2.2	6.0
9-Sep-92	12.5	2.2	5.7
9-Oct-92	18.5	1.8	10.2
8-Nov-92	11.9	2.4	5.0
8-Dec-92	25.8	2.0	13.1
2-Feb-93	18.9	1.8	10.2
30-Mar-93	21.9	1.7	13.0
27-Apr-93	12.7	0.8	16.3
20-May-93	8.6	1.1	8.1
Mean of all dates	14.7	1.8	8.8

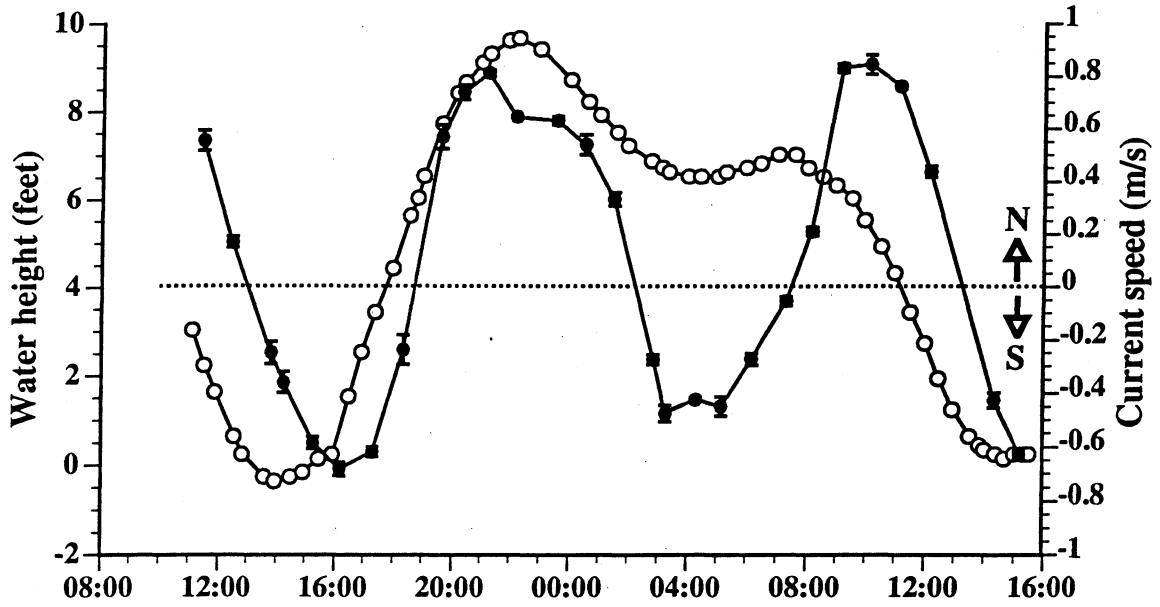

Figure 3. Water height (open circles, in feet relative to MLLW) and surface current speed (closed cicles in m/s, mean ± s.e.) in the Swinomish Channel under the Highway 20 bridge on May 20 and 21, 1992. Positive current speeds (above the dashed line) are north flowing, negative current speeds (below the dashed line) are south flowing.

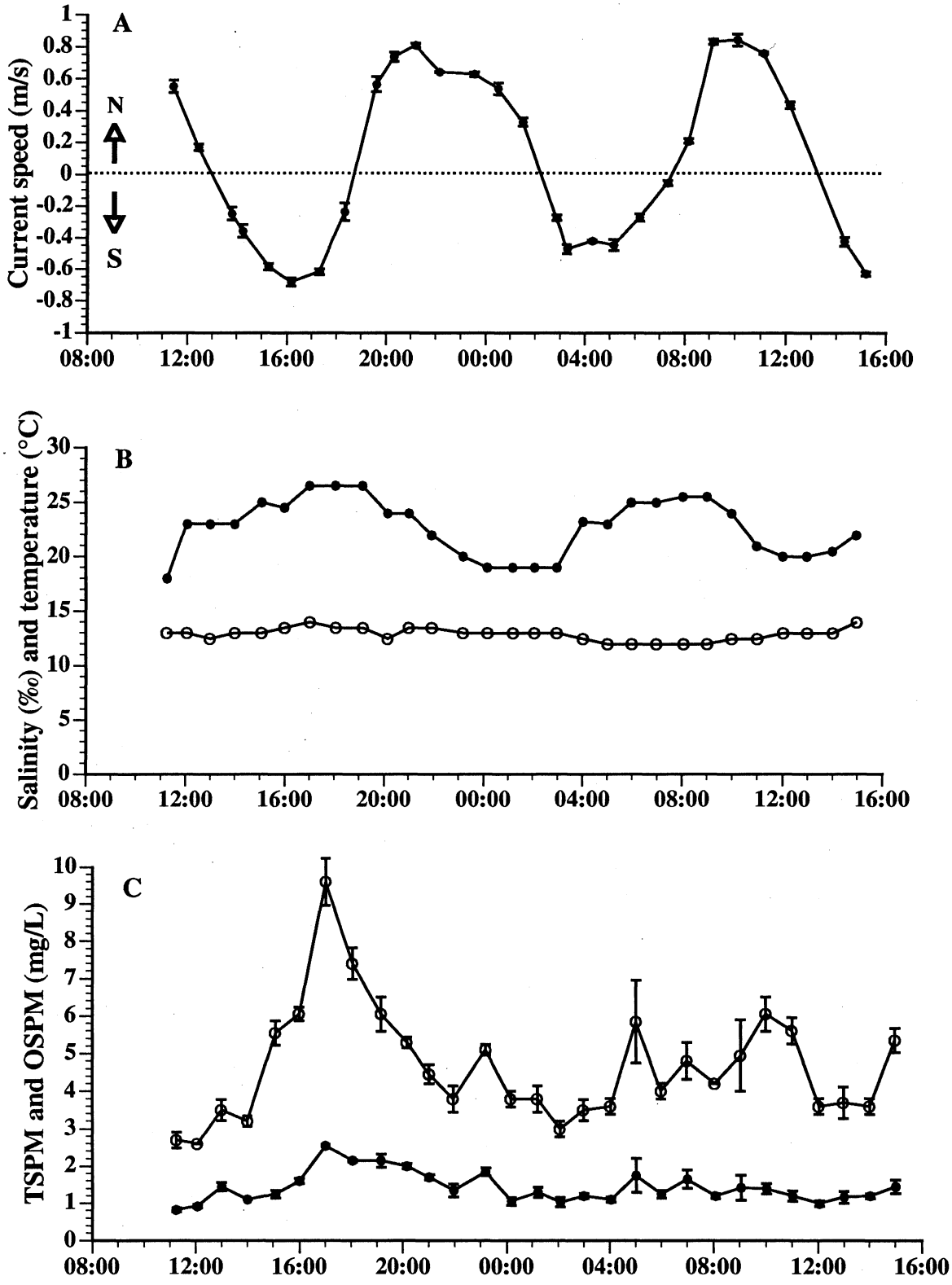

Figure 4. Water quality and current speed, as measured hourly for 28 hours, in Swinomish Channel under the Highway 20 bridge on May 20 and 21, 1992. A: Surface current speed (m/s) and direction (north is positive, south negative), mean ± s.e. (n=3). B: Salinity (solid circles) and temperature (open circles). C: Total suspended particulate matter (open circles) and organic suspended particulate matter (solid circles), mean ± s.e. (n=2).

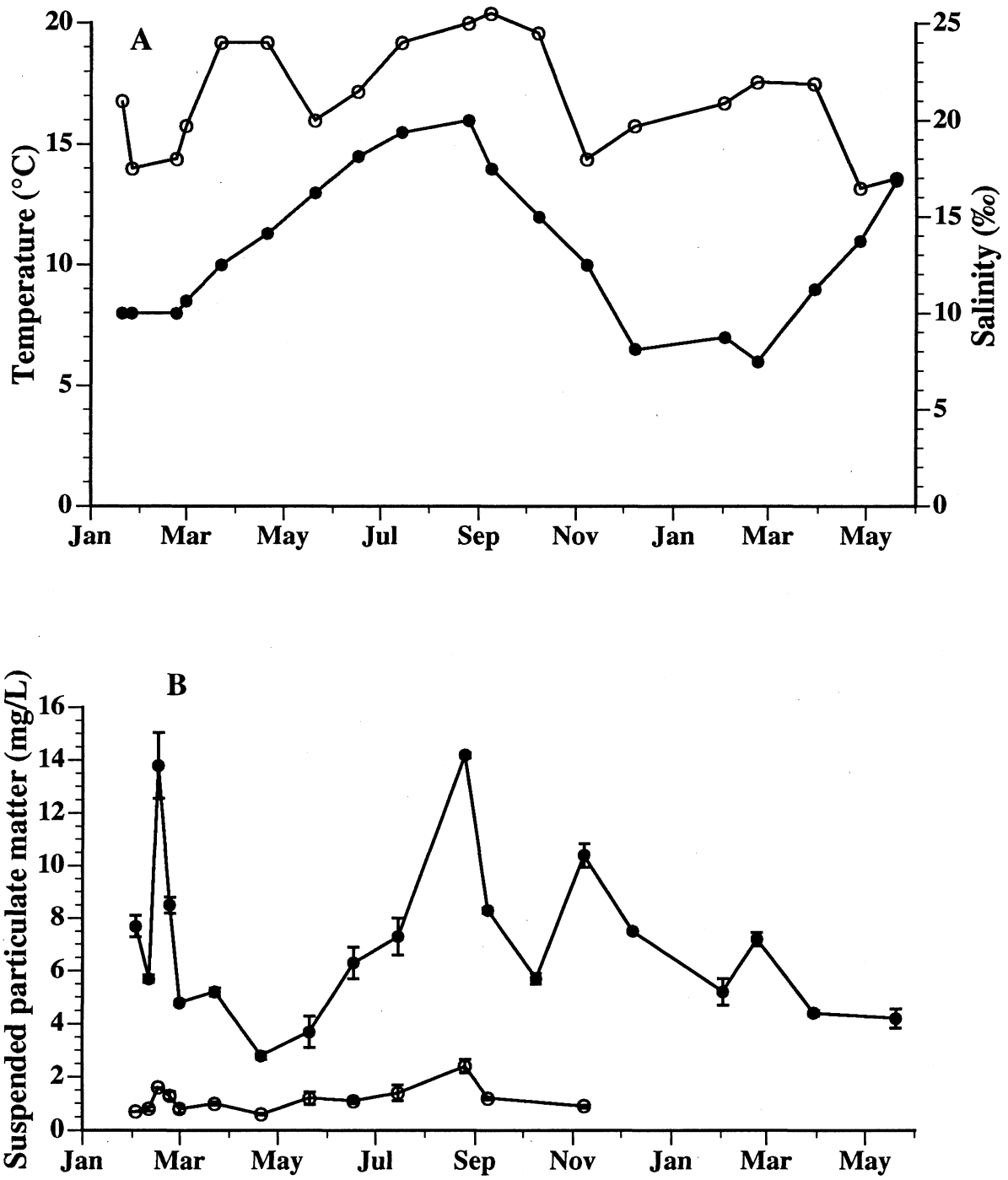

Figure 5. Water quality in the Swinomish Channel under the Highway 20 bridge from January 1992 to May 1993. A: Temperature (solid circles) and salinity (open circles). B: Mean and s.e. (n=2) for total suspended particulate matter (solid circles) and organic suspended particulate matter (open circles).

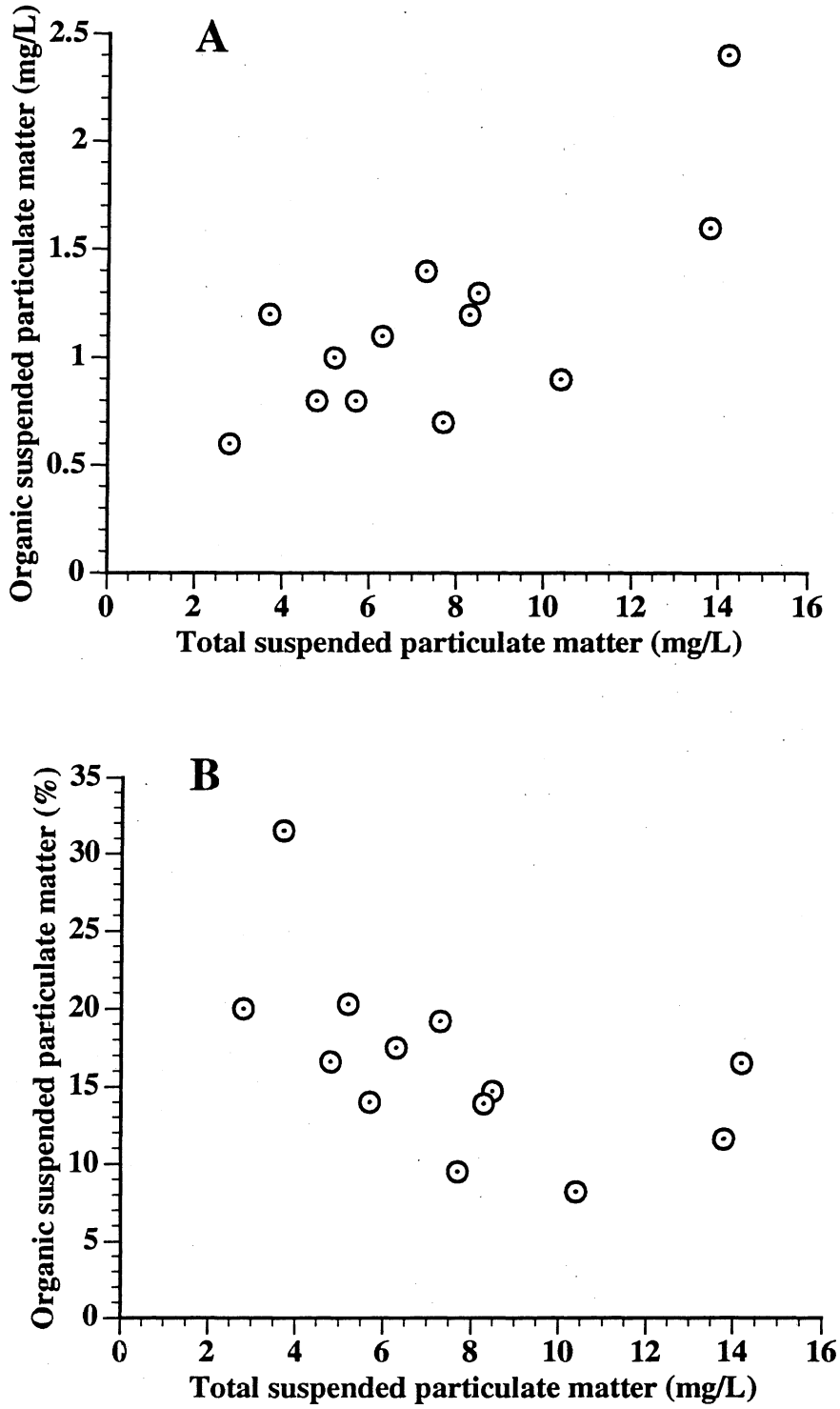

Figure 6. Total suspended particulate matter vs. organic suspended particulate matter (A) and total suspended particulate matter vs. percent of organic suspended particulate matter (B) in samples of surface water from the Swinomish Channel near the Padilla Bay entrance taken monthly from January 1992 to May 1993.

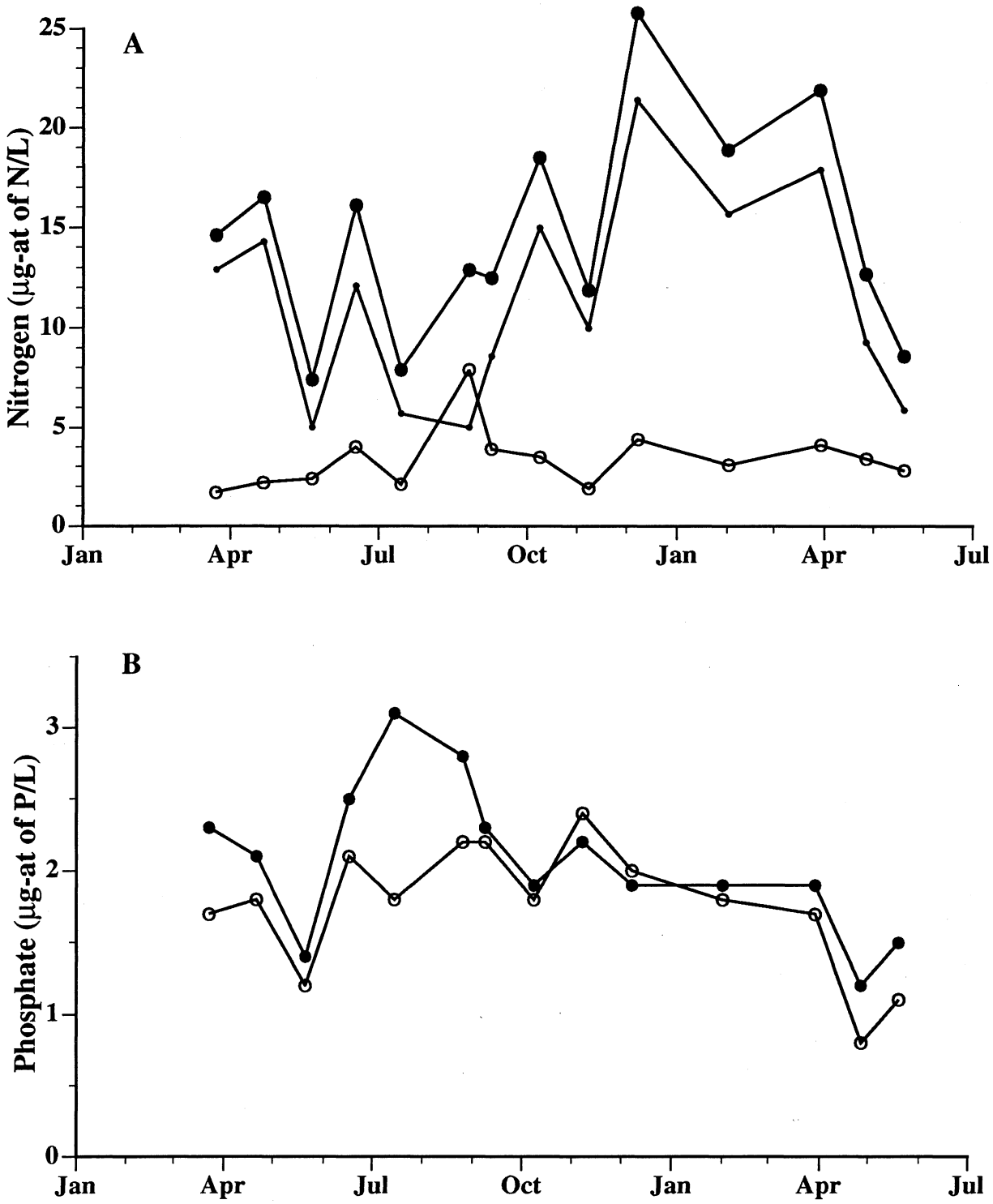

Figure 7. Concentration of some dissolved nutrients in the Swinomish Channel where it flows beneath the Highway 20 bridge from March 1992 to May 1993. A: Nitrate plus nitrite (•), ammonium (o), and total inorganic dissolved nitrogen (●). B: Total phosphate (●) and orthophosphate (o).

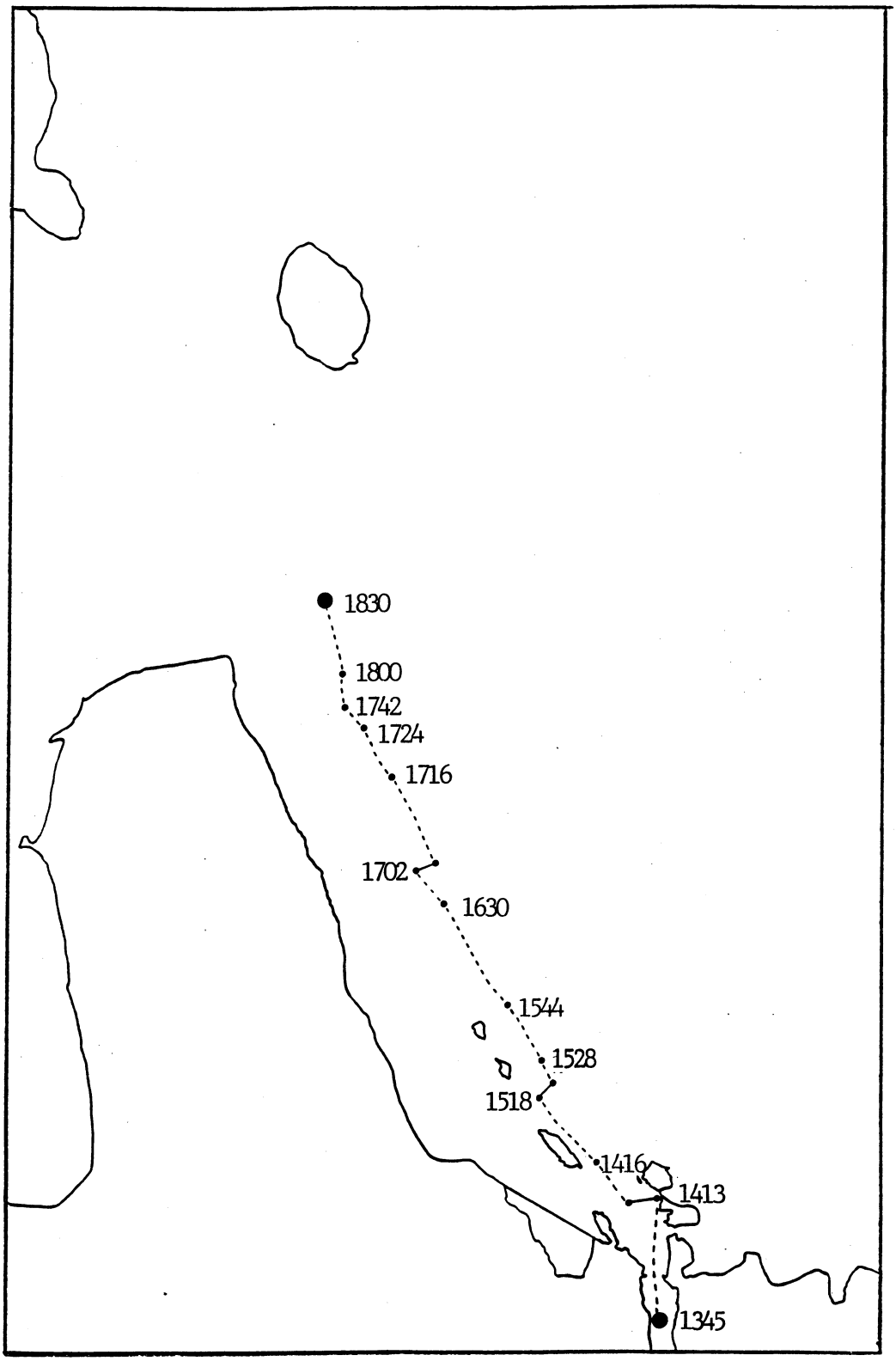

Figure 8. Movement of drift stick #7 from the time of deployment at 1345 on October 5, 1992 until it was retrieved at 1830. Times indicate when the drift stick was at the associated location. Dashed lines indicate the inferred movement between locations. Solid lines indicate where the stick became stranded on intertidal flats by the receding tide and where it was moved back in the Padilla Bay portion of the Swinomish Channel.

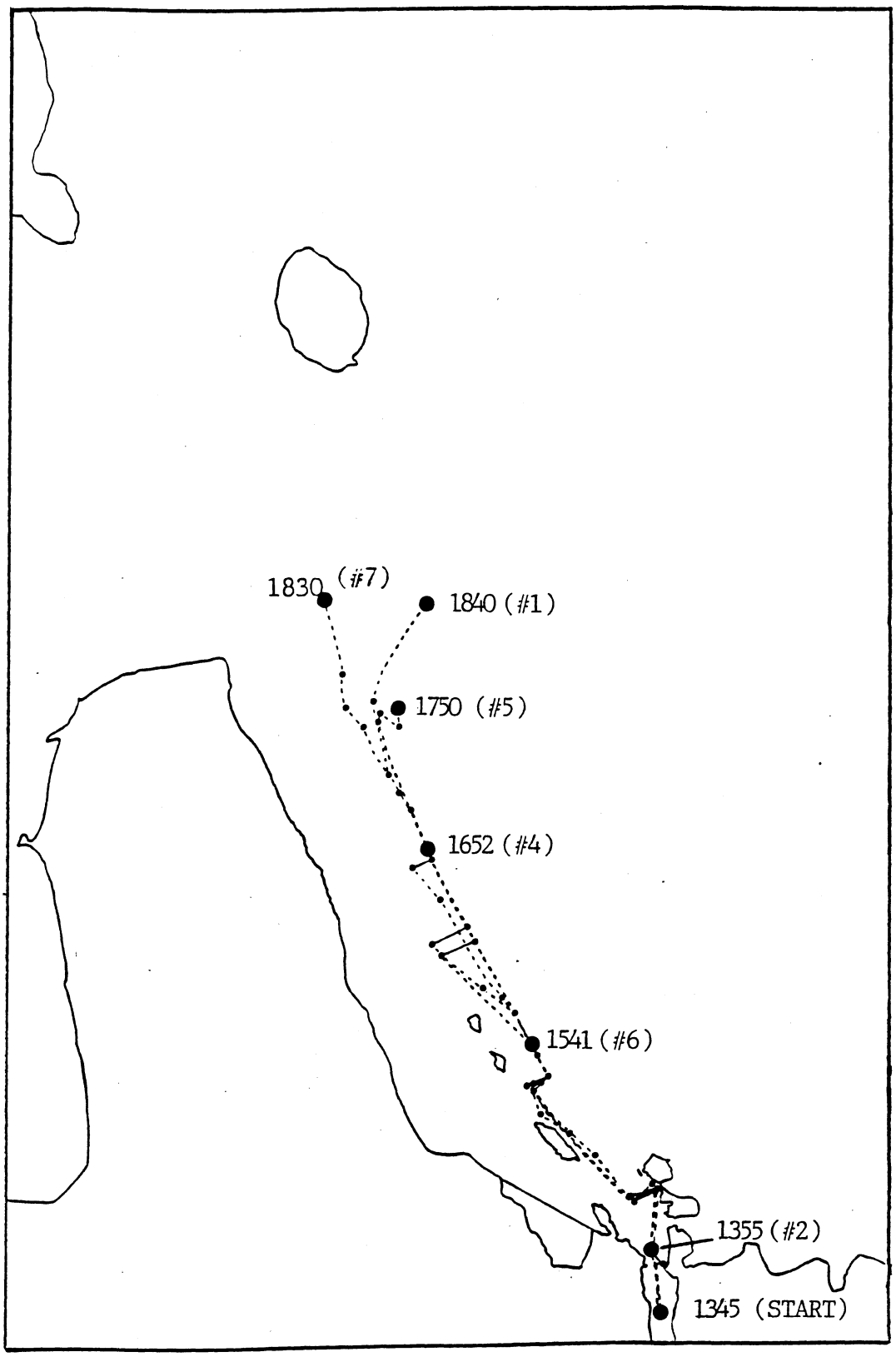

Figure 9. Movement of drift sticks #1 to #7 (there was no #3) from the time of deployment at 1345 on October 5, 1992 until each stick was retrieved. Times indicate when the drift stick was retrieved at the associated location. Dashed lines indicate inferred movement between locations. Solid lines indicate where the stick became stranded on intertidal flats by the receding tide and where it was moved back into the Padilla Bay portion of the Swinomish Channel.

