Exxon Valdez Oil Spill
Restoration Project Annual Report

Oceanography of Prince William Sound Bays and Fjords

Restoration Project 98297

Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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September 1998

Oceanography of Prince William Sound Bays and Fjords

Restoration Project 98297
Annual Report

Study History: Unexpectedly small Prince William Sound pink salmon runs in 1992 and 1993, and the almost complete collapse of the herring fishery in 1993, prompted the *Exxon Valdez* Oil Spill Trustee Council to initiate ecosystem-level studies of the region to investigate possible environmental reasons for these disasters. A collaborative effort involving the University of Alaska Fairbanks, the Prince William Sound Science Center, the Prince William Sound Aquaculture Corporation, and Alaska Department of Fish and Game resulted in the development of a coordinated plan in the fall of 1993. After substantial review, Sound Ecosystem Assessment (SEA) was approved for funding April 11, 1994. A scope of work for SEA was projected over 5-8 years at that time. Annual reports were issued in 1995 by D. K. Salmon (project number 94320-M), and in 1996, 1997, and 1998 by S. L Vaughan (project numbers 95320-M, 96320-M, and 97320-M), all as chapter contributions to the single compiled report of all SEA projects. Project results have been presented at professional meetings in 1996, 1997 and 1998. A journal article was submitted for publication in 1996 by S. M. Gay in the 1995 IAPSO Conference Proceedings. This project (98297) is a continuation of the work funded in previous years under SEA to provide physical oceanographic support to the herring component of SEA (320-T). The data collected under this project will be included in the SEA Final Report (320).

Abstract:

Observations have shown that Eaglek Bay, Whale Bay, Simpson Bay, and Zaikof Bay in Prince William Sound (PWS) historically have supported large numbers of juvenile Pacific herring. Since 1995 these 4 bays have been the focus of the Sound Ecosystem Assessment (SEA) Herring group (320-T). Hydrographic surveys and current velocity measurements from October 1995 to March 1998 show significant differences in water mass properties and circulation patterns between these 4 bays. The FY98 physical data presented here will be combined with data from previous years, and correlated with biological measurements. SEA Physical Oceanography (320-M) provided support for SEA Herring in the past, but support in FY98 was not possible because of scheduled funding cuts. This project provided physical support for the SEA Herring project, and documented physical conditions in their third and final winter sampling period, October 1997 - March 1998. The goal of this research is to identify physical factors that influence the survival of juvenile Pacific herring in PWS.

Key Words: physical oceanography, temperature, salinity, circulation, Prince William Sound, Eaglek Bay, Simpson Bay, Whale Bay, Zaikof Bay.

Project Data: Data types include temperature, salinity, dissolved oxygen, current velocity, fluorescence, zooplankton, temperature logger moorings, and satellite tracked drifting buoys, all in ascii format. The custodian of the data is S. L. Vaughan, Prince William Sound Science Center, P. O. Box 705, Cordova, Alaska, 99574, 907-424-5800, 907-424-5820 (fax), vaughan@pwssc.gen.ak.us. The data will be available after publication.

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September 28, 1998

Dr. Bob Spies
Applied Marine Sciences
2155 Las Positas, Suite S
Livermore, CA 94550

Dear Bob:

Enclosed are 3 copies of the annual report for my FY98 project entitled Oceanography of Prince William Sound Bays and Fjords (98297). I think this fulfills all the requirements. Please let me know if not. And please let me know if you have any questions.

Sincerely,

Shari

Shari L. Vaughan

cc: Stan Senner
Bruce Wright

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Executive Summary

A main objective of the Sound Ecosystem Assessment (SEA) project is to identify mechanisms that influence the survival of juvenile Pacific herring in Prince William Sound (PWS). The peripheral bays and fjords of PWS are known regions of concentrated Pacific herring spawning. Juvenile herring overwinter in these areas before joining adult populations. Four locations, Eaglek Bay, Simpson Bay, Whale Bay, and Zaikof Bay, were selected for study. Simpson Bay and Zaikof Bay are shallow bays; Whale Bay and Eaglek Bay are fjords. Oceanographic surveys were conducted in October 1997 and March 1998 in these 4 areas to document seasonal and interannual changes in temperature, salinity, and current velocities. Temperature logger moorings provided time series of temperature throughout the winter months. Satellite tracked drifting buoys provided information about how larvae in one bay (Port Gravina) might spread to the central Sound.

Comparison of these data with data from 1995 through 1997, show that the spatially averaged temperature, salinity, and density vertical structure for each region is relatively constant over time. The two fjords seem less connected to the central Sound in March, based on water mass properties, suggesting that they may be isolated during the winter. The fjords also show earlier stratification formation, which could lead to an earlier spring bloom and more food for juveniles.

Both bays and fjords often exhibit warmer surface temperatures at the heads than at the mouths. Potential retention mechanisms exist in the form of density fronts and current velocity shears. Circulation patterns within each bay are more constant in October than March. Current velocities are generally reduced within each bay, or at least some portion of each bay. Correlations with the fish data will reveal which conditions and structures enhance juvenile herring survival.

The temperature logger mooring time series show that most changes are related to atmospheric cooling events. Some of the deep variability is not linked to the surface. The drifting buoy trajectories showed that four drifters remained in Port Gravina from May to September, two exited Port Gravina quickly and left the Sound through Hinchinbrook Entrance, and three remained in the Gravina/Knowles Head area for one to two months before escaping to the central Sound

Introduction

A main objective of the Sound Ecosystem Assessment (SEA) project is to identify mechanisms that influence the survival of juvenile Pacific herring in Prince William Sound (PWS). The peripheral bays and fjords of PWS are known regions of concentrated Pacific herring spawning. Juvenile herring overwinter in these areas before joining adult populations. In 1996, the SEA Herring group (320-T) selected 4 overwintering locations as the focus of their study: Eaglek Bay, Simpson Bay, Whale Bay, and Zaikof Bay. Simpson Bay and Zaikof Bay are shallow bays; Whale Bay and Eaglek Bay are fjords. Spatially, they represent samples of 4 sub-regions of PWS (Figure 1).

A main objective of the physical oceanography component of SEA (320-M) is to determine what physcial factors influence the survival of juvenile Pacific herring. Why do the distribution of juveniles vary between bays from year to year, and why do their numbers change? It was hypothesized that bays or fjords with retention mechanisms, such as density fronts or eddies, would support higher juvenile populations than those without. A goal of the SEA oceanography component is to identify potential retention mechanisms. Another goal is to document seasonal and interannual changes in the water mass properties (temperature, salinity, and density) and circulation patterns in the 4 nearshore regions. It was hypothesized that quality of habitat also influenced the survival of juvenile herring.

Previous EVOS Work

From October 1995 to March 1997, measurements of temperature, salinity, oxygen, current velocity, fluorescence, and zooplankton data were collected in Whale, Eaglek, Simpson, and Zaikof Bays by SEA Physical Oceanography (320-M). Vertical sections of temperature, salinity, density, and current velocity were created for each cruise. Horizontal contours of temperature, salinity, and density, and horizontal velocity vector plots were also created. These hydrographic data show that unlike most of PWS, Eaglek Bay and Whale Bay (fjords) retain their upper layer stratification throughout the year. The fresh, cold suface layer is never entirely mixed. In contrast, Simpson Bay and Zaikof Bay resemble the neutrally stratified majority of PWS in March. This may mean that Eaglek Bay and Whale Bay are less connected to the Sound than Simpson Bay