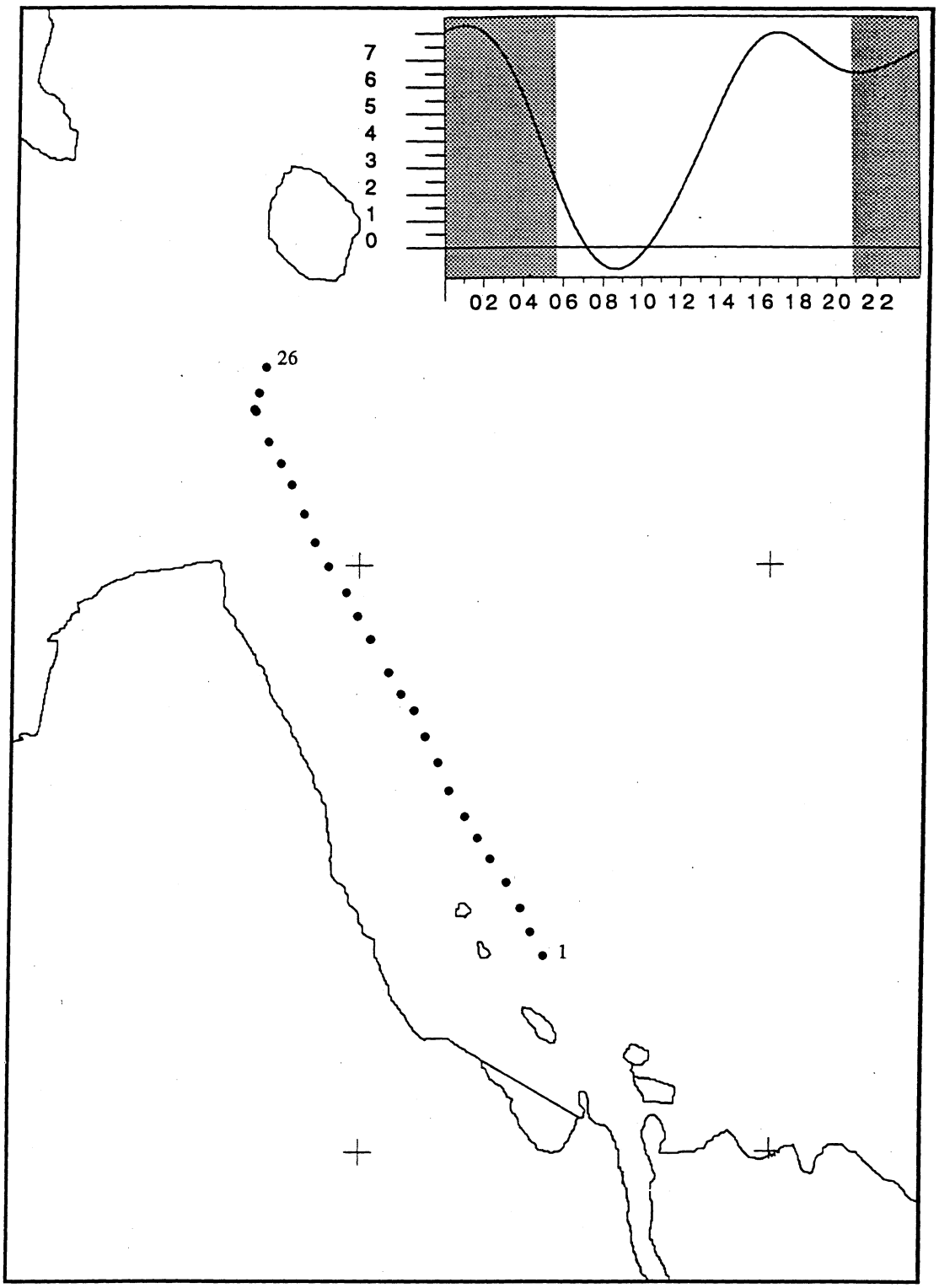

Figure 10. Locations that drift sticks were deployed on July 29, 1993 between 9:24 am (#1) and 9:47 am (#26) at the beginning of a flood tide (LLW in Swinomish Channel was predicted for 8:58 am). Drift sticks were numbered from #1 at the southern end to #26 at the northern end.

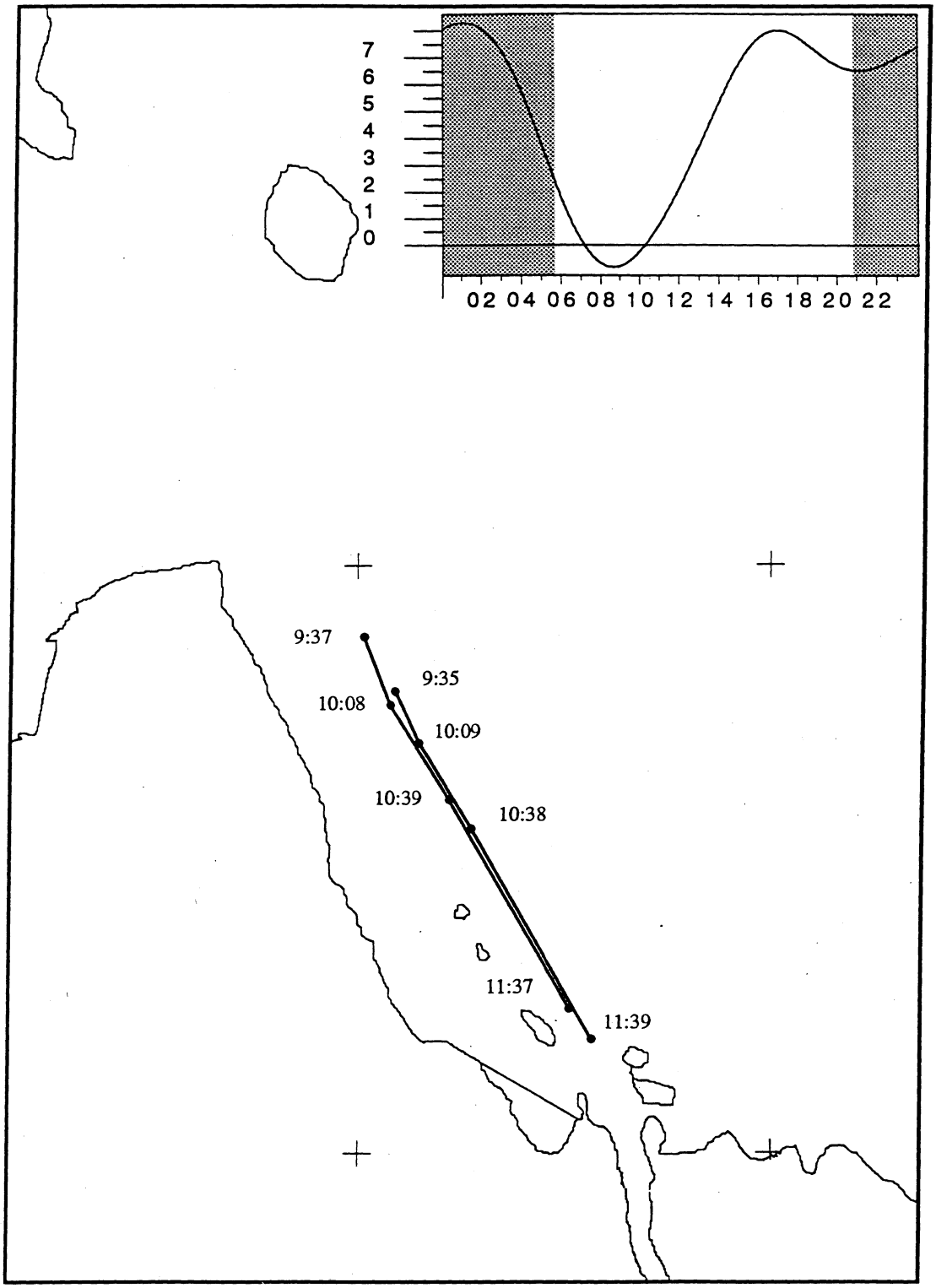

Figure 11. Movement of drift sticks 12 and 14 in Padilla Bay on July 29, 1993. Lines connect the different locations of the individual drift sticks. Drift sticks 12 and 14 were deployed at 9:35 and 9:37 am respectively. The times indicate when each drift stick was relocated; the dots indicate the measured lattitude and longitude at that time.

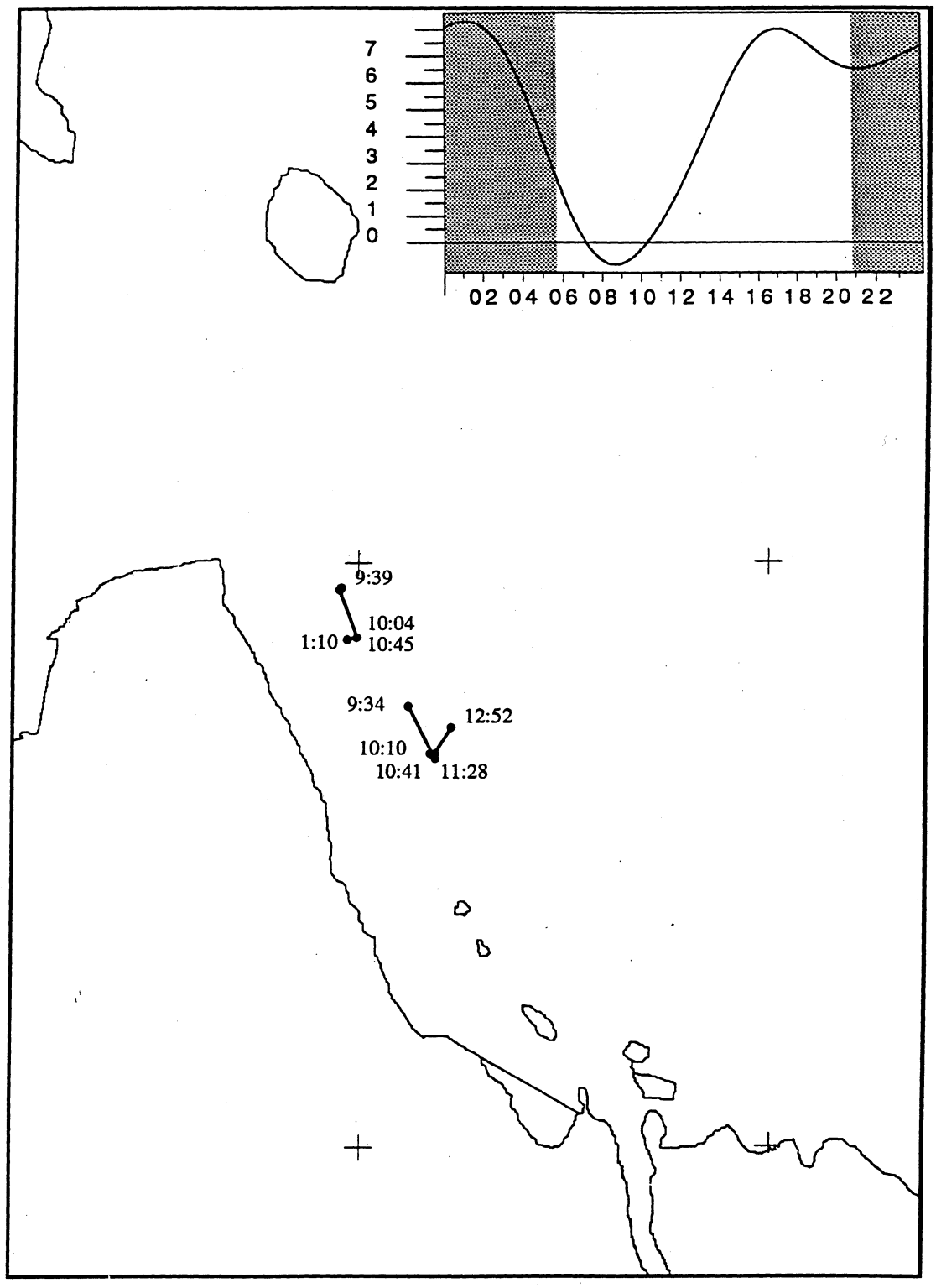

Figure 12. Movement of drift sticks 11 and 16 in Padilla Bay on July 29, 1993. Lines connect the different locations of the individual drift sticks. Drift sticks 11 and 16 were deployed at 9:34 and 9:39 am respectively. The times indicate when each drift stick was relocated; the dots indicate the measured latitude and longitude at that time.

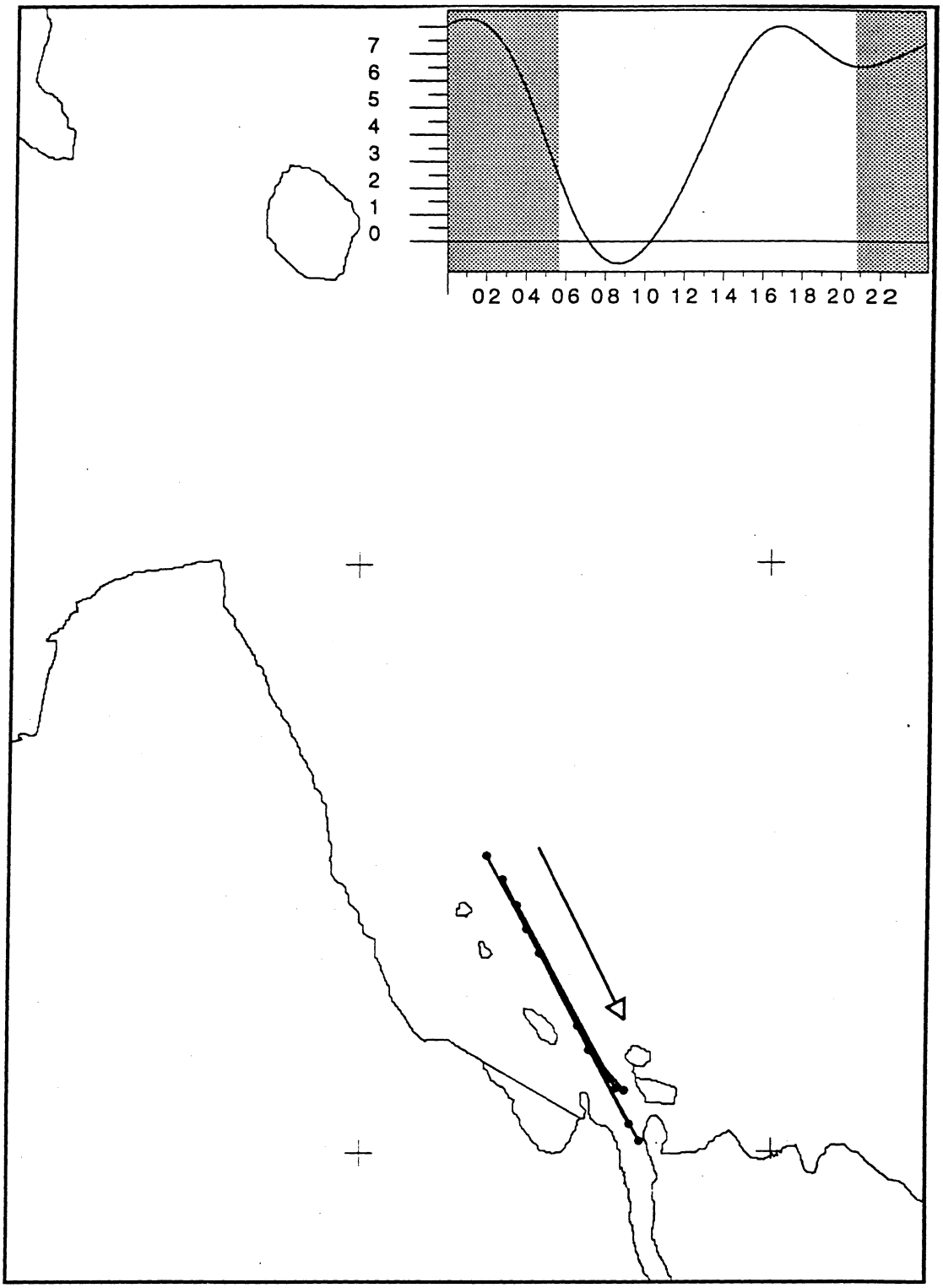

Figure 13. Movement of drift sticks 1 through 5 in Padilla Bay on July 29, 1993 (LLW in Swinomish Channel was predicted for 8:58 am). Lines connect the different locations of the individual drift sticks. The first stick was deployed at 9:24 am and the last of the five sticks retrieved at 10:31 am. All drift sticks moved south in the Swinomish Channel.

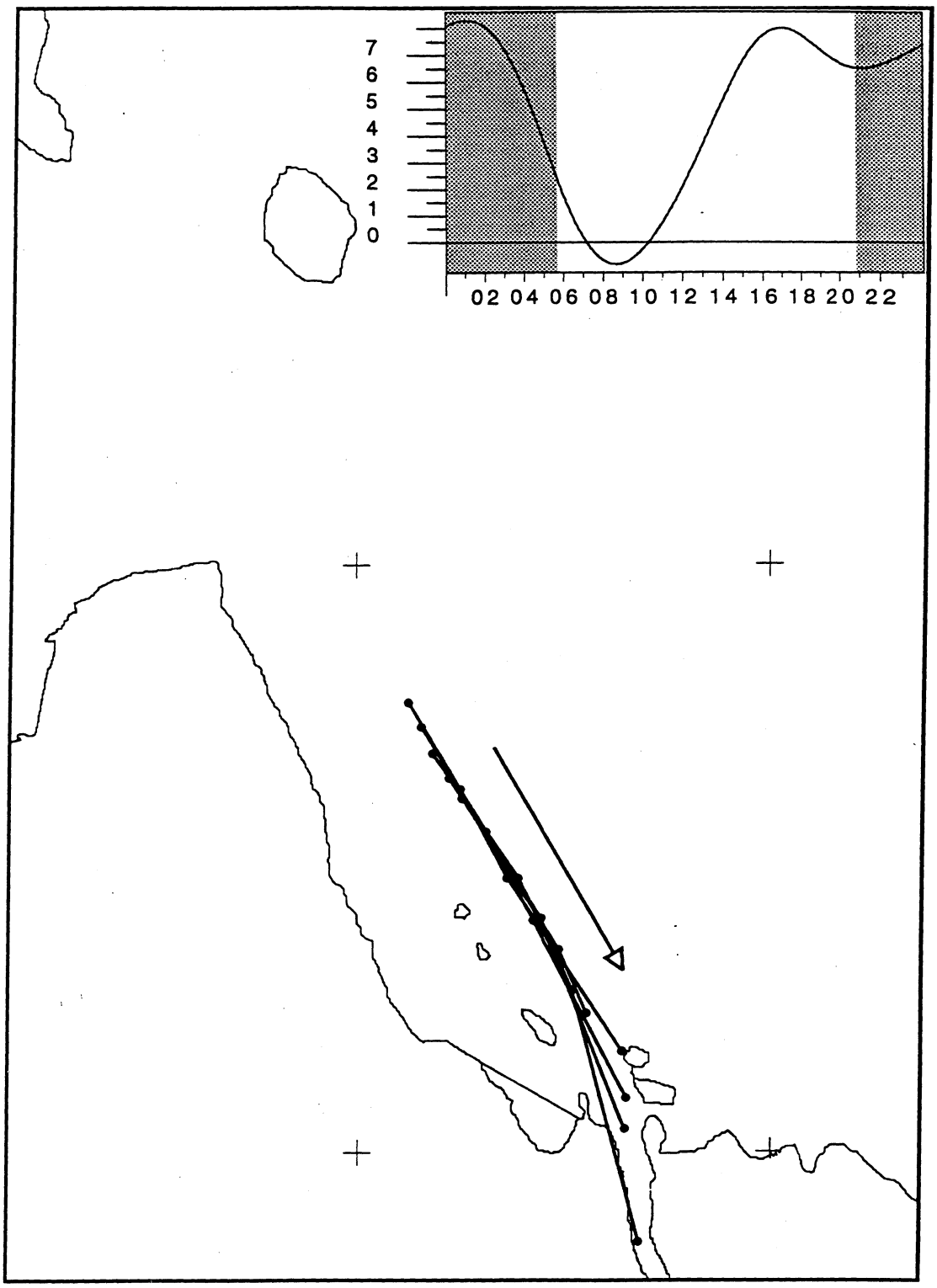

Figure 14. Movement of drift sticks 6 through 10 in Padilla Bay on July 29, 1993 during a flooding tide (LLW in Swinomish Channel was predicted for 8:58 am). Lines connect the different locations of the individual drift sticks. The first stick was deployed at 9:29 am and the last of the five sticks retrieved at 12:10 pm. All drift sticks moved south in the Swinomish Channel.

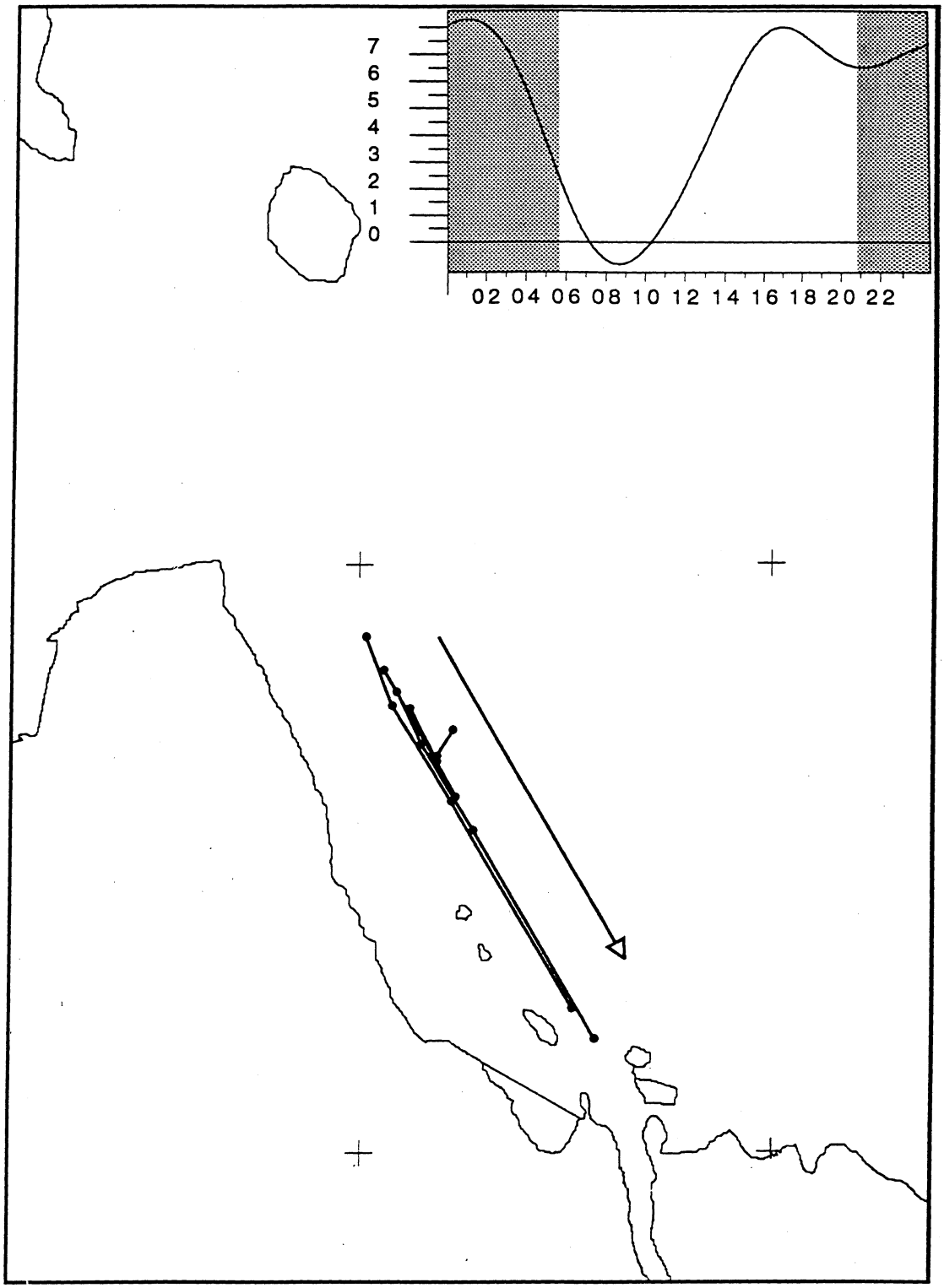

Figure 15. Movement of drift sticks 11 through 14 in Padilla Bay on July 29, 1993 during a flooding tide (LLW in Swinomish Channel was predicted for 8:58 am, HHW for 4:39 pm). Lines connect the different locations of the individual drift sticks. The first stick was deployed at 9:34 am and the last of the four sticks retrieved at 12:52 pm.

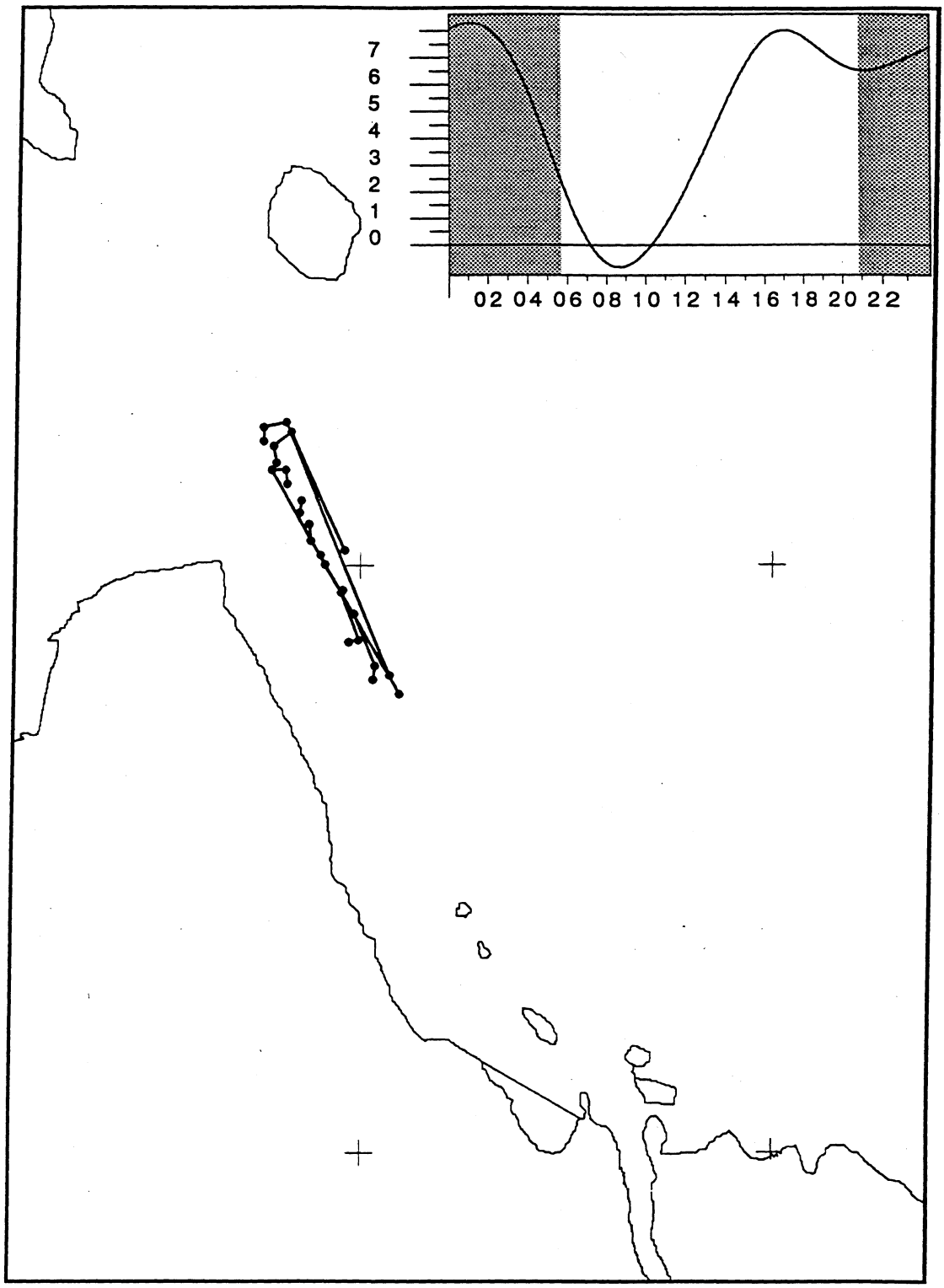

Figure 16. Movement of drift sticks 15 through 22 in Padilla Bay on July 29, 1993 during a flooding tide (LLW in Swinomish Channel was predicted for 8:58 am, HHW for 4:39 pm). Lines connect the different locations of the individual drift sticks. The first stick was deployed at 9:38 am and the last of the eight sticks retrieved at 1:20 pm.

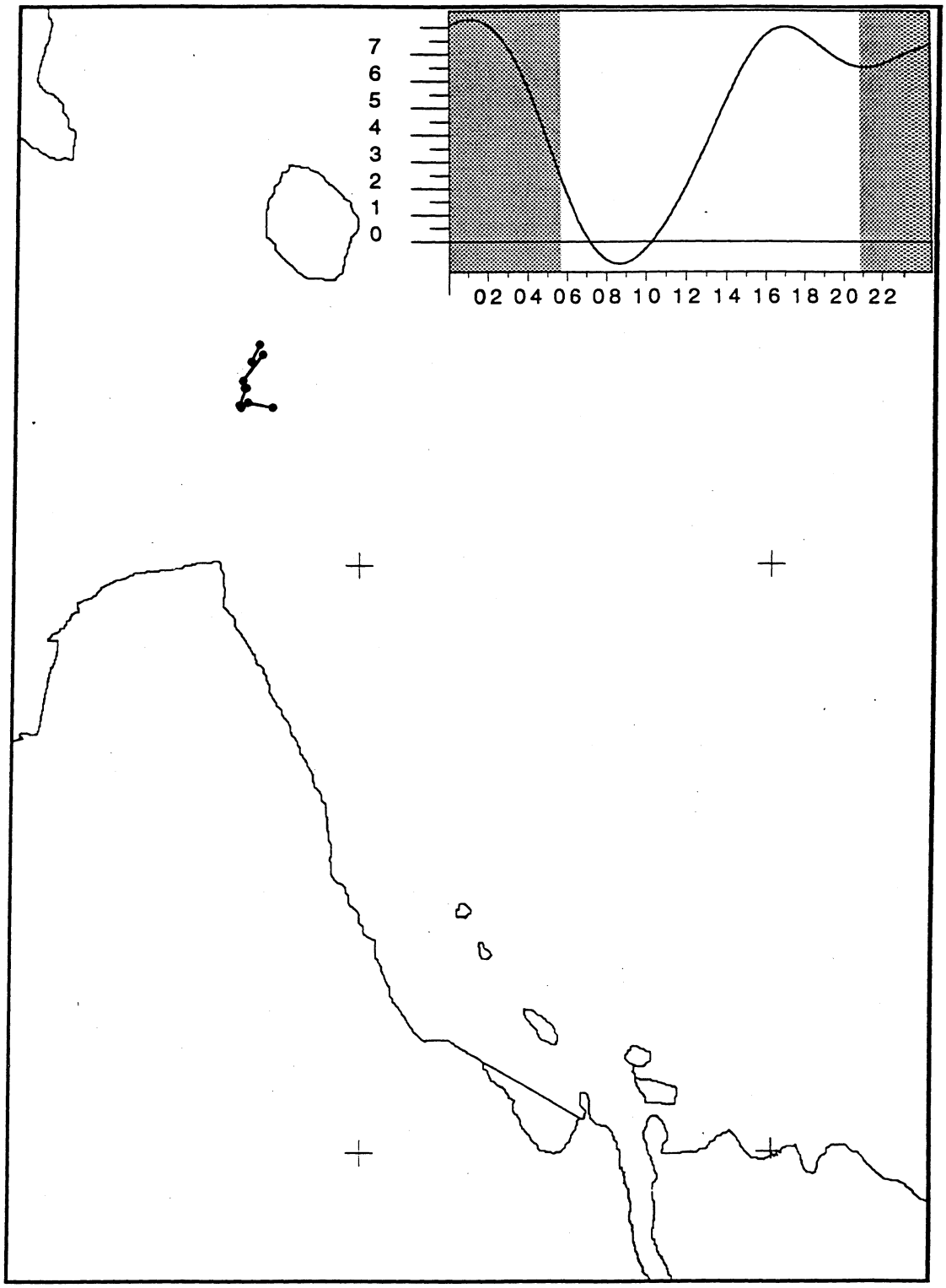

Figure 17. Movement of drift sticks 23 through 26 in Padilla Bay on July 29, 1993 during a flooding tide (LLW in Swinomish Channel was predicted for 8:58 am, HHW for 4:39 pm). Lines connect the different locations of the individual drift sticks. The first stick was deployed at 9:45 am and the last of the four sticks retrieved at 11:06 am.

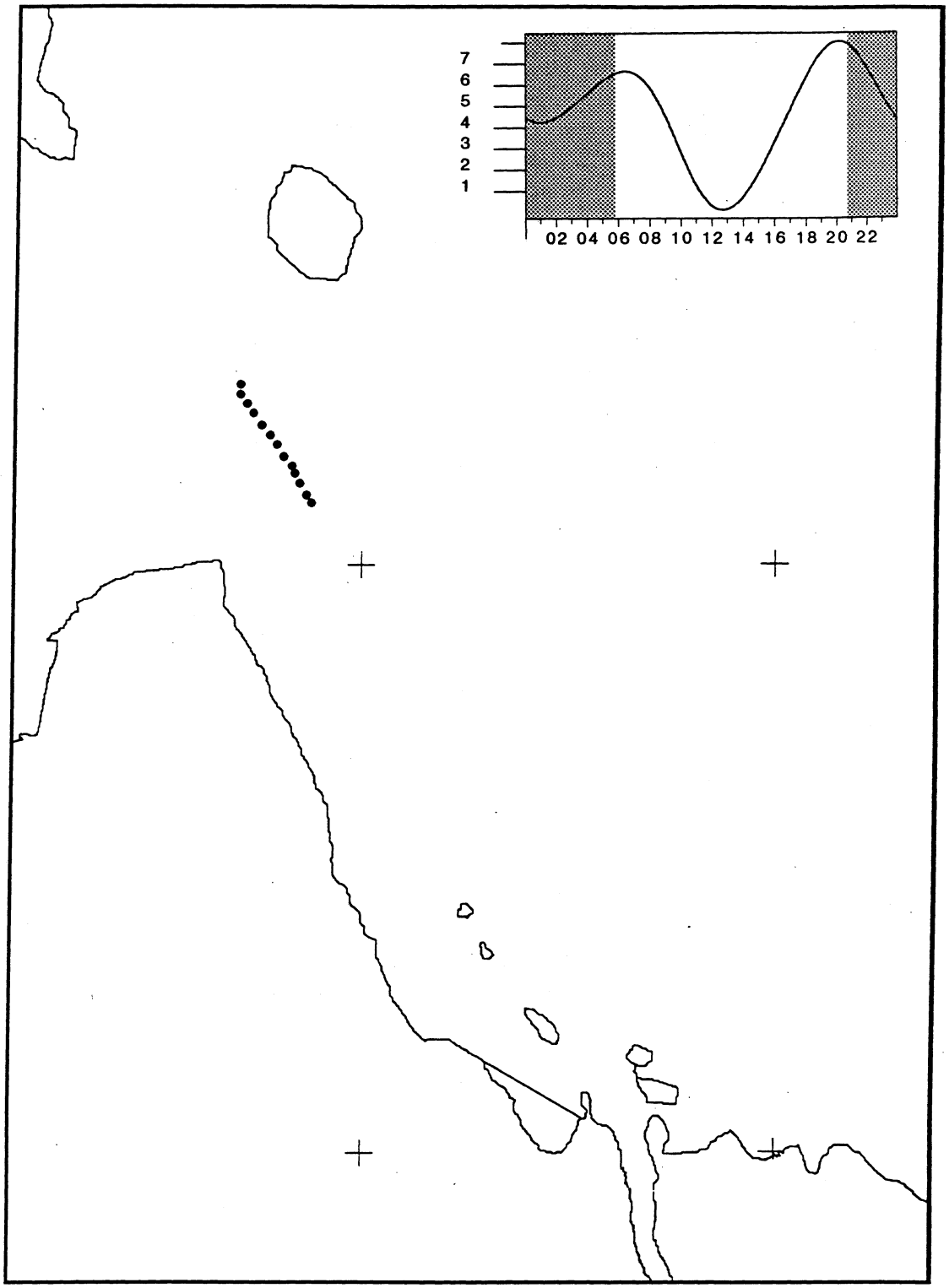

Figure 18. Locations that drift sticks were deployed at the northern end of Swinomish Channel on August 4, 1993 (drogue trial #3) between 12:07 pm and 12:13 pm at the beginning of a flood tide (LLW in Swinomish Channel was predicted for 1:00 pm, HHW for 7:46 pm).

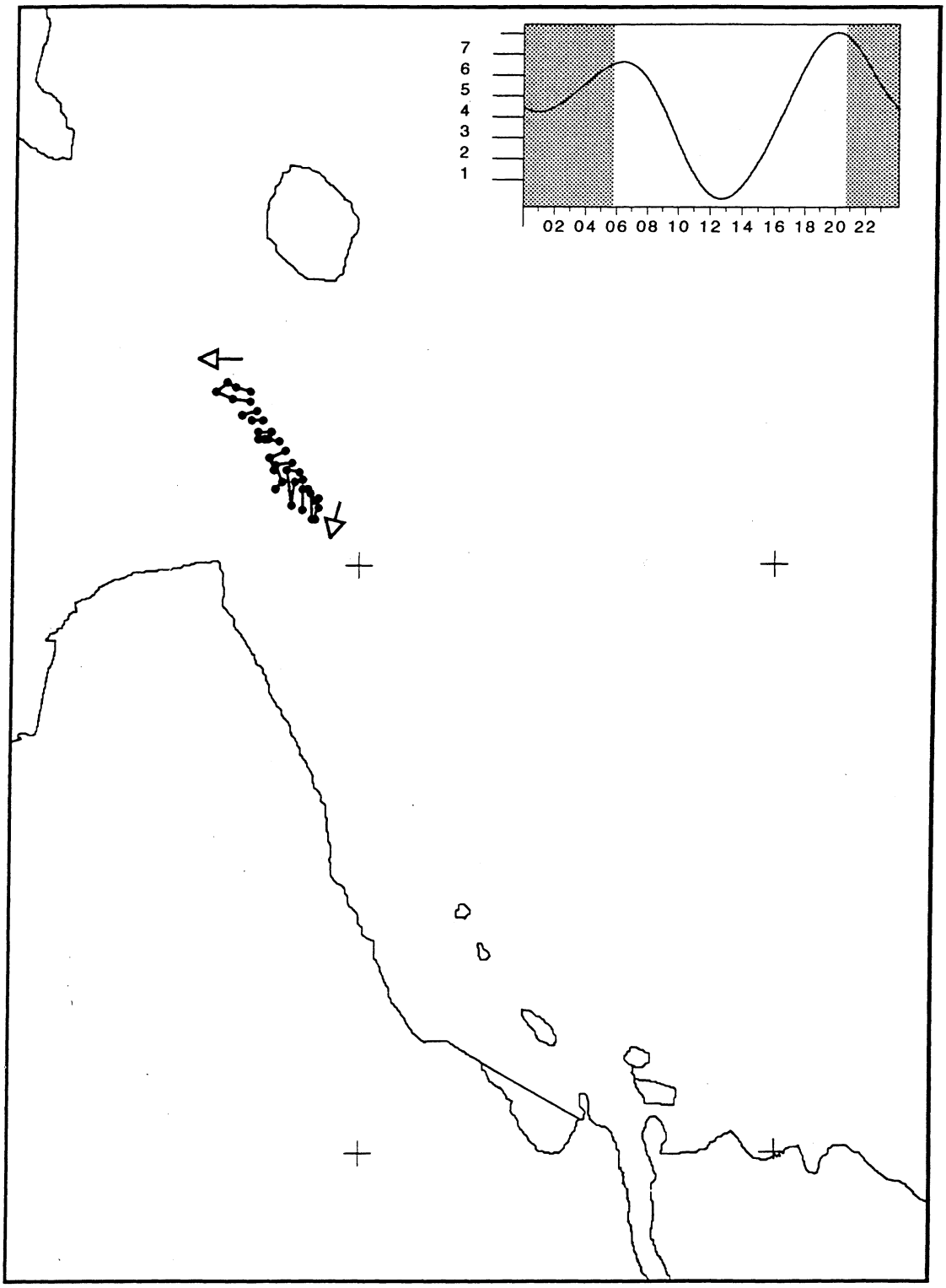

Figure 19. Movement of drift sticks during drogue trial #3 during the first hour after deployment (12:07 to 12:13) and before predicted LLW (1:00 pm) in Swinomish Channel on August 4, 1993. Lines connect the different locations of the individual drift sticks.

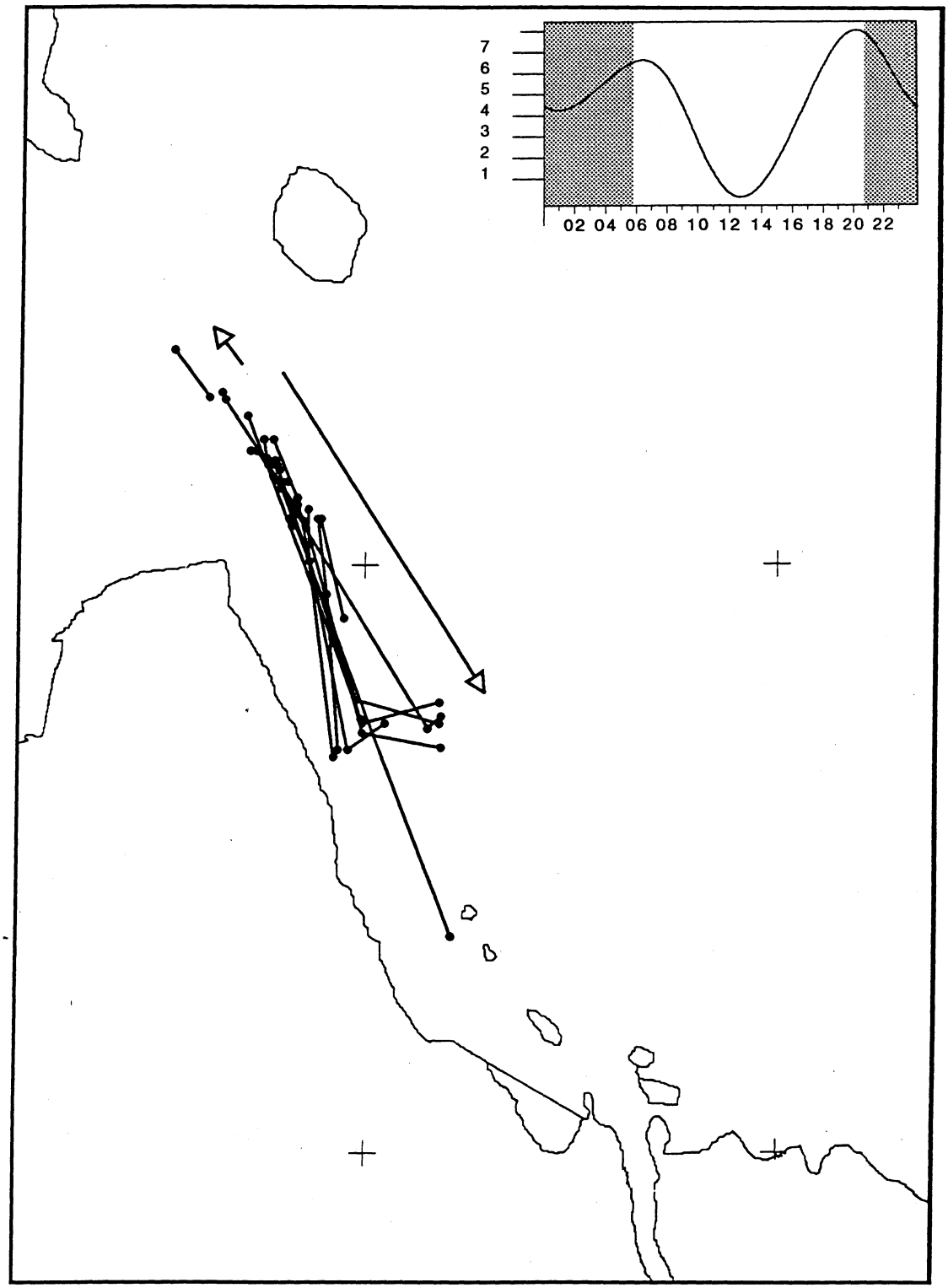

Figure 20. Movement of drift sticks after LLW in drogue trial #3 on August 4, 1993 during a flooding tide (LLW in Swinomish Channel was predicted for 1:00 pm, HHW for 7:46 pm). Lines connect the different locations of the individual drift sticks. The last drift stick was retrieved at 8:33 pm. One stick travelled northwest, the rest of the sticks travelled southeast.

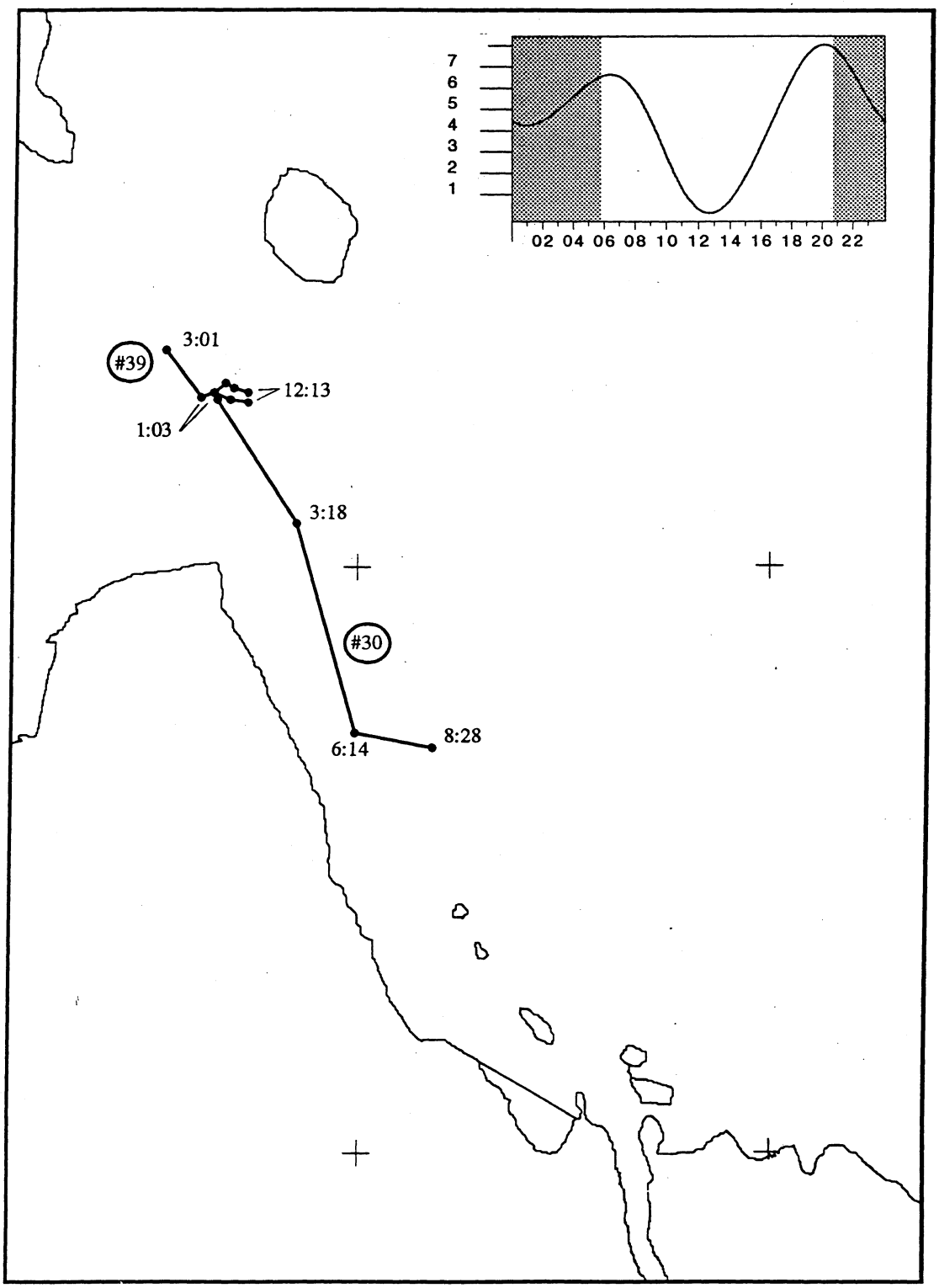

Figure 21. Movement of drift sticks #30 and #39 in drogue trial #3 on August 4, 1993 during a flooding tide (LLW in Swinomish Channel was predicted for 1:00 pm, HHW for 7:46 pm). Both sticks were deployed within 30 seconds of each other at 12:13 pm. Lines connect the different locations of the individual drift sticks, times indicate when the sticks were at the associated locations.

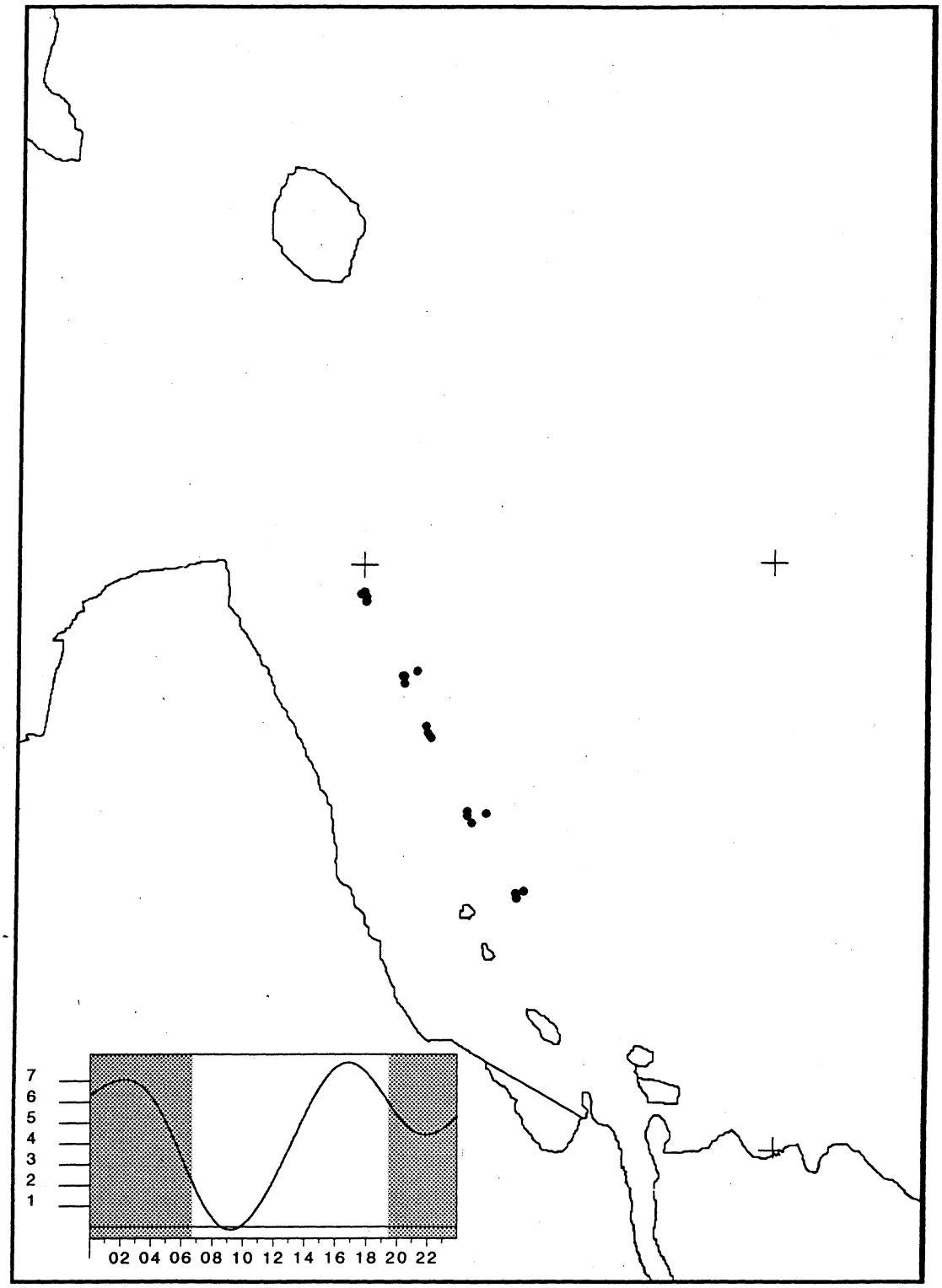

Figure 22. Locations that drift sticks were deployed during the later part of a flooding tide in the Padilla Bay portion of the Swinomish Channel on September 13, 1993 (drogue trial #4). At each of five sites a drift stick was released at 1:00 pm, 2:00 pm, 3:00 pm, and 4:00 pm (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm).

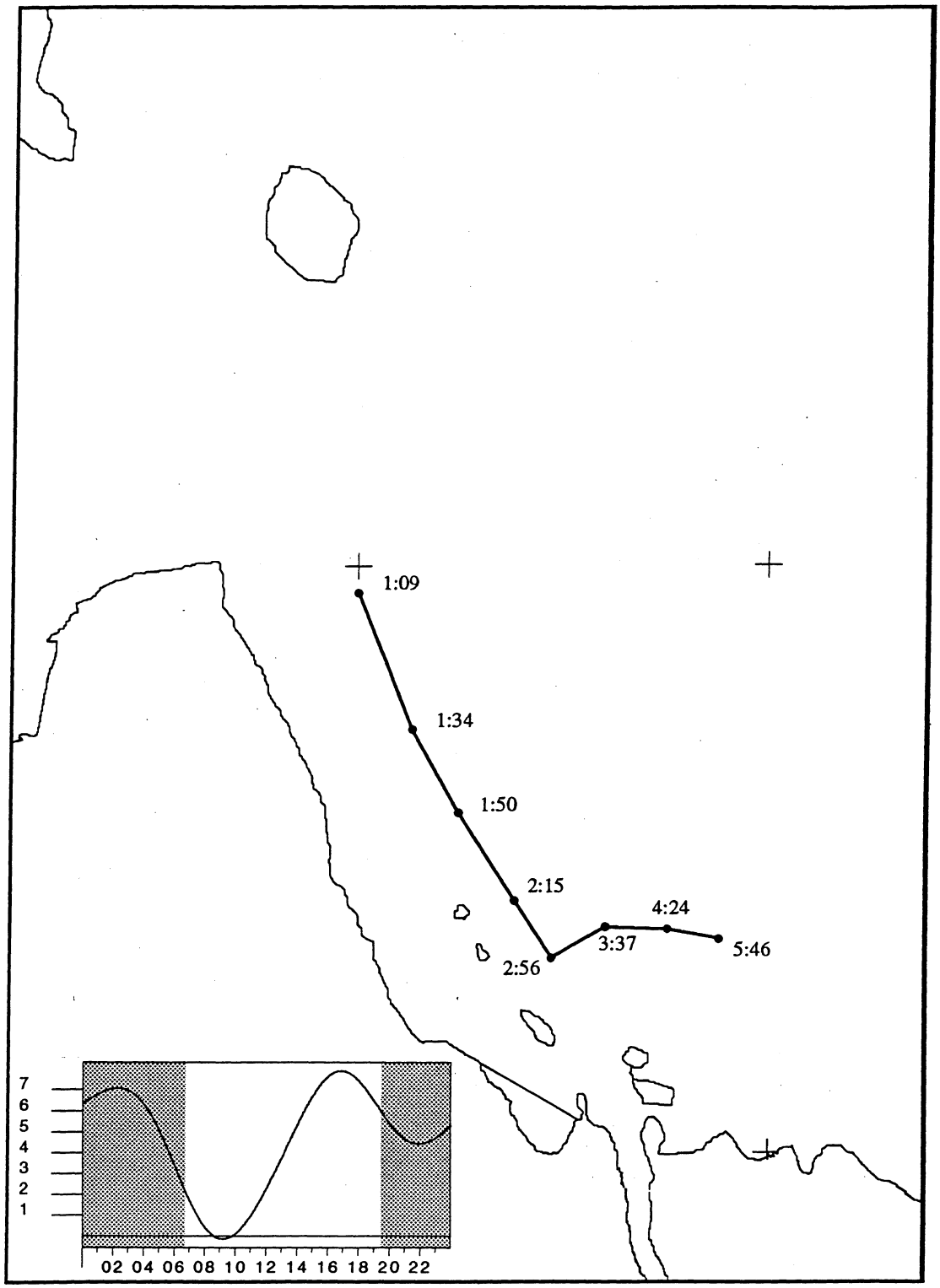

Figure 23. Movement of drift stick #24 in drogue trial #4 on September 13, 1993 during the later part of a flooding tide (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm). Times indicate when the drift stick was at the indicated latitude and longitude.

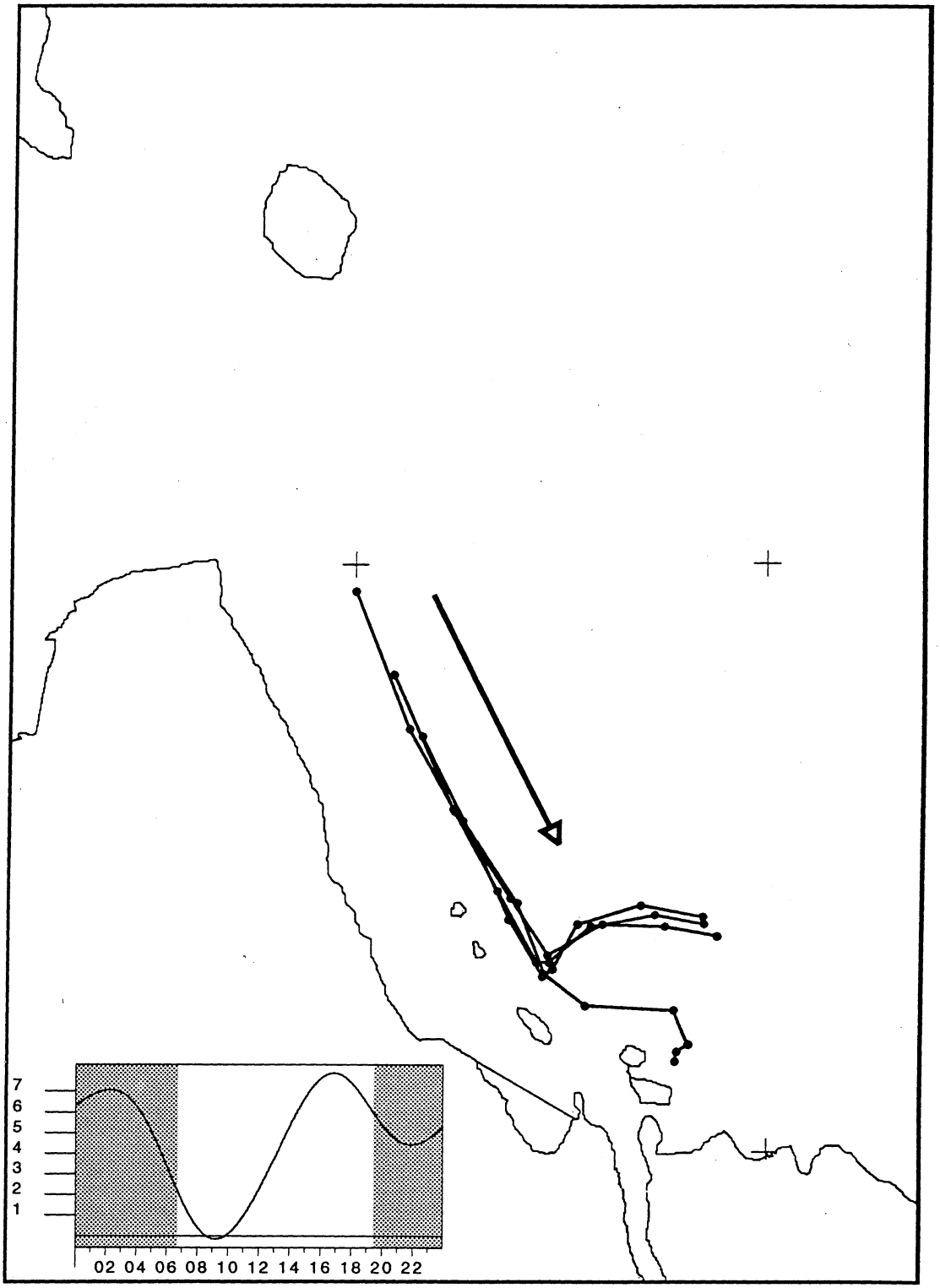

Figure 24. Movement of drift sticks 21-24 that were released at about 1:00 pm on September 13, 1993 (drogue trial #4) during the later part of a flooding tide (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm). Dots indicate where the latitude and longitude of individual drift sticks was determined; lines connect the different locations of the individual drift sticks. The drift sticks were recovered (at the location of the last dot on each line) between 4:54 and 5:57 pm.

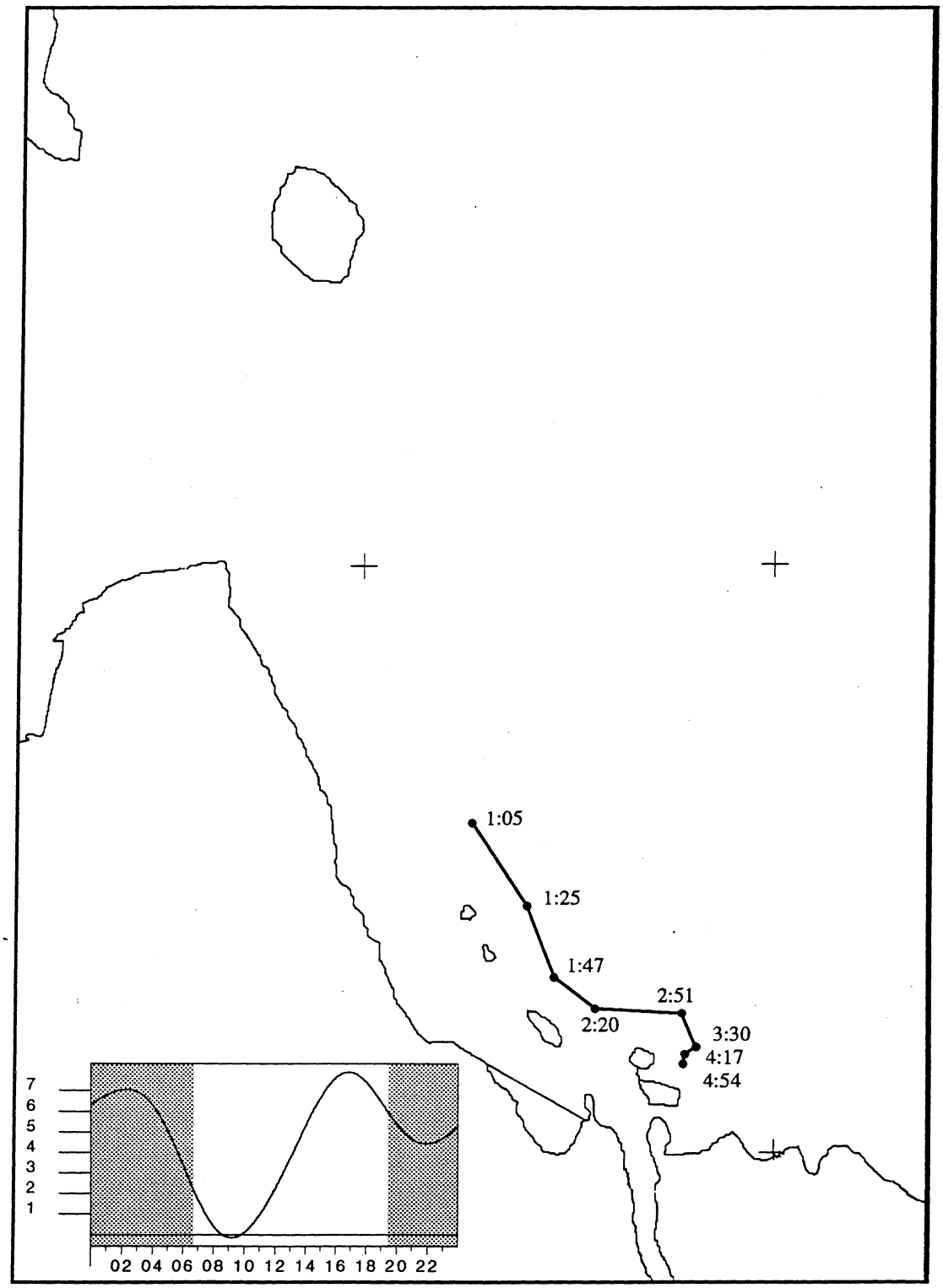

Figure 25. Movement of drift stick #21 in drogue trial #4 on September 13, 1993 during the later part of a flooding tide (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm). Times indicate when the drift stick was at the indicated latitude and longitude.

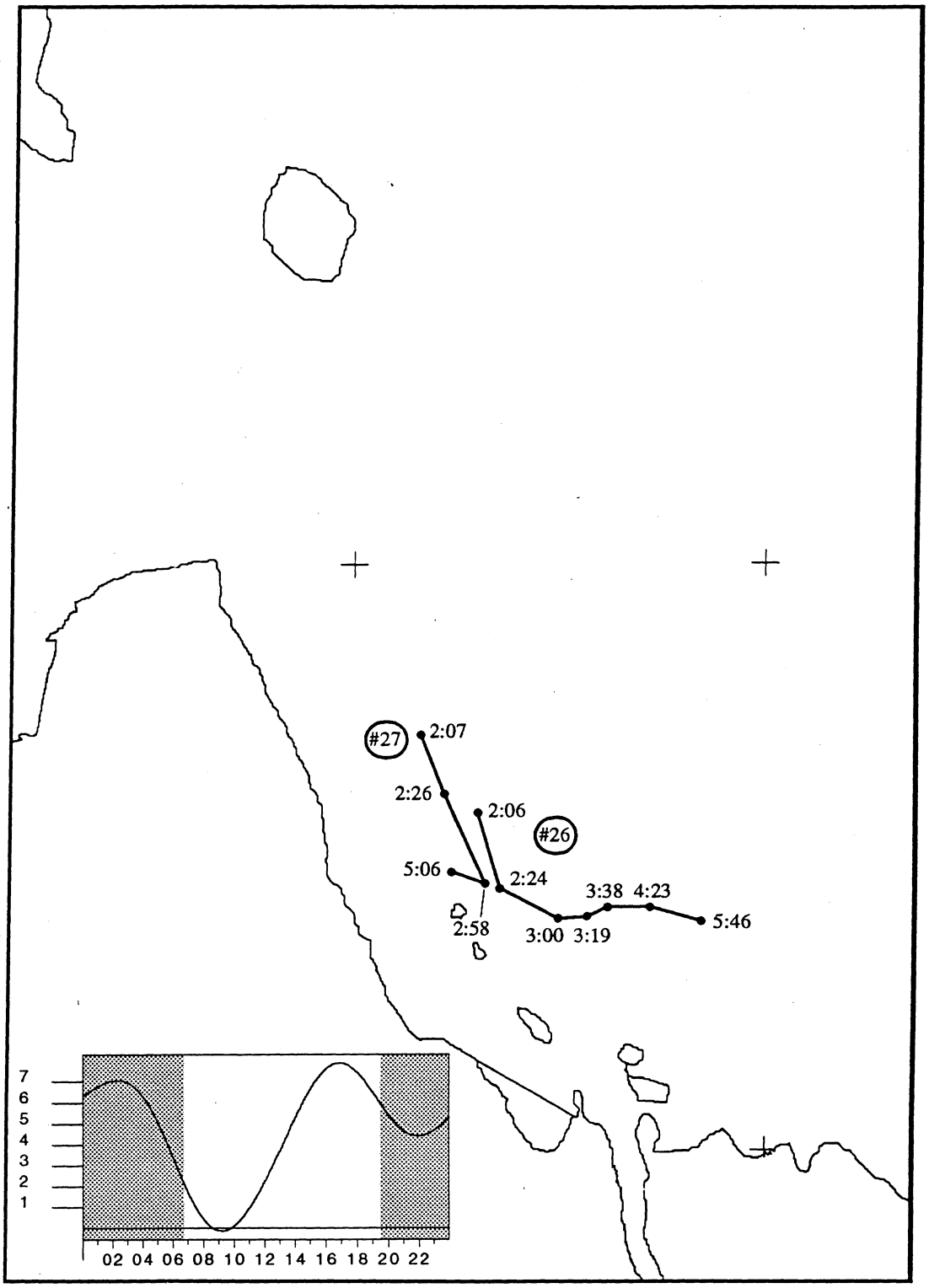

Figure 26. Movement of drift sticks 26 and 27 in drogue trial #4 on September 13, 1993 during the later part of a flooding tide (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm). Times indicate when the drift sticks were at the indicated position.

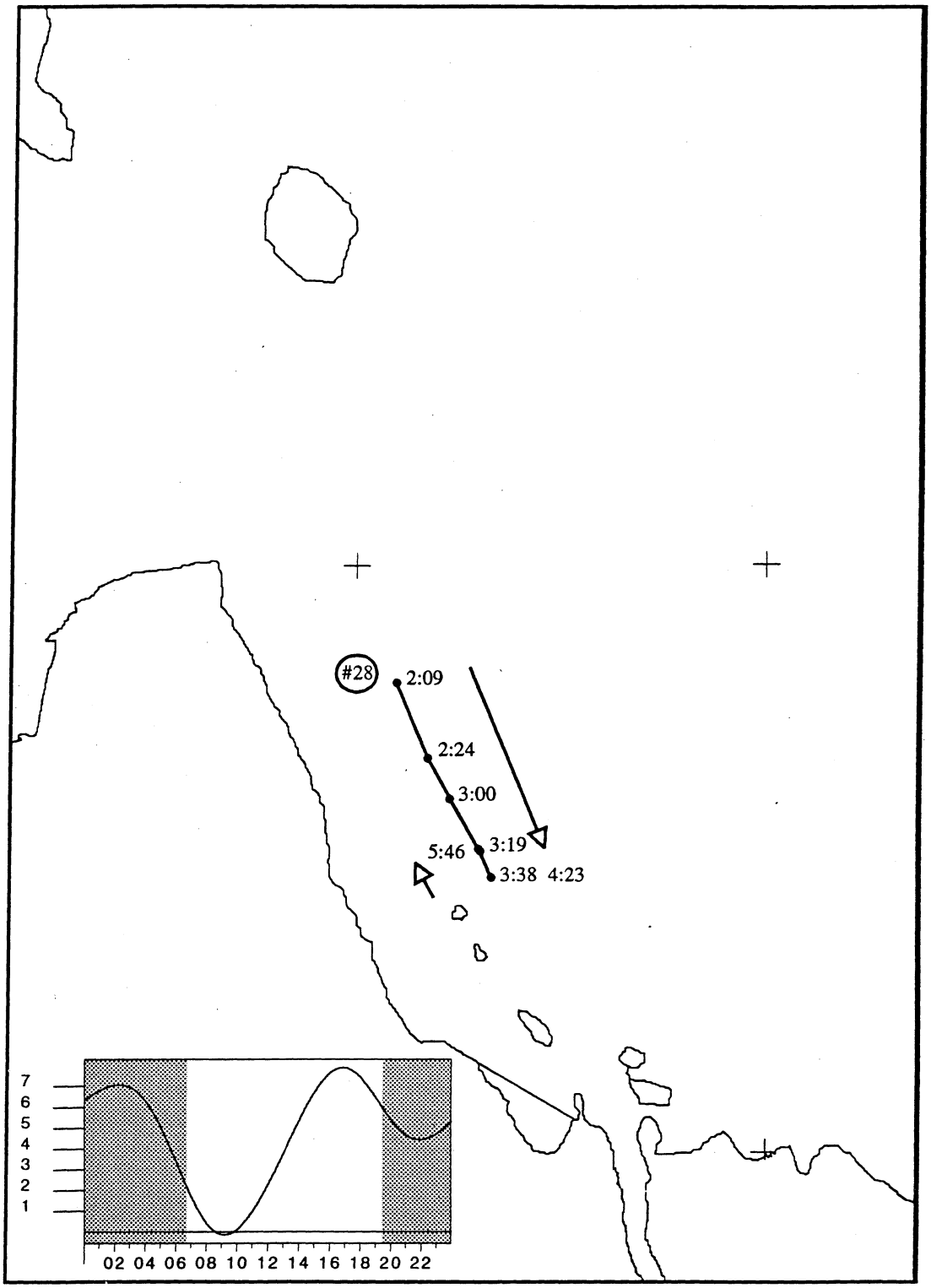

Figure 27. Movement of drift stick 28 in drogue trial #4 on September 13, 1993 during the later part of a flooding tide (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm). Times indicate when the drift stick was at the indicated position; drift stick 28 was released at 2:09 and retrieved at 5:46 pm.

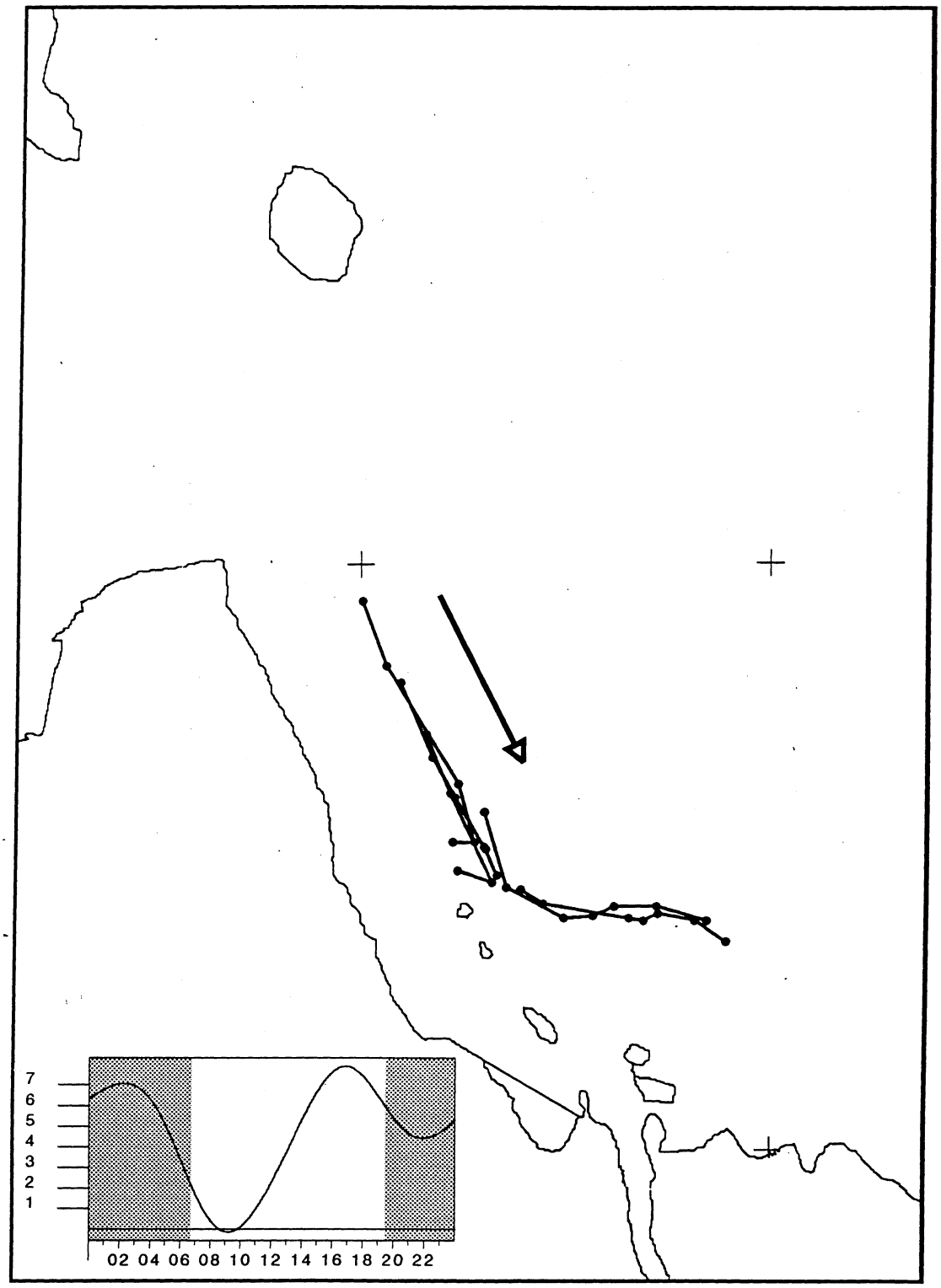

Figure 28. Movement of drift sticks 25-29 that were released at about 2:00 pm on September 13, 1993 (drogue trial #4) during the later part of a flooding tide (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm). Dots indicate where the latitude and longitude of individual drift sticks was determined; lines connect the different locations of the individual drift sticks. The drift sticks were recovered (at the location of the last dot on each line) between 4:30 and 5:47 pm.

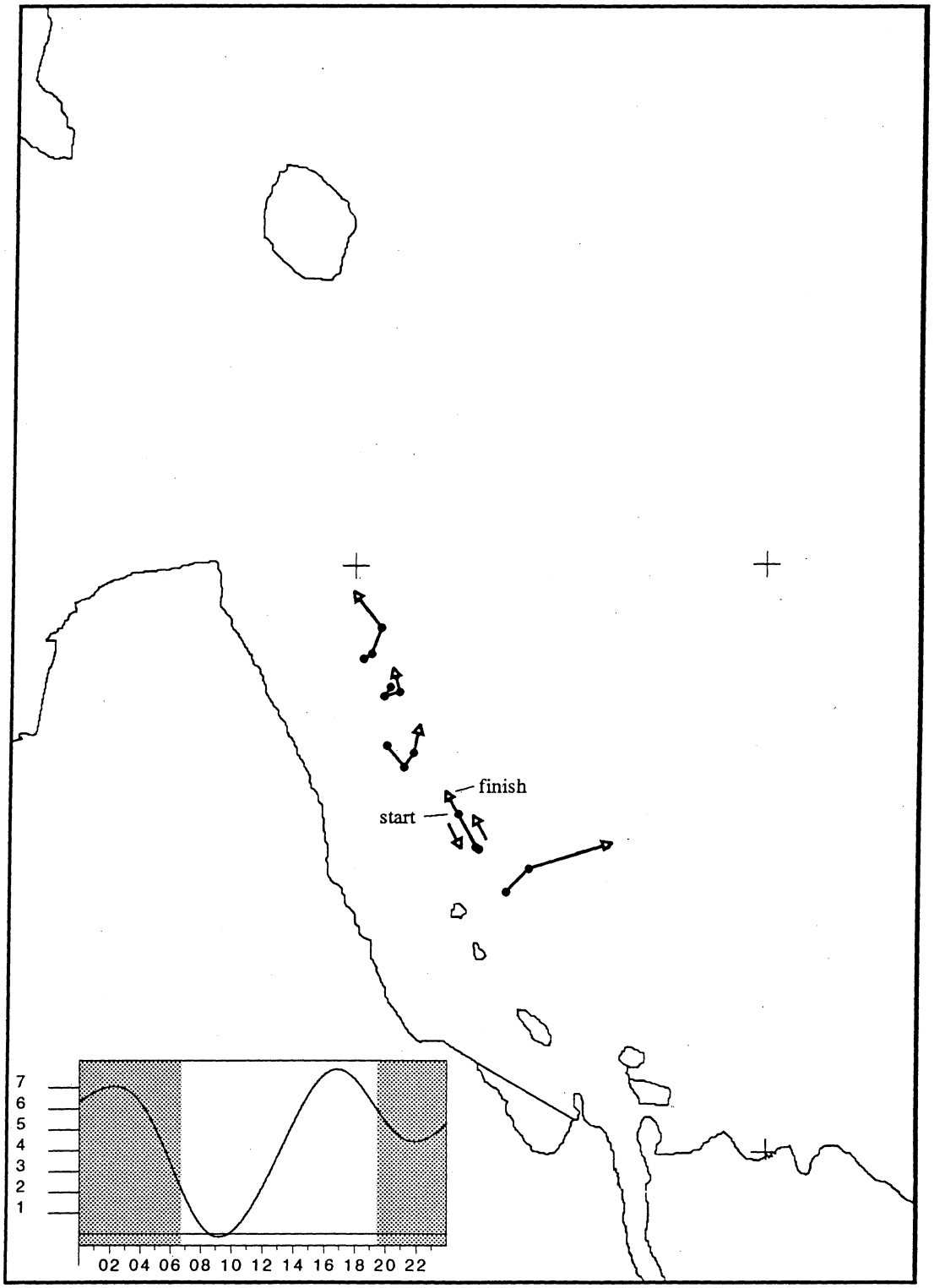

Figure 29. Movement of drift sticks 30-34 that were released at about 3:00 pm on September 13, 1993 (drogue trial #4) during the later part of a flooding tide (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm). Dots indicate where the latitude and longitude of individual drift sticks was determined; lines connect the different locations of the individual drift sticks. The drift sticks were recovered (at the location of the arrow at the end of each line) between 5:00 and 5:27 pm.

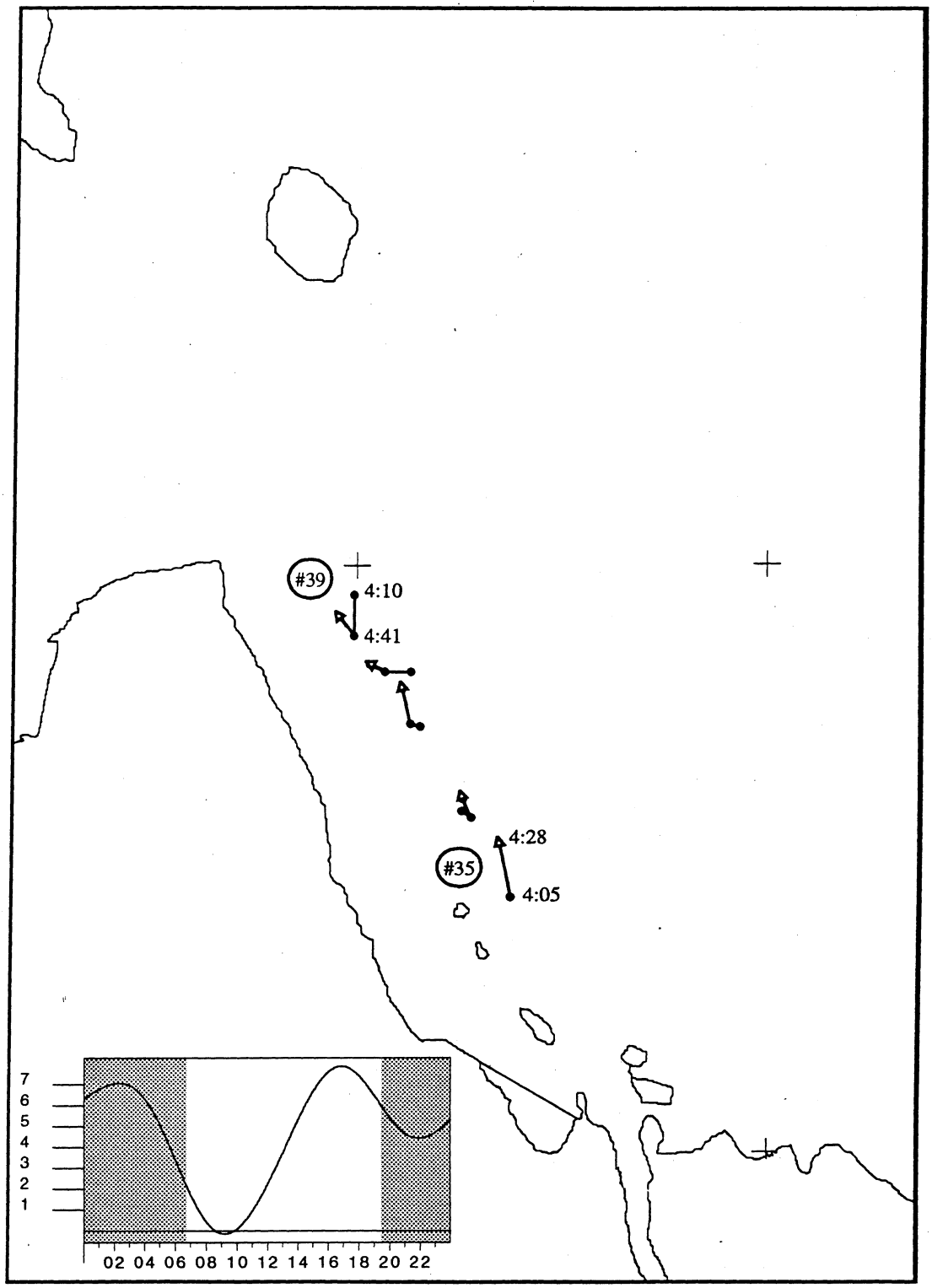

Figure 30. Movement of drift sticks 35-39 that were released at about 4:00 pm on September 13, 1993 (drogue trial #4) during the later part of a flooding tide (LLW in Swinomish Channel was predicted to occur at 9:31 am and HHW at 4:28 pm). Dots indicate where the latitude and longitude of individual drift sticks was determined; arrows the location at which each stick was retrieved; lines connect the different locations of each drift stick. The drift sticks were recovered between 4:28 and 5:24 pm.

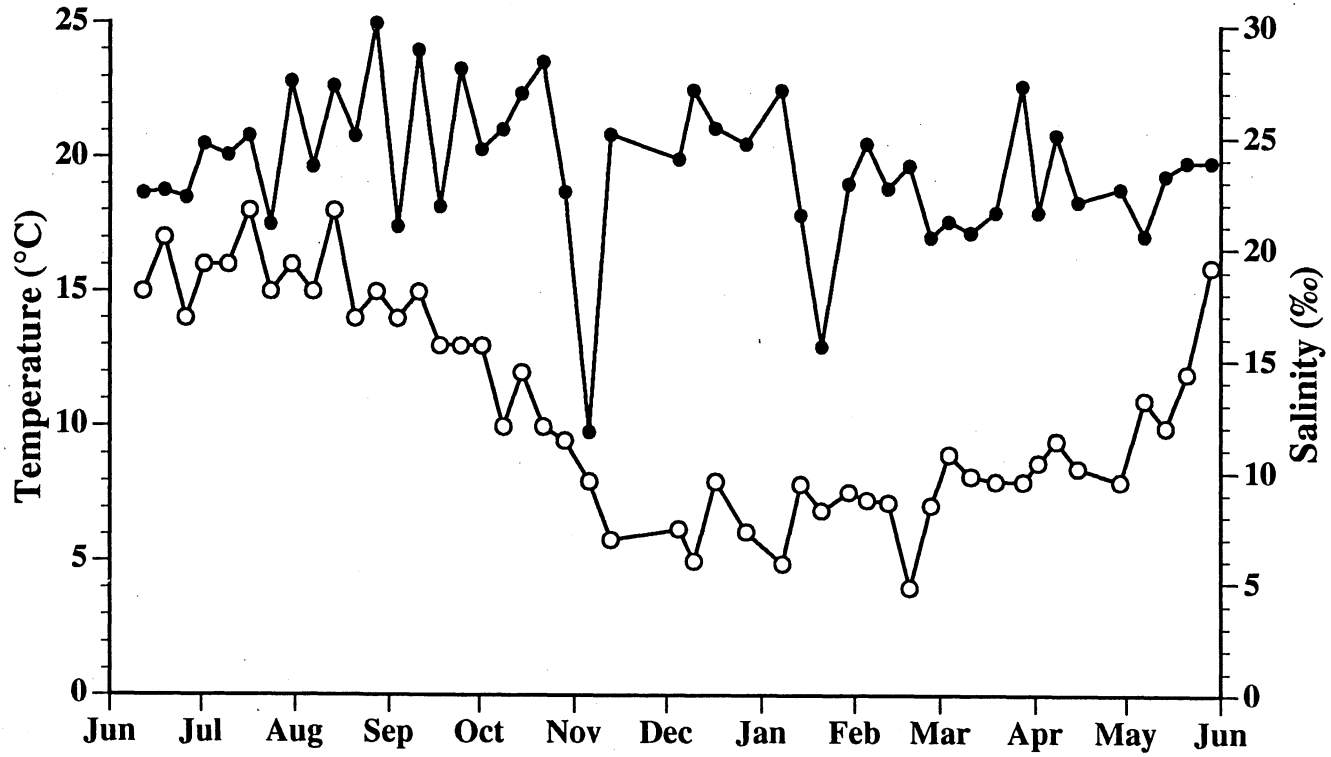

Figure 31. Temperature (open circles) and salinity (closed circles) in the Swinomish Channel at the entrance to Padilla Bay from June 1985 to May 1986. Data extracted from Cassidy and Mckeen (1986).

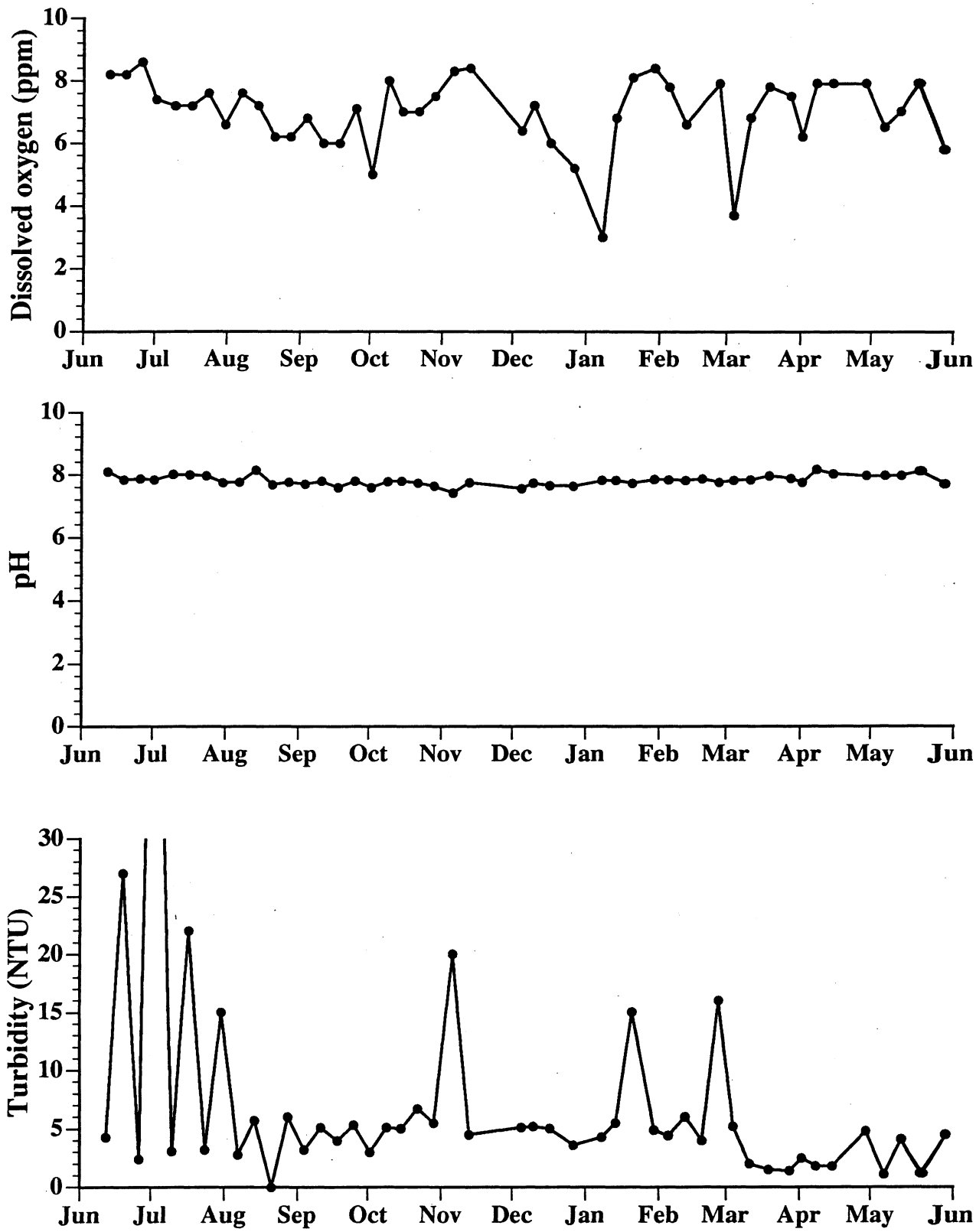

Figure 32. Dissolved oxygen, pH, and turbidity in Swinomish Channel at the entrance to Padilla Bay from June 1985 to May 1986. Data extracted from Cassidy and McKeen (1986). The turbidity value beyond the range of the graph was 66 NTU on July 2, 1985.

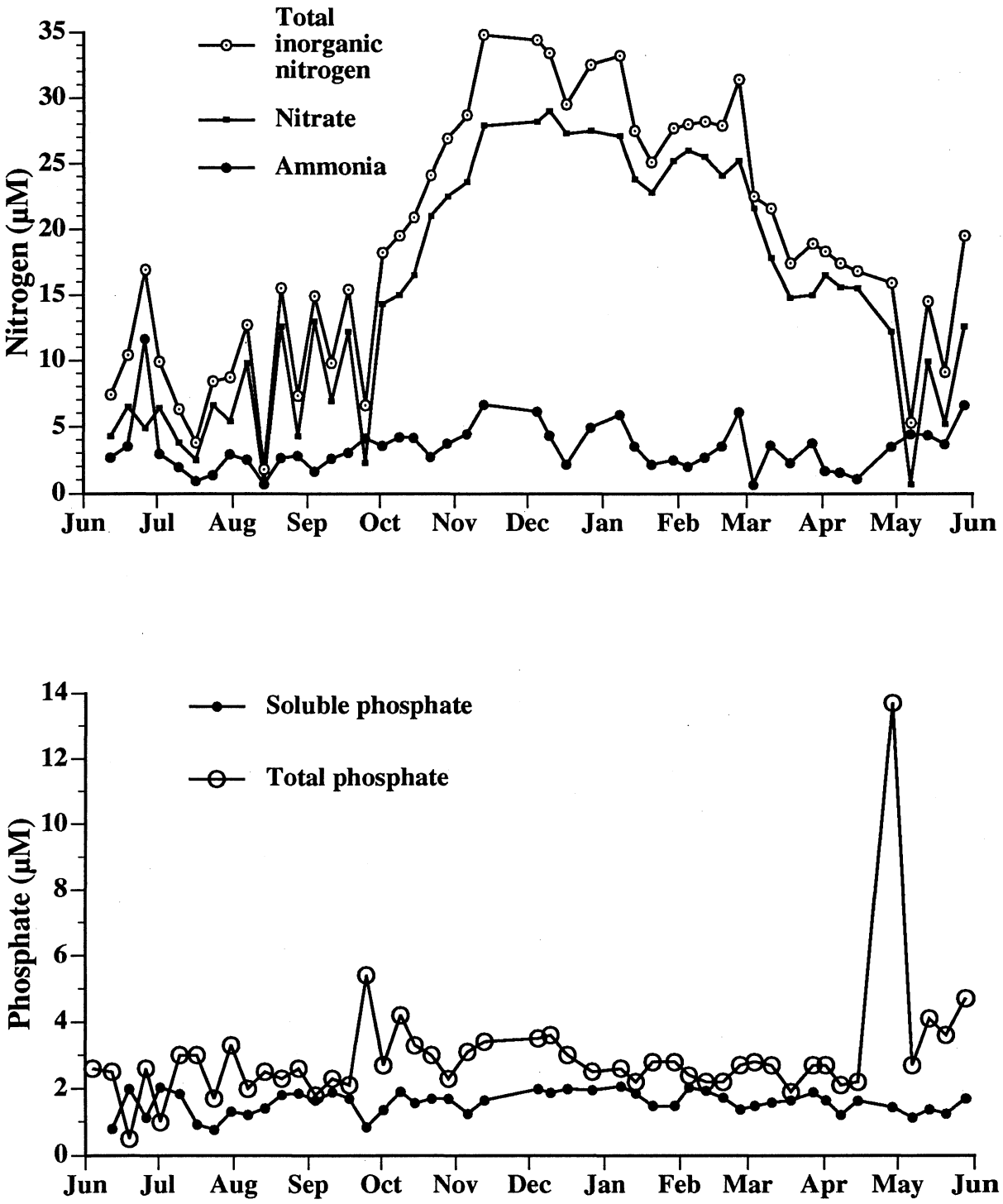

Figure 33. Dissolved nitrate, dissolved ammonium, total dissolved inorganic nitrogen, soluble reactive phosphate, and total dissolved phosphate in surface water from the Swinomish Channel at the entrance to Padilla Bay from June 1985 to May 1986. Data extracted from Cassidy and McKeen (1986).

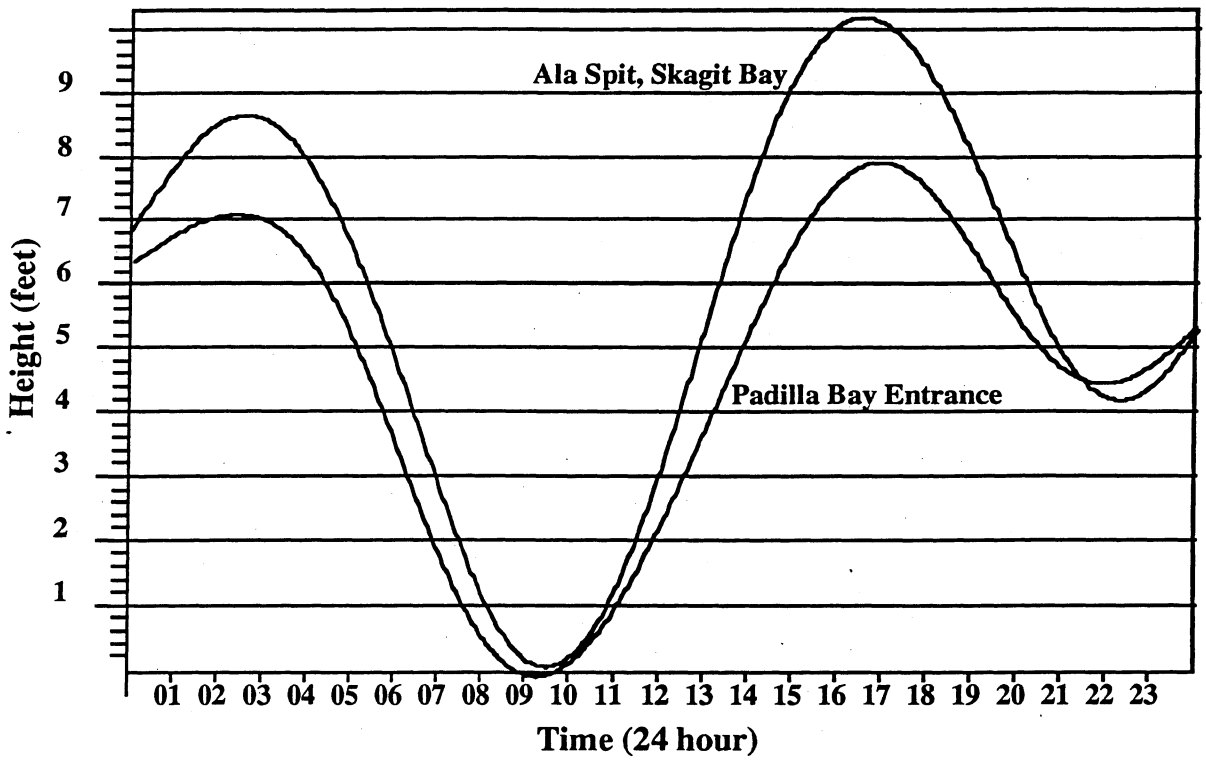

Figure 34. Tidal elevations at the southern end of Swinomish Channel in Skagit Bay (Ala Spit) and at the Padilla Bay Entrance of Swinomish Channel on September 13, 1993.

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Appendix A. Data sheets from 29 hour study in Swinomish Channel on May 20 & 21, 1992.

Appendix A-1. Data sheet from 29 hour sampling of Swinomish Slough under the Highway 20 bridge at the entrance to Padilla Bay on May 20 & 21, 1992. The travel time is over a distance of 75 feet. Vertical profiles of temperature, salinity and suspended solids (at selected depths) were measured at 1300 on May 20 and at 0205-0224 and 1326 on May 21.

Date	Time	Sample No.	Sample depth (m)	Temper-ature (°C)	Salinity (‰)	Flow (direction)	Travel time (min:sec)	Total suspended solids (mg/L)	Total volatile suspended solids (mg/L)
20-May-92	1115	WT1112	1	13	18			2.4	0.74
20-May-92	1115	WT1113	1					3	0.9
20-May-92	1122					north	0:47.05		
20-May-92	1126					north	0:39.92		
20-May-92	1130					north	0:37.28		
20-May-92	1204	WT1114	1	13	23			2.6	0.99
20-May-92	1204	WT1115	1					2.6	0.86
20-May-92	1223					north	1:46.05		
20-May-92	1227					north	2:17.22		
20-May-92	1232					north	2:39.87		
20-May-92	1300	WT1116	6					4.1	1.5
20-May-92	1300	WT1117	6					3.3	1.2
20-May-92	1300	WT1119	3.5					2.3	0.85
20-May-92	1300	WT1120	3.5					2.7	1
20-May-92	1300	WT1121	1	12.5	23			3.9	1.6
20-May-92	1300	WT1122	1					3.1	1.3
20-May-92	1300		6	12.5	23				
20-May-92	1300		5	12.5	23				
20-May-92	1300		4	12.5	22.5				
20-May-92	1300		3	12.5	22.5				
20-May-92	1300		2	12.5	23				
20-May-92	1300		1	12.5	23				
20-May-92	1344					south	1:13.28		
20-May-92	1348					south	2:06.69		
20-May-92	1354					south	1:18.10		
20-May-92	1400	WT1123	1	13	23			3	1.1
20-May-92	1400	WT1124	1					3.4	1.1
20-May-92	1407					south	0:51.34		
20-May-92	1414					south	1:10.41		
20-May-92	1418					south	1:09.89		
20-May-92	1505	WT1125	1	13	25			5.1	1.1
20-May-92	1505	WT1126	1					6	1.4
20-May-92	1511					south	0:39.78		
20-May-92	1516					south	0:36.34		
20-May-92	1518					south	0:41.14		
20-May-92	1600	WT1127	1	13.5	24.5			5.8	1.5
20-May-92	1600	WT1128	1					6.3	1.7
20-May-92	1608					south	0:31.32		
20-May-92	1610					south	0:35.72		
20-May-92	1615					south	0:33.59		
20-May-92	1701	WT1129	1	14	26.5			8.7	2.5
20-May-92	1701	WT1130	1					10.5	2.6
20-May-92	1715					south	0:38.51		
20-May-92	1718					south	0:37.67		
20-May-92	1721					south	0:34.95		

Appendix A-1. Continued.

Date	Time	Sample No.	Sample depth (m)	Temper-ature (°C)	Salinity (‰)	Flow (direction)	Travel time (min:sec)	Total suspended solids (mg/L)	Total volatile suspended solids (mg/L)
20-May-92	1804	WT1131	1	13.5	26.5			6.8	2.1
20-May-92	1804	WT1132	1					8	2.2
20-May-92	1809					south	0:53.08		
20-May-92	1812					south	1:00.14		
20-May-92	1820					south	1:50.77		
20-May-92	1830					south	1:57.00		
20-May-92	1832					south	2:24.00		
20-May-92	1910	WT1133	1	13.5	26.5			6.7	2.4
20-May-92	1910	WT1134	1					5.4	1.9
20-May-92	1924					north	0:37.57		
20-May-92	1937					north	0:45.46		
20-May-92	1947					north	0:41.00		
20-May-92	2010	WT1135	surface	12.5	24			5.1	1.9
20-May-92	2010	WT1136	surface					5.5	2.1
20-May-92	2015					north	0:33.27		
20-May-92	2020					north	0:29.10		
20-May-92	2023					north	0:30.69		
20-May-92	2102	WT1137	surface	13.5	24			4.1	1.6
20-May-92	2102	WT1138	surface					4.8	1.8
20-May-92	2102		1	13.5	24				
20-May-92	2106					north	0:28.91		
20-May-92	2112					north	0:28.31		
20-May-92	2113					north	0:27.43		
20-May-92	2157	WT1139	surface	13.5	22			4.3	1.6
20-May-92	2157	WT1140	surface					3.3	1.1
20-May-92	2205					north	0:35.55		
20-May-92	2209					north	0:36.00		
20-May-92	2212					north	0:35.14		
20-May-92	2312	WT1141	1	13	20			4.9	1.7
20-May-92	2312	WT1142	1					5.3	2
20-May-92	2325					north	0:37.00		
20-May-92	2333					north	0:34.63		
20-May-92	2338					north	0:37.40		
21-May-92	11	WT1145	1	13	19			3.5	0.91
21-May-92	13	WT1146	1					4.1	1.2
21-May-92	27					north	0:37.50		
21-May-92	31					north	0:47.60		
21-May-92	33					north	0:42.26		
21-May-92	113	WT1147	1	13	19			4.3	1.5
21-May-92	119	WT1148	1					3.3	1.1
21-May-92	125					north	1:01.51		
21-May-92	130					north	1:05.40		
21-May-92	134					north	1:20.00		
21-May-92	205	WT1149	1	13	19			3.3	1.2
21-May-92	210	WT1150	1					2.7	0.86
21-May-92	217	WT1151	5.5					2.7	0.81
21-May-92	224	WT1152	5.5					3.1	0.93

Appendix A-1. Continued.

Date	Time	Sample No.	Sample depth (m)	Temper-ature (°C)	Salinity (‰)	Flow (direction)	Travel time (min:sec)	Total suspended solids (mg/L)	Total volatile suspended solids (mg/L)
21-May-92	224	WT1153	9.5					3.6	1.3
21-May-92	224	WT1154	9.5					3.4	0.99
21-May-92	224		7	13	20.5				
21-May-92	224		8	12.5	21.5				
21-May-92	247					south	1:34.60		
21-May-92	252					south	1:15.80		
21-May-92	255					south	1:20.70		
21-May-92	300	WT1155	1	13	19			3.9	1.3
21-May-92	305	WT1156	1					3.1	1.1
21-May-92	315					south	0:54.70		
21-May-92	317					south	0:45.40		
21-May-92	319					south	0:44.50		
21-May-92	403	WT1157	surface	12.5	23.2			3.9	1.2
21-May-92	404	WT1158	surface					3.3	1
21-May-92	416					south	0:56.28		
21-May-92	418					south	0:52.63		
21-May-92	422					south	0:53.73		
21-May-92	502	WT1159	surface	12	23			7.4	2.4
21-May-92	502	WT1160	surface					4.3	1.1
21-May-92	508					south	0:53.28		
21-May-92	510					south	0:43.58		
21-May-92	515					south	0:56.10		
21-May-92	600	WT1161	surface	12	25			4.3	1.4
21-May-92	600	WT1162	surface					3.7	1.1
21-May-92	603					south	1:14.32		
21-May-92	611					south	1:21.03		
21-May-92	615					south	1:37.65		
21-May-92	700	WT1163	surface	12	25			4.1	1.3
21-May-92	700	WT1164	surface					5.5	2
21-May-92	711					south	4:09.49		
21-May-92	719					south	6:49.78		
21-May-92	734					south	10:36.56		
21-May-92	805	WT1165	surface	12	25.5			4.2	1.1
21-May-92	805	WT1166	surface					4.2	1.3
21-May-92	807					north	1:52.99		
21-May-92	810					north	1:56.99		
21-May-92	811					north	1:33.18		
21-May-92	903	WT1167	surface	12	25.5			6.3	1.9
21-May-92	903	WT1168	surface					3.6	0.94
21-May-92	906					north	0:28.16		
21-May-92	910					north	0:26.50		
21-May-92	913					north	0:27.84		
21-May-92	1001	WT1169	surface	12.5	24			5.4	1.2
21-May-92	1001	WT1170	surface					6.7	1.6
21-May-92	1005					north	0:28.53		
21-May-92	1007					north	0:27.84		
21-May-92	1010					north	0:24.84		

Appendix A-1. Continued.

Date	Time	Sample No.	Sample depth (m)	Temper-ature (°C)	Salinity (‰)	Flow (direction)	Travel time (min:sec)	Total suspended solids (mg/L)	Total volatile suspended solids (mg/L)
21-May-92	1101	WT1171	surface	12.5	21			5.1	1
21-May-92	1101	WT1172	surface					6.1	1.4
21-May-92	1104					north	0:29.36		
21-May-92	1108					north	0:30.19		
21-May-92	1109					north	0:30.44		
21-May-92	1203	WT1173	surface	13	20			3.9	1.1
21-May-92	1203	WT1174	surface					3.3	0.89
21-May-92	1206					north	0:49.07		
21-May-92	1210					north	0:50.77		
21-May-92	1216					north	0:57.01		
21-May-92	1300	WT1175	surface	13	20			3.1	0.93
21-May-92	1300	WT1176	surface					4.3	1.4
21-May-92	1320					slack			
21-May-92	1326		surface	13	20				
21-May-92	1326		1	13	20				
21-May-92	1326		2	13	20				
21-May-92	1326		3	13	20				
21-May-92	1326		4	13	20				
21-May-92	1326		5	13	20				
21-May-92	1326		6	13	20				
21-May-92	1402	WT1177	surface	13	20.5			3.3	1.1
21-May-92	1402	WT1178	surface					3.9	1.3
21-May-92	1404					south	0:52.51		
21-May-92	1420					south	1:00.66		
21-May-92	1424					south	0:48.26		
21-May-92	1500	WT1181	surface	14	22			5.8	1.7
21-May-92	1500	WT1182	surface					4.9	1.2
21-May-92	1507					south	0:37.34		
21-May-92	1512					south	0:34.91		
21-May-92	1514					south	0:37.03		

Appendix A-2. Water height in Swinomish Channel under the Highway 20 bridge as measured on a temporary gauge during a 29 hour study on May 20-21, 1992. Zero is approximately MLLW.

Date	Time	Water height (feet)
20-May-92	1107	3.05
20-May-92	1131	2.25
20-May-92	1153	1.65
20-May-92	1233	0.65
20-May-92	1250	0.25
20-May-92	1335	-0.25
20-May-92	1357	-0.35
20-May-92	1430	-0.25
20-May-92	1456	-0.15
20-May-92	1528	0.15
20-May-92	1556	0.25
20-May-92	1629	1.55
20-May-92	1655	2.55
20-May-92	1723	3.45
20-May-92	1758	4.45
20-May-92	1833	5.65
20-May-92	1848	6.05
20-May-92	1900	6.55
20-May-92	1937	7.75
20-May-92	2007	8.45
20-May-92	2024	8.7
20-May-92	2058	9.15
20-May-92	2115	9.35
20-May-92	2153	9.65
20-May-92	2213	9.7
20-May-92	2257	9.45
21-May-92	0	8.75
21-May-92	36	8.25
21-May-92	100	7.95
21-May-92	135	7.55
21-May-92	157	7.25
21-May-92	245	6.9
21-May-92	307	6.75
21-May-92	321	6.65
21-May-92	400	6.55
21-May-92	425	6.55
21-May-92	500	6.55
21-May-92	516	6.65
21-May-92	557	6.75

Appendix A-2. [Continued]

Date	Time	Water height (feet)
21-May-92	626	6.85
21-May-92	701	7.05
21-May-92	735	7.05
21-May-92	800	6.75
21-May-92	830	6.55
21-May-92	857	6.35
21-May-92	930	6.05
21-May-92	956	5.55
21-May-92	1030	4.95
21-May-92	1058	4.35
21-May-92	1130	3.45
21-May-92	1200	2.75
21-May-92	1227	1.95
21-May-92	1256	1.25
21-May-92	1330	0.65
21-May-92	1350	0.45
21-May-92	1400	0.35
21-May-92	1422	0.25
21-May-92	1440	0.15
21-May-92	1500	0.25
21-May-92	1518	0.25
21-May-92	1530	0.25

Appendix B. Data sheets for water quality samples taken in Swinomish Channel from February 1992 to May 1993.

Appendix B-1. Water quality data collected February 1992 through May 1993 mid-channel (except for samples on March 23, 1992 when samples were taken from east to west perpendicular to the long axis of the channel) in the Swinomish Slough under the Highway 20 bridge.

Date	Sample No.	Time	Sample depth (m)	Temp. (°C)	Salinity (‰)	Total depth (m)	TSS (mg/L)	TVSS (mg/L)	Total coliform bacteria (#/100ml)	Fecal coliform bacteria (#/100ml)	NH4-N (mg/L)	Nitrate+ nitrite-N (mg/L)	Nitrite-N (mg/L)	Reactive soluble PO4-P (mg/L)	Total soluble PO4-P (mg/L)
3-Feb-92	B005	2255	surface	7.5	13	0.9			210	43					
3-Feb-92	B006	2255	surface						64	3.6					
3-Feb-92	W03989	2257	surface				7.3	0.73							
3-Feb-92	W03990	2257	surface				8.1	0.73							
11-Feb-92	B007	1653	surface	12	17.9	1.2			150	23					
11-Feb-92	B008	1655	surface						93	9.1					
11-Feb-92	W04991	1655	surface				5.8	0.87							
11-Feb-92	W04992	1657	surface				5.5	0.71							
17-Feb-92	B009	2221	surface	7	16.5	0.95			39	3.6					
17-Feb-92	B010	2223	surface						39	9.1					
17-Feb-92	W05022	2223	surface				15	1.6							
17-Feb-92	W05023	2224	surface				12.5	1.6							
24-Feb-92	W06024	1626	surface	8	18	0.75	8.2	1.1							
24-Feb-92	W06025	1627	surface				8.8	1.4							
24-Feb-92	B011	1629	surface						43	23					
24-Feb-92	B012	1629	surface						210	64					
1-Mar-92	W07026	2147	surface	8.5	19.7	1.25	4.7	0.66							
1-Mar-92	W07027	2148	surface				4.9	0.93							
1-Mar-92	B013	2149	surface						43	3.1					
1-Mar-92	B014	2149	surface						75	9.1					
23-Mar-92	W08046	1339	surface				4.5	0.58							
23-Mar-92	W08047		surface				4.8	0.77							
23-Mar-92	W09048	1350	surface	10	24		4.3	0.86							
23-Mar-92	W09049		surface				5.2	1.2							
23-Mar-92	W09N01	1352	1								0.026	0.18	0.003	0.056	0.066
23-Mar-92	W09N02	1354	1								0.022	0.18	0.003	0.055	0.081
23-Mar-92	W10050	1404	surface				5.2	0.78							
23-Mar-92	W10051						5.2	0.99							

Appendix B-1. Continued

Date	Sample No.	Time	Sample depth (m)	Temp. (°C)	Salinity (‰)	Total depth (m)	TSS (mg/L)	TVSS (mg/L)	Total coliform bacteria (#/100ml)	Fecal coliform bacteria (#/100ml)	NH4-N (mg/L)	Nitrate+ nitrite-N (mg/L)	Nitrite-N (mg/L)	Reactive soluble PO4-P (mg/L)	Total soluble PO4-P (mg/L)
23-Mar-92	W11052	1406	surface				5.3	1							
23-Mar-92	W11053						4.3	0.99							
23-Mar-92	W12054	1418	surface				4.9	1.2							
23-Mar-92	W12055						5.7	1.4							
23-Mar-92	W13056	1420	surface				5.7	1.2							
23-Mar-92	W13057						6.2	1.2							
23-Mar-92	W14058	1423	surface				5.3	1.2							
23-Mar-92	W14059						5.6	1.3							
21-Apr-92	W15082	1458	1	11.3	24	<7	2.9	0.58							
21-Apr-92	W15083	1500	1				2.6	0.52							
21-Apr-92	B015	1500	surface						23	15					
21-Apr-92	B016	1500	surface						460	43					
21-Apr-92	W15N03	1505	1								0.029	0.2	0.001	0.059	0.069
21-Apr-92	W15N04	1506	1								0.032	0.2	0.003	0.058	0.064
21-May-92	WT1175	1300	surface	13	20		3.1	0.93							
21-May-92	WT1176	1300	surface	13	20		4.3	1.4							
21-May-92	B017	1321	surface						8	2					
21-May-92	B018	1321	surface						5	2					
21-May-92	WT1N05	1316	1								0.033	0.07	0.001	0.038	0.044
17-Jun-92	W17239	1310	1	14.5	21.5	<3.5	5.7	1							
17-Jun-92	W17240	1310	1	14.5	21.5		6.9	1.2							
17-Jun-92	B019	1305	surface						2	2					
17-Jun-92	B020	1305	surface						2	<2					
17-Jun-92	W17N06	1310	1								0.056	0.17	0.007	0.067	0.08
15-Jul-92	W18269	1230	1	15.5	24		6.6	1.1							
15-Jul-92	W18270	1230	1	15.5	24	no read	8	1.7							
15-Jul-92	W18N07	1230	1								0.03	0.08	0.017	0.056	0.1
15-Jul-92	B021	1224	surface						20	10					

Appendix B-1. Continued

Date	Sample No.	Time	Sample depth (m)	Temp. (°C)	Salinity (‰)	Total depth (m)	TSS (mg/L)	TVSS (mg/L)	Total coliform bacteria (#/100ml)	Fecal coliform bacteria (#/100ml)	NH4-N (mg/L)	Nitrate+ nitrite-N (mg/L)	Nitrite-N (mg/L)	Reactive soluble PO4-P (mg/L)	Total soluble PO4-P (mg/L)
15-Jul-92	B022	1224	surface						22	2					
26-Aug-92	W19299	1030	1	16	25	<4.5	14.1	2.1							
26-Aug-92	W19300	1030	1	16	25		14.3	2.6							
26-Aug-92	W19N08	1045	1								0.11	0.07	0.005	0.069	0.09
26-Aug-92	B023	1045	surface						40	15					
26-Aug-92	B024	1045	surface						40	12					
9-Sep-92	B025	910	surface						110	30					
9-Sep-92	B026	910	surface						160	20					
9-Sep-92	W20N09	910	1	14	25.5	no read					0.055	0.12	0.007	0.07	0.073
9-Sep-92	W20319	915	1				8.2	1.1							
9-Sep-92	W20320	915	1				8.4	1.2							
9-Oct-92	B027	1035	surface						150	81					
9-Oct-92	B028	1035	surface						120	119					
9-Oct-92	W21N10	1035	1	12	24.5	8					0.049	0.21	0.007	0.058	0.061
9-Oct-92	W21321	1033	1				5.9								
9-Oct-92	W21322	1033	1				5.5								
8-Nov-92	B029	2114	surface						80	10					
8-Nov-92	B030	2114	surface						100	28					
8-Nov-92	W22N11	2110	1	10	18	8					0.027	0.14	0.055	0.077	0.071
8-Nov-92	W22341	2110	1				9.9	0.8							
8-Nov-92	W22342	2110	1				10.8	0.9							
8-Dec-92	B031	2230	surface						460	93					
8-Dec-92	B032	2230	surface						no data,	lab error					
8-Dec-92	W23N12	2230	1	6.5	19.7	7.5					0.061	0.3	0.005	0.063	0.062
8-Dec-92	W23361	2220	1				7.4								
8-Dec-92	W23362	2220	1				7.5								
2-Feb-93	B035	1950	surface						12	9					
2-Feb-93	B036	1950	surface						18	5					

Appendix B-1. Continued

Date	Sample No.	Time	Sample depth (m)	Temp. (°C)	Salinity (‰)	Total depth (m)	TSS (mg/L)	TVSS (mg/L)	Total coliform bacteria (#/100ml)	Fecal coliform bacteria (#/100ml)	NH4-N (mg/L)	Nitrate+ nitrite-N (mg/L)	Nitrite-N (mg/L)	Reactive soluble PO4-P (mg/L)	Total soluble PO4-P (mg/L)
2-Feb-93	W25N14	2000	1	7	20.9	7					0.044	0.22	0.006	0.059	0.062
2-Feb-93	W25383	2000	1				4.7								
2-Feb-93	W25384	2000	1				5.7								
23-Feb-93	B037	1230	surface												
23-Feb-93	B038	1230	surface												
23-Feb-93	W26N15	1225	1	6	22	no read									
23-Feb-93	W26403	1225	1				7.4								
23-Feb-93	W26404	1225	1				6.9								
30-Mar-93	B039	1607	surface						2	2					
30-Mar-93	B040	1607	surface						4	14					
30-Mar-93	W27N16	1607	1	9	21.9	no read					0.057	0.25	0.004	0.054	0.06
30-Mar-93	W27421	1607	1				4.5								
30-Mar-93	W27422	1607	1				4.3								
27-Apr-93	B041	1520	surface						51	62					
27-Apr-93	B042	1520	surface						44	46					
27-Apr-93	W28N17	1520	1	11	16.5	5.9					0.048	0.13	0.004	0.025	0.038
27-Apr-93	W28441	1520	1												
27-Apr-93	W28442	1520	1												
20-May-93	B043	1120	surface						13	4					
20-May-93	B044	1120	surface						7	7					
20-May-93	W29N18	1120	1	13.5	17	7					0.039	0.082	0.006	0.034	0.048
20-May-93	W29443	1115	1				3.8								
20-May-93	W29444	1115	1				4.5								

Appendix C. Data sheets for drogue trials on July 29, August 4, and September 13, 1993.

Appendix C-1. Time and location of drift sticks at deployment, relocation, and retrieval during drogue trial #2 on July 29, 1993. The last column indicates the time relative to predicted lower low water in the Swinomish Channel at the Padilla Bay entrance.

drift stick #	Time	Latitude	Longitude	delta LLW
1	9:24 AM	28.27	31.49	-0:26
1	10:26 AM	27.49	30.87	-1:28
2	9:25 AM	28.37	31.57	-0:27
2	10:22 AM	27.56	30.93	-1:24
3	9:26 AM	28.47	31.63	-0:28
3	10:20 AM	27.71	31.01	-1:22
4	9:27 AM	28.58	31.72	-0:29
4	10:19 AM	27.87	31.18	-1:21
4	10:30 AM	27.7	30.96	-1:32
5	9:28 AM	28.68	31.82	-0:30
5	10:18 AM	27.97	31.25	-1:20
5	10:31 AM	27.75	31.06	-1:33
6	9:29 AM	28.77	31.9	-0:31
6	10:17 AM	28.09	31.3	-1:19
6	10:32 AM	27.81	31.13	-1:34
7	9:30 AM	28.86	31.98	-0:32
7	10:17 AM	28.23	31.41	-1:19
7	10:33 AM	27.91	31.22	-1:35
7	12:10 PM	26.78	30.58	-3:12
8	9:31 AM	28.97	32.08	-0:33
8	10:15 AM	28.41	31.55	-1:17
8	10:34 AM	28.06	31.32	-1:36
8	11:48 AM	27.29	30.89	-2:50
9	9:32 AM	29.09	32.15	-0:34
9	10:14 AM	28.62	31.75	-1:16
9	10:35 AM	28.22	31.46	-1:37
9	11:44 AM	27.43	30.88	-2:46

Appendix C-1. Continued

drift stick #	Time	Latitude	Longitude	delta LLW
10	9:33 AM	29.2	32.23	-0:35
10	10:13 AM	28.81	31.91	-1:15
10	10:36 AM	28.41	31.62	-1:38
10	11:40 AM	27.64	30.91	-2:42
11	9:34 AM	29.31	32.3	-0:36
11	10:10 AM	29.09	32.13	-1:12
11	10:41 AM	29.11	32.16	-1:43
11	11:28 AM	29.11	32.13	-2:30
11	12:52 PM	29.22	32.03	-3:54
12	9:35 AM	29.38	32.38	-0:37
12	10:09 AM	29.16	32.23	-1:11
12	10:38 AM	28.8	31.9	-1:40
12	11:39 AM	27.92	31.15	-2:41
13	9:36 AM	29.47	32.46	-0:38
13	10:38 AM	28.94	32.01	-1:40
14	9:37 AM	29.61	32.57	-0:39
14	10:08 AM	29.32	32.41	-1:10
14	10:39 AM	28.92	32.04	-1:41
14	11:37 AM	28.05	31.29	-2:39
15	9:38 AM	29.71	32.65	-0:40
15	10:44 AM	29.49	32.52	-1:46
15	11:24 AM	29.43	32.53	-2:26
16	9:39 AM	29.81	32.72	-0:41
16	10:04 AM	29.8	32.73	-1:06
16	10:45 AM	29.6	32.62	-1:47
16	1:10 PM	29.59	32.68	-4:12
17	9:40 AM	29.92	32.83	-0:42
17	10:03 AM	29.96	32.86	-1:05
18	9:41 AM	30.02	32.92	-0:43
18	10:02 AM	30.09	32.93	-1:04

Appendix C-1. Continued

drift stick #	Time	Latitude	Longitude	delta LLW
19	9:42 AM	30.14	32.99	-0:44
19	10:01 AM	30.19	32.98	-1:03
20	9:43 AM	30.26	33.07	-0:45
20	10:00 AM	30.32	33.08	-1:02
20	10:51 AM	30.32	33.17	-1:53
20	1:01 PM	29.37	32.37	-4:03
21	9:44 AM	30.35	33.14	-0:46
21	9:59 AM	30.42	33.16	-1:01
21	11:08 AM	30.48	33.05	-2:10
21	1:20 PM	29.98	32.71	-4:22
22	9:45 AM	30.44	33.22	-0:47
22	9:58 AM	30.5	33.22	-1:00
22	11:07 AM	30.52	33.08	-2:09
22	1:06 PM	29.45	32.43	-4:08
23	9:45 AM	30.57	33.3	-0:47
23	9:57 AM	30.59	33.26	-0:59
23	11:06 AM	30.57	33.11	-2:08
24	9:46 AM	30.58	33.31	-0:48
24	9:56 AM	30.65	33.27	-0:58
25	9:47 AM	30.65	33.28	-0:49
25	9:56 AM	30.68	33.29	-0:58
25	10:54 AM	30.79	33.17	-1:56
26	9:47 AM	30.76	33.24	-0:49
26	9:54 AM	30.83	33.19	-0:56

Appendix C-2. Time and location of drift sticks at deployment, relocation, and retrieval during drogue trial #3 on August 4, 1993. The last column indicates the time relative to predicted lower low water in the Swinomish Channel at the Padilla Bay entrance.

drift stick #	Time	Latitude	Longitude	delta LLW
3	12:12 PM	30.53	33.22	0:48
3	12:29 PM	30.53	33.29	0:31
3	1:49 PM	30.4	33.33	-0:49
3	3:13 PM	30.4	33.29	-2:13
3	6:30 PM	29.23	32.22	-5:30
3	8:31 PM	29.28	32.14	-7:31
6	12:07 PM	30.16	32.87	0:53
6	12:25 PM	30.2	32.87	0:35
6	12:46 PM	30.11	32.89	0:14
6	1:29 PM	29.69	32.74	-0:29
7	12:11 PM	30.44	33.12	0:49
7	12:28 PM	30.45	33.21	0:32
7	12:57 PM	30.45	33.19	0:03
7	1:37 PM	30.2	33.04	-0:37
7	6:19 PM	29.14	32.71	-5:19
7	8:00 PM	29.25	32.48	-7:00
8	12:08 PM	30.24	32.94	0:52
8	12:26 PM	30.24	32.97	0:34
8	12:53 PM	30.15	32.97	0:07
8	1:34 PM	29.93	32.96	-0:34
8	6:16 PM	29.11	32.8	-5:16
8	8:05 PM	29.11	32.8	-7:05
30	12:13 PM	30.65	33.3	0:47
30	12:32 PM	30.67	33.39	0:28
30	12:43 PM	30.69	33.44	0:17
30	1:02 PM	30.65	33.51	-0:02
30	1:53 PM	30.62	33.49	-0:53
30	3:18 PM	30.1	32.99	-2:18
30	6:14 PM	29.21	32.62	-5:14
30	8:28 PM	29.15	32.14	-7:28
31	12:08 PM	30.19	32.9	0:52
31	12:25 PM	30.22	32.92	0:35
31	12:53 PM	30.11	32.91	0:07
31	1:31 PM	29.79	32.85	-0:31
31	6:18 PM	29.14	32.77	-5:18

Appendix C-2. Continued

drift stick #	Time	Latitude	Longitude	delta LLW
32	12:10 PM	30.4	33.08	0:50
32	12:27 PM	30.37	33.18	0:33
32	12:56 PM	30.32	33.15	0:04
32	1:44 PM	30.34	33.22	-0:44
32	3:15 PM	30.34	33.17	-2:15
32	6:10 PM	29.35	32.66	-5:10
32	8:30 PM	29.25	32.15	-7:30
33	12:10 PM	30.35	33.04	0:50
33	12:27 PM	30.34	33.14	0:33
33	12:55 PM	30.27	33.1	0:05
33	1:43 PM	30.29	33.19	-0:43
33	3:16 PM	30.24	33.14	-2:16
33	6:46 PM	28.35	32.07	-5:46
35	12:09 PM	30.28	32.97	0:51
35	12:26 PM	30.27	33.02	0:34
35	12:54 PM	30.17	33.04	0:06
35	1:36 PM	30.08	33.07	-0:36
14	12:12 PM	30.57	33.26	0:48
14	12:29 PM	30.55	33.35	0:31
14	6:11 PM	29.27	32.63	-5:11
16	12:11 PM	30.48	33.17	0:49
16	12:28 PM	30.48	33.25	0:32
16	12:58 PM	30.45	33.25	0:02
16	1:46 PM	30.37	33.23	-0:46
16	3:14 PM	30.36	33.18	-2:14
16	6:12 PM	29.25	32.62	-5:12
16	8:33 PM	29.34	32.15	-7:33
39	12:13 PM	30.61	33.3	0:47
39	12:30 PM	30.62	33.41	0:30
39	12:43 PM	30.65	33.51	0:17
39	1:03 PM	30.63	33.59	-0:03
39	3:01 PM	30.83	33.81	-2:01
42	12:09 PM	30.31	32.99	0:51
42	12:26 PM	30.32	33.07	0:34
42	12:54 PM	30.17	33.04	0:06
42	1:36 PM	30.11	33.09	-0:36

Appendix C-3. Time and location of drift sticks at deployment, relocation, and retrieval during drogue trial #4 on September 13, 1993. The last column indicates the time relative to predicted lower low water in the Swinomish Channel at the Padilla Bay entrance.

drift stick #	Time	Latitude	Longitude	delta LLW
21	1:05 PM	28.83	31.93	-3:34
21	1:25 PM	28.48	31.59	-3:54
21	1:47 PM	28.18	31.42	-4:16
21	2:20 PM	28.05	31.17	-4:49
21	2:51 PM	28.03	30.63	-5:20
21	3:30 PM	27.89	30.54	-5:59
21	4:17 PM	27.86	30.61	-6:46
21	4:54 PM	27.82	30.62	-7:23
22	1:06 PM	29.19	32.19	-3:35
22	1:31 PM	28.73	31.85	-4:00
22	1:48 PM	28.41	31.64	-4:17
22	2:18 PM	28.17	31.43	-4:47
22	2:56 PM	28.2	31.37	-5:25
22	3:36 PM	28.39	31.22	-6:05
22	4:22 PM	28.47	30.84	-6:51
22	5:45 PM	28.42	30.46	-8:14
23	1:08 PM	29.45	32.37	-3:37
23	1:32 PM	28.88	31.99	-4:01
23	1:49 PM	28.53	31.71	-4:18
23	2:18 PM	28.23	31.47	-4:47
23	2:56 PM	28.23	31.39	-5:25
23	3:37 PM	28.38	31.14	-6:06
23	4:23 PM	28.43	30.75	-6:52
23	5:46 PM	28.39	30.45	-8:15
24	1:09 PM	29.8	32.61	-3:38
24	1:34 PM	29.22	32.27	-4:03
24	1:50 PM	28.87	31.98	-4:19
24	2:15 PM	28.5	31.63	-4:44
24	2:56 PM	28.26	31.4	-5:25
24	3:37 PM	28.39	31.07	-6:06
24	4:24 PM	28.38	30.69	-6:53
24	5:47 PM	28.34	30.37	-8:16

Appendix C-3. Continued

drift stick #	Time	Latitude	Longitude	delta LLW
25	2:04 PM	28.54	31.61	-4:33
25	2:16 PM	28.48	31.47	-4:45
25	3:02 PM	28.42	30.94	-5:31
25	3:20 PM	28.41	30.85	-5:49
25	3:39 PM	28.44	30.76	-6:08
25	4:24 PM	28.41	30.53	-6:53
25	5:47 PM	28.32	30.34	-8:16
26	2:06 PM	28.87	31.84	-4:35
26	2:24 PM	28.55	31.7	-4:53
26	3:00 PM	28.42	31.34	-5:29
26	3:19 PM	28.43	31.16	-5:48
26	3:38 PM	28.47	31.03	-6:07
26	4:23 PM	28.47	30.77	-6:52
26	5:46 PM	28.41	30.46	-8:15
27	2:07 PM	29.2	32.2	-4:36
27	2:26 PM	28.95	32.05	-4:55
27	2:58 PM	28.57	31.79	-5:27
27	5:06 PM	28.62	32.0	-7:35
28	2:09 PM	29.42	32.36	-4:38
28	2:27 PM	29.1	32.16	-4:56
28	3:05 PM	28.72	31.84	-5:34
28	3:41 PM	28.6	31.76	-6:10
28	4:29 PM	28.71	31.83	-6:58
28	5:11 PM	28.93	32.02	-7:40
29	2:10 PM	29.76	32.6	-4:39
29	2:29 PM	29.49	32.45	-4:58
29	3:07 PM	28.99	32.0	-5:36
29	3:45 PM	28.74	31.9	-6:14
29	4:30 PM	28.74	32.03	-6:59
30	3:09 PM	28.53	31.66	-5:38
30	3:42 PM	28.63	31.52	-6:11
30	5:00 PM	28.73	31.04	-7:29

Appendix C-3. Continued

drift stick #	Time	Latitude	Longitude	delta LLW
31	3:11 PM	28.86	31.96	-5:40
31	3:44 PM	28.72	30.85	-6:13
31	4:29 PM	28.71	31.83	-6:58
31	5:11 PM	28.93	32.02	-7:40
32	3:12 PM	29.21	32.21	-5:41
32	3:47 PM	29.12	32.24	-6:16
32	4:33 PM	29.06	32.3	-7:02
32	5:27 PM	29.15	32.41	-7:56
33	3:13 PM	29.45	32.36	-5:42
33	3:49 PM	29.38	32.33	-6:18
33	4:35 PM	29.36	32.43	-7:04
33	5:16 PM	29.4	32.39	-7:45
34	3:14 PM	29.78	32.6	-5:43
34	3:50 PM	29.65	32.45	-6:19
34	4:36 PM	29.54	32.51	-7:05
34	5:18 PM	29.52	32.56	-7:47
35	4:05 PM	28.51	31.65	-6:34
35	4:28 PM	28.74	31.72	-6:57
36	4:06 PM	28.88	31.96	-6:35
36	4:31 PM	28.85	31.9	-7:00
36	5:10 PM	28.93	31.95	-7:39
37	4:08 PM	29.24	32.22	-6:37
37	4:34 PM	29.25	32.28	-7:03
37	5:24 PM	29.4	32.33	-7:53
38	4:08 PM	29.47	32.28	-6:37
38	4:36 PM	29.47	32.44	-7:05
38	5:17 PM	29.5	32.53	-7:46
39	4:10 PM	29.79	32.63	-6:39
39	4:41 PM	29.62	32.63	-7:10
39	5:20 PM	29.7	32.72	-7:49

Appendix D-1. Excerpts from Sylvester & Clogston (1958) that refer to currents and current studies in Swinomish Channel (pages 4 (summary), 31-32, 35, 37, 39, 47, 52-55).

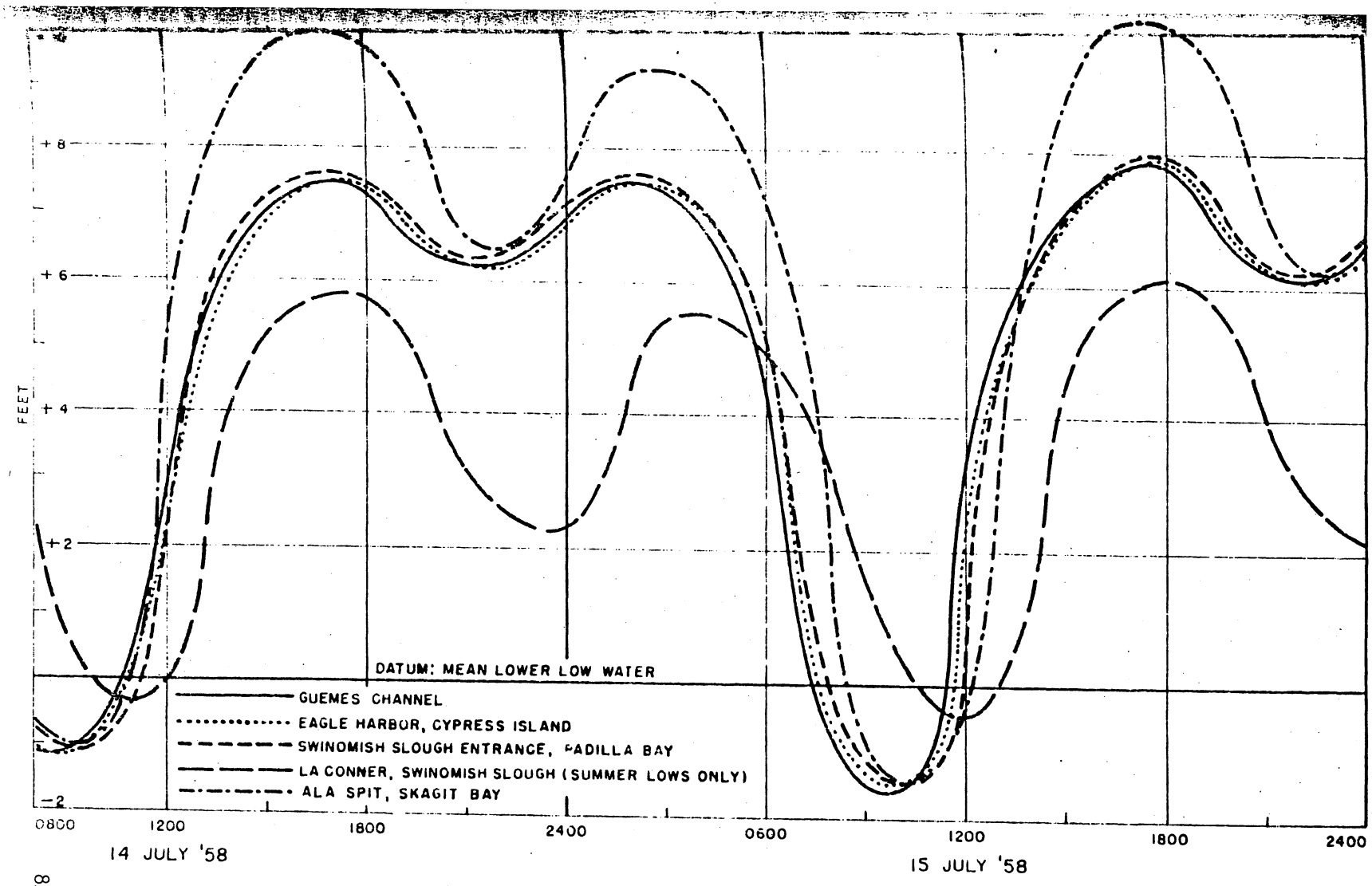
Current meter studies were made over a tidal cycle in Guemes Channel and in Swinomish Channel. These studies together with planimetered areas and volumes indicate that on the greater ebb, Guemes Channel passes from two to three times the volume of water that lies in the entire tidal prism of Fidalgo and Padilla Bays. During a flood tide, the discharge through Guemes Channel is only slightly greater than the intertidal volume in Fidalgo and Padilla Bays. Current studies also indicate that over half of the ebb tide outflow into Padilla Bay from Swinomish Channel comes from Skagit Bay while on a flood tide, only a small portion of Swinomish Channel water passes into Skagit Bay. These observations are of course modified by strong winds or by weak tides.

from p. 4 (summary)

CURRENT STUDIES

The Strait of Georgia and adjacent waters are fed on a flood tide primarily from the Strait of Juan de Fuca through Haro and Rosario Straits (see Fig. 1). On an ebb tide, these same straits carry this large volume of water back into the Strait of Juan de Fuca. The strong currents found in Rosario and Haro Straits are largely tidal in nature (1) but are influenced by the large seasonal volume of surface water runoff in the area and by strong winds in the Straits of Juan de Fuca and Georgia. Local current velocities and direction are dependant upon the water depth and upon the bathymetry of the area. The deeper currents are usually lower in velocity than the surface currents and their time-direction pattern may differ markedly from the surface currents (23). Guemes Channel is a side-channel off the east side of Rosario Strait with a relatively shallow entrance (depth of about 10 fathoms--see Fig. 2) that feeds water into both Fidalgo and Padilla Bays and into Swinomish Channel. According to reference (1), average surface current velocities in Guemes Channel are 2.5 knots; tropic velocities are 3.8 knots; flood currents vary from weak and variable to a maximum of 4.4 knots and ebb currents vary from a minimum of 1.4 to a maximum of 5.6 knots. Ebbing surface currents exceed the flooding currents both in velocity and in duration. At Anacortes, the mean tidal range is 4.8 ft.; diurnal range 8.2 ft. and the mean tidal level is 5.0 ft. (2). Extreme tidal ranges vary from a usual yearly low of -2.5 ft. to a yearly high of 9.4 ft.

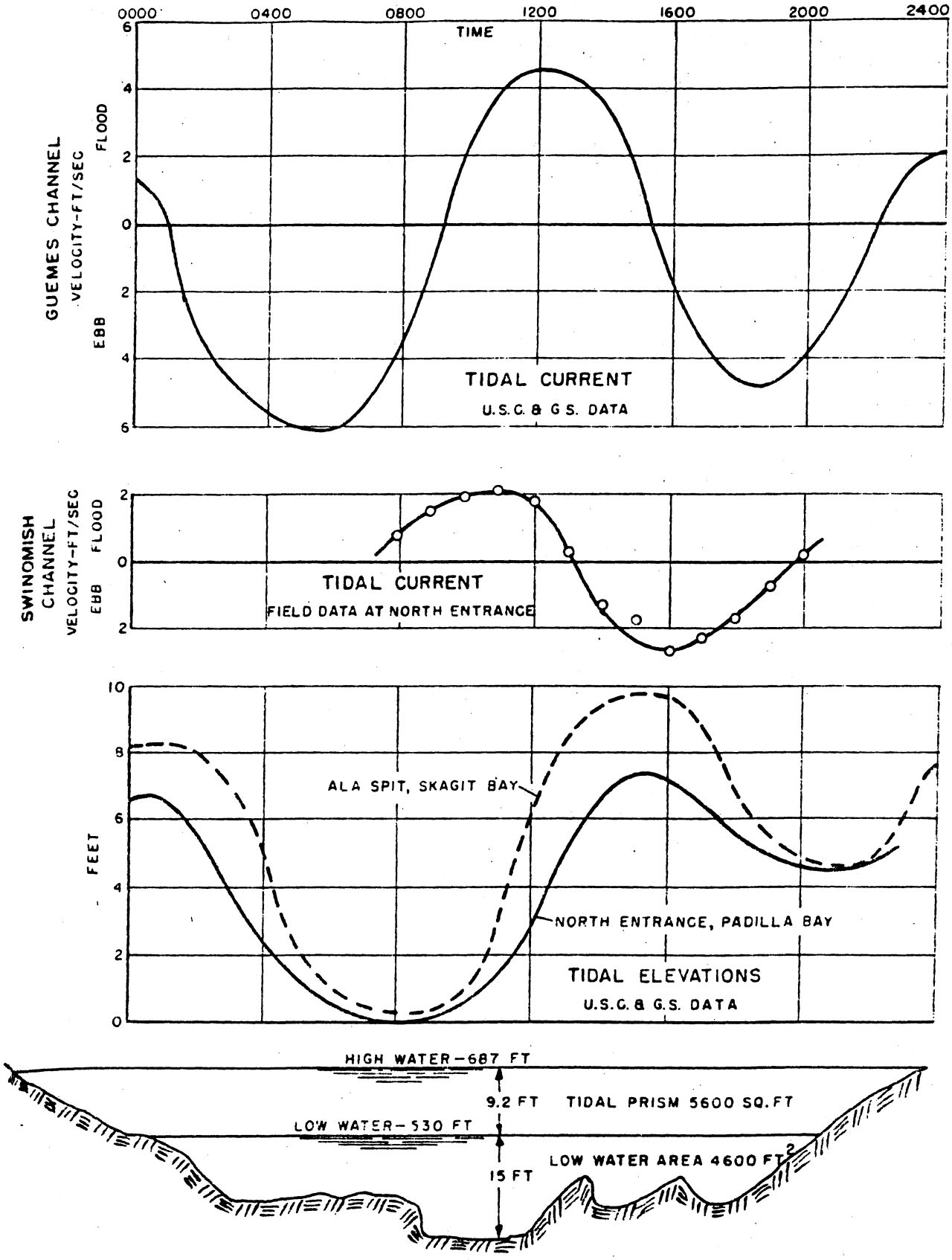
Figure 3 shows typical tide curves for five stations in the vicinity of Anacortes. The diurnal inequality of the tides in this region is well



TYPICAL TIDAL RANGES AND TIMES
0800, 14 JULY '58 TO 2400, 15 JULY '58
FROM U.S.C. & G.S. TIDE TABLES

illustrated. Tidal ranges are similar for Anacortes, Eagle Harbor on Cypress Island off Bellingham Channel and for Swinomish Channel entrance in Padilla Bay. Contrasted with these three stations is the large difference in the height of the high tides at Ala Spit in Skagit Bay. The higher high tides in Skagit Bay produce a head differential for the ebb tide discharge of some Skagit Bay water through Swinomish Channel into Padilla Bay. Tidal ranges for La Conner that are shown apply only during low levels of the channel which usually occur in midsummer.

Currents were measured in the north end of Swinomish Channel from the highway bridge, using a Gurley current meter over a complete tidal cycle of about 12 hours. Meter readings were usually taken at 0.6 depth in mid-channel, assuming parabolic flow distribution as in a river. Figure 7 includes a plot of these average current velocities, a plot of the channel cross section and predicted surface current velocities in Guemes Channel and plots of the predicted tidal elevations in Skagit Bay and at the north entrance to Swinomish Channel. These channel currents were measured during a period of strong flood and ebb tides. Flood and ebb currents commenced in the channel about two hours before they commenced in Guemes Channel (this has been observed on other occasions). On a flooding tide (not a weak flood) the current passes from Padilla Bay southward through Swinomish Channel and into Skagit Bay. On a weak flood or with strong southerly winds, the current floods into Swinomish Channel from both ends, converging near La Conner, according to the towboat people in Anacortes and La Conner. The ebb current period is about one hour longer than the flood and it has a higher average velocity than the flood current. The water in the northern portion of Skagit Bay that does not ebb through Deception Pass, flows northward through Swinomish Channel and into Padilla Bay. This predominance of the ebb current over the flood has been observed by the Washington Department of Fisheries and by the local oyster growers. As shown on Fig. 7, low tidal elevations in Skagit Bay are about the same as in Padilla Bay while the high tide elevations in Skagit Bay are one to three feet higher than in Padilla Bay. This difference in high-tide elevation provides a driving force for passage of water out through Swinomish Channel on the ebbing tide. Table 7 gives approximate calculations for inflow and outflow from Fidalgo, Padilla and Skagit Bays and is discussed in a later portion of this report section.



CHANNEL CROSS-SECTION AT ANACORTES HIGHWAY

SWINOMISH CHANNEL

TIDAL ELAVATIONS AND CURRENTS FOR SEPT. 10, 1958

85

FIG 7

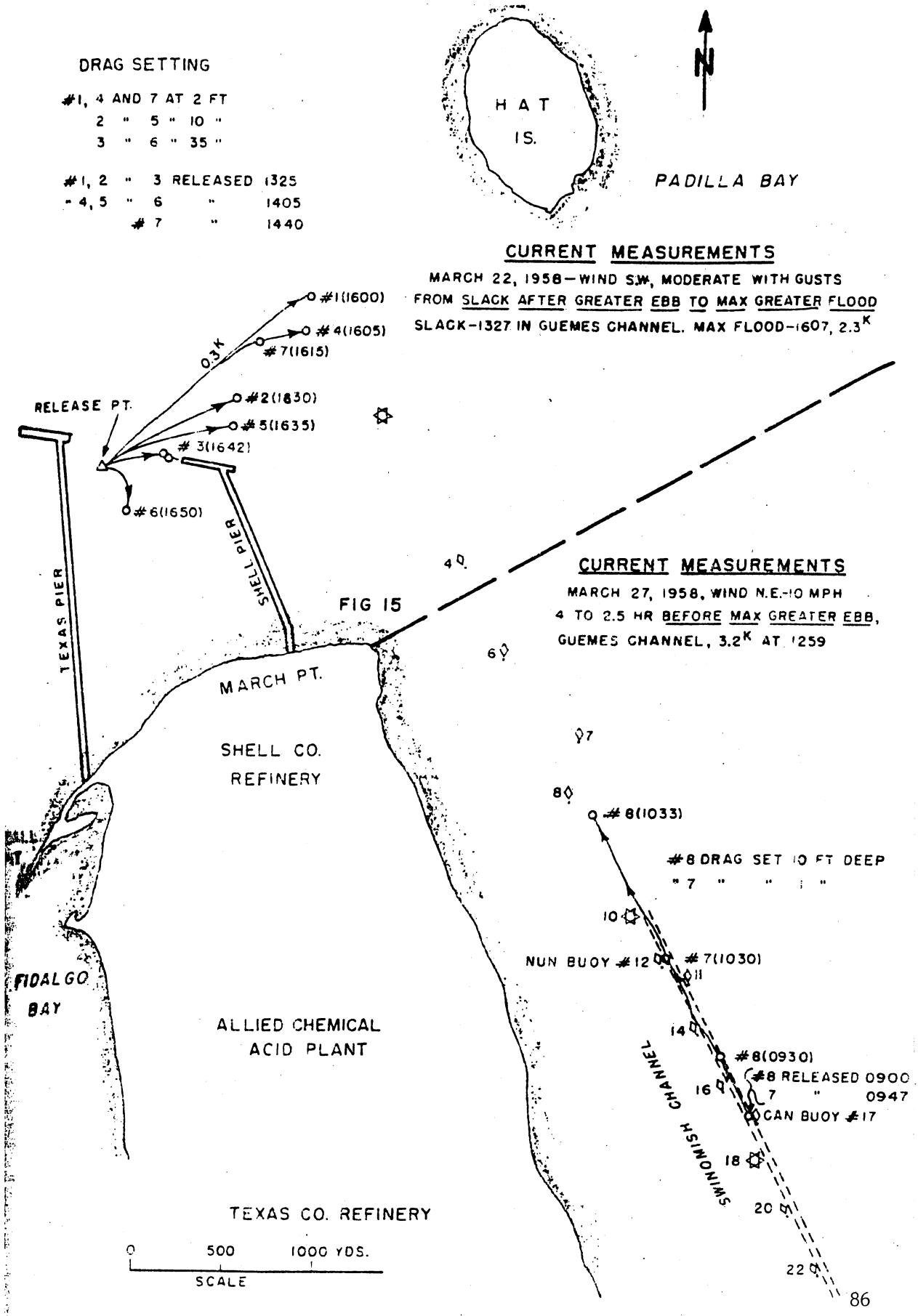

DRAG SETTING
#1, 4 AND 7 AT 2 FT
2 " 5 " 10 "
3 " 6 " 35 "
#1, 2 " 3 RELEASED 1325
" 4, 5 " 6 " 1405
7 " 1440
HAT IS.
PADILLA BAY
N
CURRENT MEASUREMENTS
MARCH 22, 1958—WIND S.W., MODERATE WITH GUSTS
FROM SLACK AFTER GREATER EBB TO MAX GREATER FLOOD
SLACK-1327 IN GUEMES CHANNEL. MAX FLOOD-1607, 2.3K
#1(1600)
#4(1605)
#7(1615)
0.3K
RELEASE PT.
#2(1630)
#5(1635)
#3(1642)
#6(1650)
TEXAS PIER
SHELL PIER
FIG 15
CURRENT MEASUREMENTS
MARCH 27, 1958, WIND N.E.-10 MPH
4 TO 2.5 HR BEFORE MAX GREATER EBB,
GUEMES CHANNEL, 3.2K AT 1259
MARCH PT.
SHELL CO.
REFINERY
#8(1033)
#8 DRAG SET 10 FT DEEP
" 7 " " 1 "
NUN BUOY #12
#7(1030)
FIDALGO BAY
ALLIED CHEMICAL
ACID PLANT
#8(0930)
#8 RELEASED 0900
7 " 0947
CAN BUOY #17
SWINOMISH CHANNEL
TEXAS CO. REFINERY
0 500 1000 YDS.
SCALE

FIG 16

Swinomish Channel, North Approach: Drags released at 1- and 10-foot depths in the channel approach, at about the time of slack water before ebb in Guemes Channel (Fig. 16), moved rapidly down the channel in a northerly direction. This movement was against a 10 m.p.h. NE wind.

Computation of Inflow and Outflow

A computation of the approximate inflow and outflow to Fidalgo, Padilla and Skagit Bays for September 10 and 11, 1958 is given in Table 7. The table was constructed using U.S.C. & G.S. tide and current tables and current measurements made in the field, considering the flow in Guemes and Swinomish Channels as being similar to the flow pattern found in a deep-flowing river. The table indicates that Guemes Channel on an ebb tide passes from two to three times the volume of water that lies in the entire tidal prism of Fidalgo and Padilla Bays. This large volume of additional water that is carried out into Rosario Strait must come from the water masses north of William Point since the inflow from Swinomish Channel is less than 3 percent of the tidal prism volume in Fidalgo and Padilla Bays. On the flood tide, the discharge volume through Guemes Channel is only slightly greater than the intertidal volume in Fidalgo and Padilla Bays, resulting in a small water movement northward of William Point from Padilla Bay.

Subtracting the tidal prism volume in Swinomish Channel from the inflow and outflow at the northern end of the channel, Table 7 shows that on an ebb tide, over half of the outflow into Padilla Bay comes from Skagit Bay. On a flood tide, the inflow to the channel from Padilla Bay exceeds by only a small amount the intertidal volume in the channel. This leaves a minor water surplus for inflow to Skagit Bay. While these computations were made only for the period of September 10 and 11, 1958, it is considered that their over-all implications roughly represent the normal water mass

Table 7 - Computation of Approximate Inflow and Outflow to Fidalgo and Padilla Bays[1]

Location	Current	Period Hrs.	Average[2] Velocity Ft./Sec.	Tidal[3] Range, Feet	Average Channel Cross-Sect. Ft.^{2} x 10^{-3}	Discharge Volume Acre-Feet x 10^{-3}	Tidal[5] Prism Volume Acre-Feet x 10^{-3}	Flow Into (+) or From (-) Skagit Bay[6] Acre-Feet x 10^{-3}
Guemes Channel	Ebb	8.2	2.2	6.7	214.6	320	147	-
" "	Flood	6.0	1.6	7.4	215.8	171	163	-
" "	Ebb	6.8	1.7	2.9	223.7	213	64	-
" "	Flood	4.3	0.8	2.4	222.7	64	53	-
Swinomish Channel[4]	Ebb	6.2	1.4	6.7	6.58	4.7*	2.8	2.7-
" "	Flood	6.0	0.9	7.4	6.80	3.0	3.1	0
" "	Ebb	6.5	1.1	2.9	8.28	4.9	1.2	3.7-
" "	Flood	4.4	0.4	2.4	8.10	1.2	1.0	0.2+
" "	Ebb	2.2	0.8	6.9	6.64	1.0*	2.9	4.1-

* For portion of ebb only.

1. From 0110 on September 10 to 0224 on September 11, 1958, using U.S.C. and G.S. Current and Tide Tables and current data obtained by field measurement in Guemes and Swinomish Channels.
2. Avg. vel. in center of channel = 0.85 x velocity given in current table.
   " " " channel cross-section = 0.7 x avg. vel. at channel center line.
   " " during tidal cycle = 0.6 x max. velocity given in tables.
3. Using N. entrance for Swinomish Channel.
4. Ebb is northerly flow and flood is southerly flow.
5. For Fidalgo and Padilla Bays, east of Port Dock and south of William Pt.-Clark Pt.; mean tidal area of 22,000 acres.
6. Swinomish Channel mean tidal area of 420 acres. Inflow and outflow computed for entire tidal cycle.

distribution for the area. These calculations for the Swinomish Channel outflow corroborate observations (34) made by the Washington Department of Fisheries.

A study of the water quality data tends to verify the calculations in Table 7. However, this verification is not conclusive since water samples were collected at different times and because there is mixing of the water between stations.

Current Summary

Current studies indicate that Fidalgo and Padilla Bays are filled through Guemes Channel and that the flood flow is sufficient to pass water through Swinomish Channel into Skagit Bay and to cause a slight northerly flow past William Point. The ebb flow through Guemes Channel is more than double the flood flow during a tidal day. Considerably more than half of the ebb flow in Guemes Channel comes from the water masses northward of William Point. The majority of the ebb flow passing into Padilla Bay from Swinomish Channel originated in Skagit Bay.

Appendix D-2. Excerpts from Shannon Point Marine Lab Physical Oceanography Class (1991) that refer to currents and current studies in Swinomish Channel (page 27, figures 9 & 10).

TIDAL CURRENTS AND DIRECTION

Tidal currents were measured with a surface drogue during flood tides on four separate occasions; 04-12-90, 05-10-90, 05-24-90 and 06-05-90. Drogue trajectories for these dates are shown in Figure 9.

On 04-12-90, the drogue was deployed at a point in Guemes Channel north, northeast of Cap Sante. The drogue followed an eastward course at an average velocity of 0.5m/s.

On 05-10-90, the drogue was deployed between southeast Point and Hat Island. It was initially carried south approximately 300m, then began a northeastward path. The average velocity was 0.7m/s.

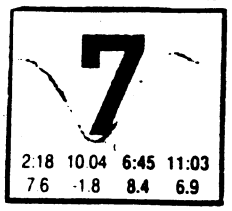
On 05-24-90, the drogue was deployed at a point due east of Cap Sante and was initially carried west approximately 200m before being swept eastward. The average velocity was 0.5m/s.

On 06-07-90, the drogue was deployed north, northeast of March Point and was carried on a vector to the south at a rate of 0.5 m/s.

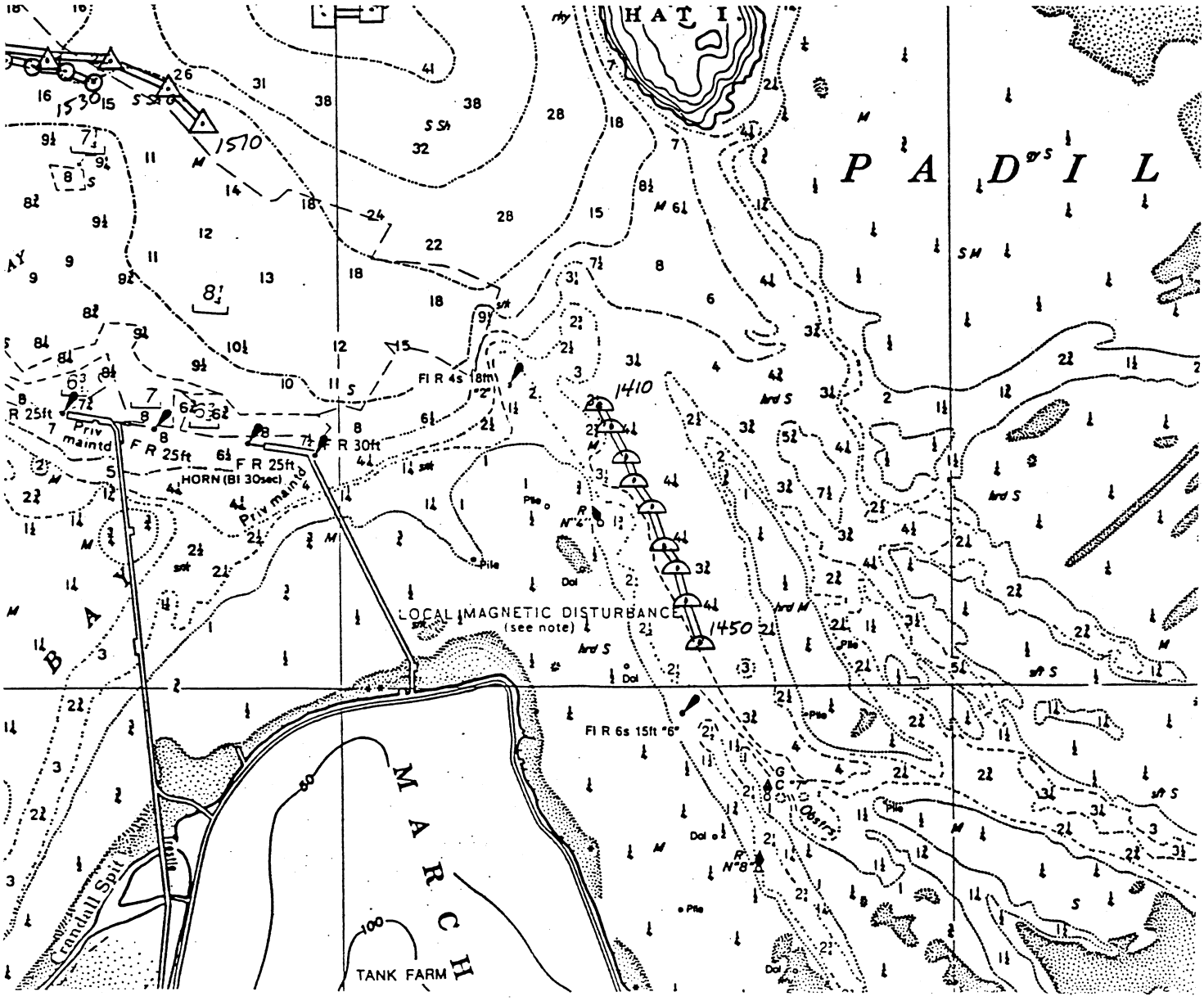
The drogue data from 05-24-90 indicated that flood tide flow through Guemes Channel creates a clockwise eddy to the east of Cap Sante. The water on the south side of Guemes Channel appears to flow in a generally eastward direction, then gradually veers south midway between Cap Sante and Hat Island. The 05-10-90 data suggests two main currents flow in the vicinity of Southeast Point, one flowing southward along the east side of the point and another flowing eastward along its southern aspect. The southward flow causes a southern deflection of eastbound waters of Guemes Channel. Waters south of Hat Island appear to flow generally toward the Swinomish Channel. The above observations apply to flood tides only.

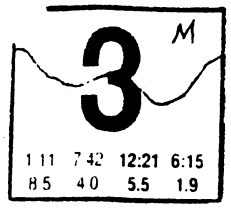
Tidal current velocities and directions during non-flood tides were determined using drogue trajectories on two occasions. These trajectories are depicted in Figure 10. On 04-19-90, a subsurface drogue at a 15m depth was deployed approximately 300m southwest of the southern tip of Hat Island. The drogue proceeded to travel due west at a velocity of approximately .31m/s for a distance of 275m. On 05-03-90, a surface drogue was deployed approximately 500m east of the northern tip of March Point near Buoy #6. The drogue proceeded to travel in a north-northwest direction toward Hat Island at a velocity of .11m/s for a distance of 230m.

Results of the deep drogue trajectory indicates that during non-flood or ebb tide there is a general westward deep tidal current southwest of Hat Island flowing toward Guemes Channel. The surface drogue trajectory east of March Point indicates that there is a surface tidal current during non-flood periods, flowing northwest from the Swinomish Channel direction toward the center of the study area and Guemes Channel.



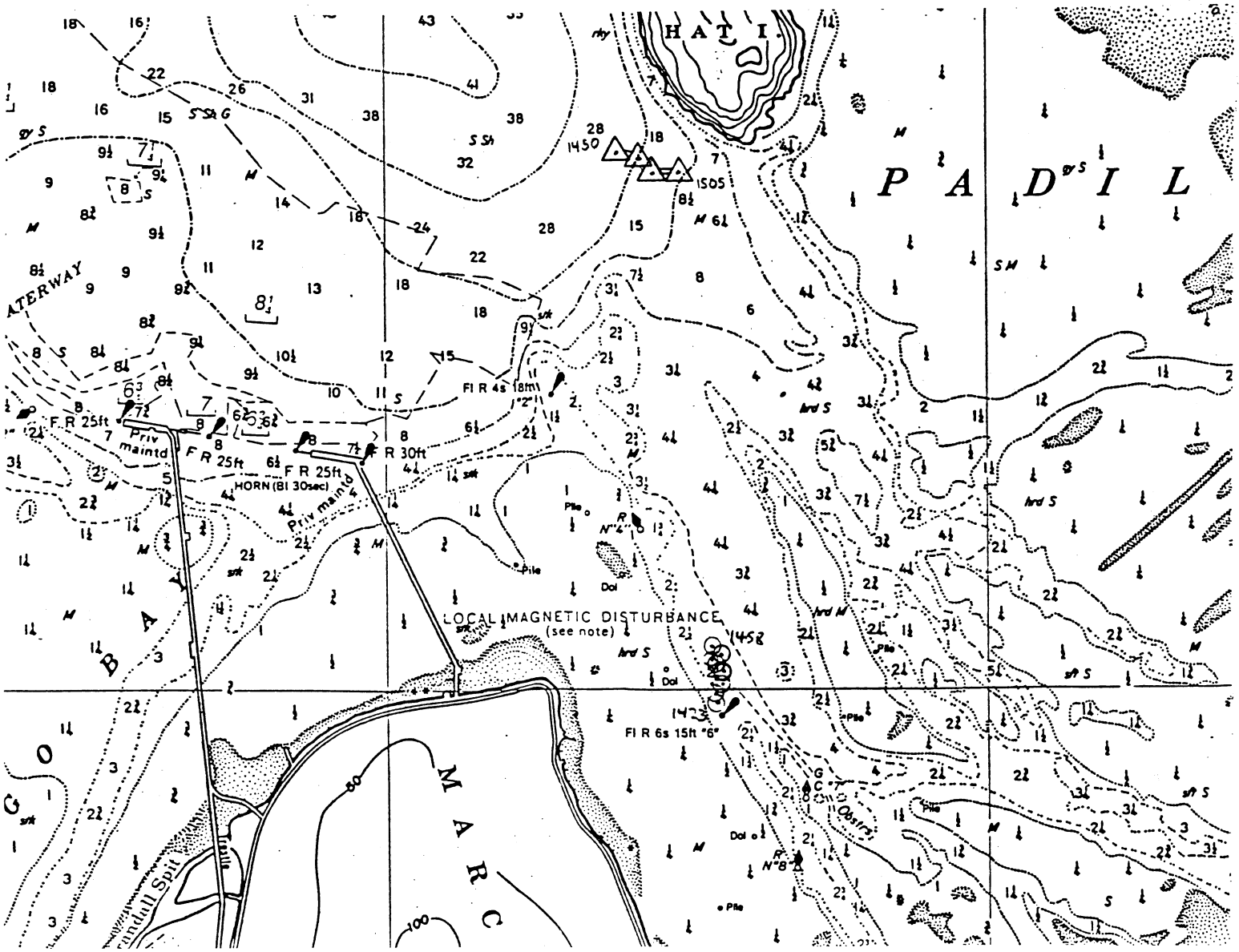
06-07-90
Symbol:
Time: 1410-1450





05-03-90
Symbol: O
Time: 1423 - 1458

Velocity: .11 m/s



Appendix D-3. Excerpts from URS Corporation (1985?) that refer to currents and current studies in Swinomish Channel (pages 3-18 to 3-21).

3.4.4 SIGNIFICANT UNAVOIDABLE ADVERSE IMPACTS

None are expected.

3.5 WATER QUALITY

3.5.1 AFFECTED ENVIRONMENT

The Swinomish Marina would be located on the west side of the Swinomish Channel which connects Skagit and Padilla Bays (refer to Figure 1-1). The Swinomish Channel is a tidal channel which experiences swift tidal currents and has a net northerly flow. Padilla Bay is a shallow bay with extensive mud flats exposed at low tide. Sixty (60) percent of Padilla Bay is exposed mudflat at low tide.

There are no major direct freshwater inputs to Padilla Bay although the Swinomish Channel does carry Skagit River water into the Bay. Rainfall in the area averages 26 inches per year. Winds are generally from the southeast in winter and from the southwest in summer.

Current Regime

The mean tidal range in Padilla Bay is 8.4 feet. This is the average height difference between mean higher high water and mean lower low water. The mean tidal range in Skagit Bay is 11.5 feet. Most of this difference is due to a much higher high tide in Skagit Bay. In addition low and high tides occur about one-half hour earlier in Skagit Bay. The flow in the Swinomish Channel reverses with tides. However, a net northerly flow exists because of the time and height differences of the tides between Skagit and Padilla Bays.

One of the major concerns of this project was the potential for contaminants from the marina to flow into the estuarine sanctuary. It has been established that there is a net northerly flow in the Swinomish Channel and a net westerly flow in Guemes Channel (Ebbesmeyer et al, 1980). However, between these two areas circulation was poorly understood.

A drift sheet study was conducted in Padilla Bay to determine the speed and direction of tidal currents in the area of the proposed marina (Quinlan et al., 1986). Drift sheets were deployed near potential marina entrance sites. Trajectories measured on February 22 and 23, 1985 are shown in Figures 3-6 and 3-7. The starting and ending times are listed for each trajectory. The start of the trajectory is marked with the drift sheet number. Current speeds associated with the trajectories shown in Figures 3-6 and 3-7 are listed in Table 3-4.

For the most part, the drift sheets followed the swift moving currents in the channel. In only one instance did a drift sheet move into the eastern half of Padilla Bay. This implies that discharges of materials from the marina would tend to move north-northwest along the channel toward Guemes Channel. Once in Guemes Channel, water tends to move westerly out of the area.

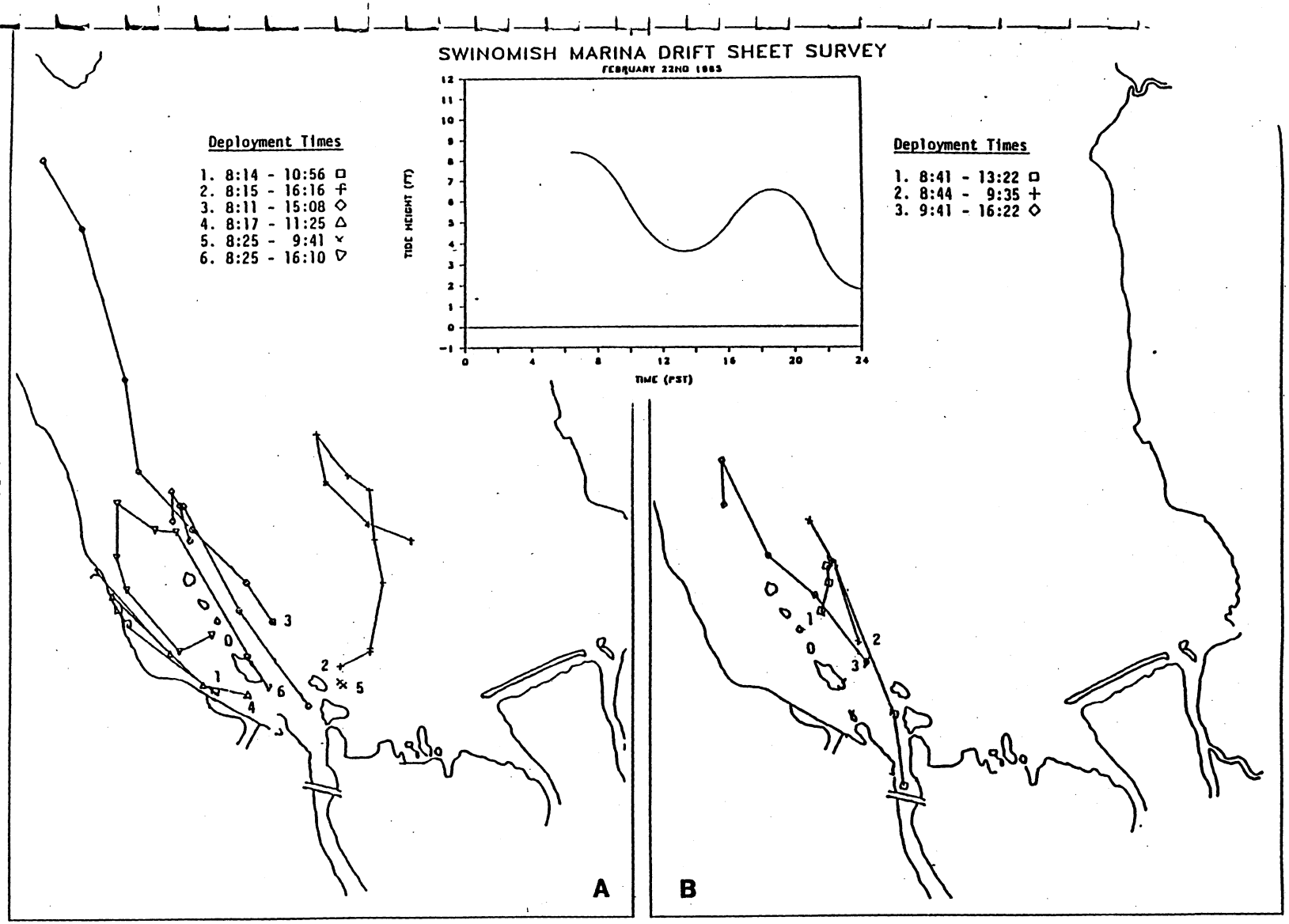


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FIGURE 3-6
DRIFT SHEET TRAJECTORIES MEASURED ON FEB. 22, 1985 DURING EBB AND FLOOD TIDES

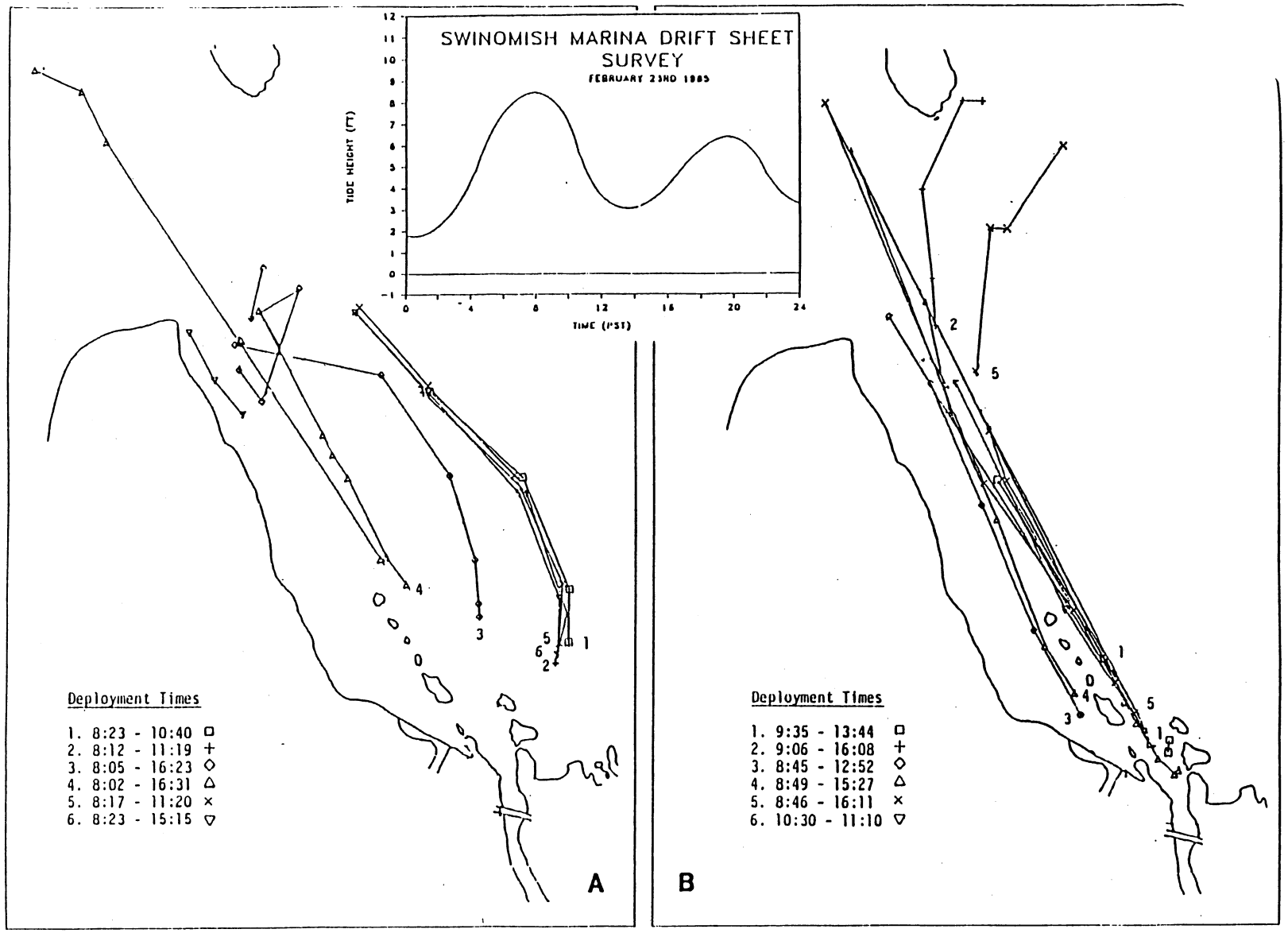
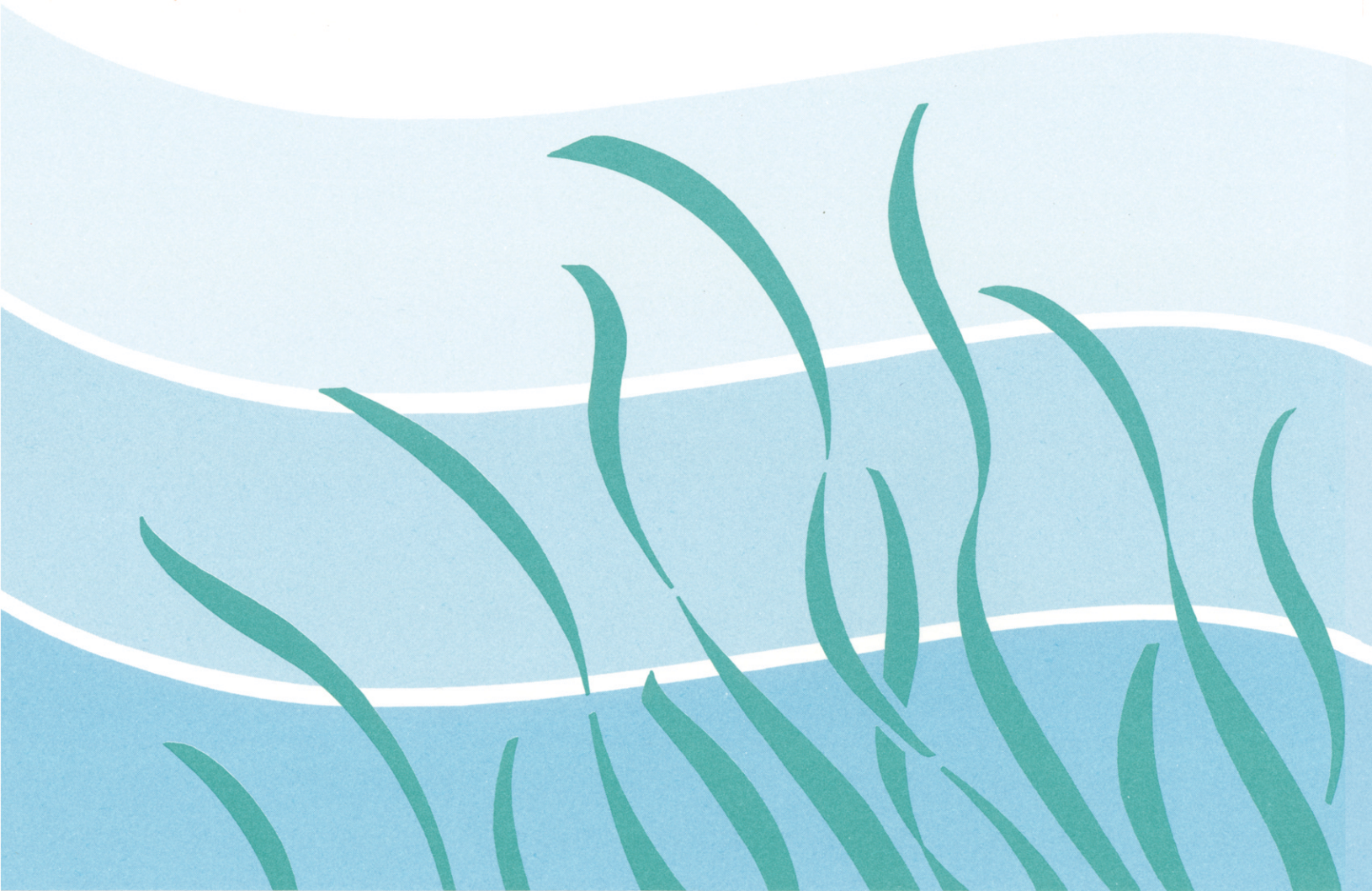


FIGURE 3-7
DRIFT SHEET TRAJECTORIES MEASURED
ON FEB. 23, 1985 DURING EBB AND FLOOD TIDES

TABLE 3-4

Average Current Speeds of Drift Sheets Shown in Figures 3-6 and 3-7

Refer to Figure	Drift Sheet No.	Speed (cm/s)	Refer to Figure	Drift Sheet No.	Speed (cm/s)
3-6A	1	15	3-7A	1	44
	2	14		2	45
	3	40		3	37
	4	24		4	54
	5	5		5	43
	6	19		6	27
3-6B	1	24	3-7B	1	35
	2	68		2	29
	3	19		3	35
				4	21
				5	39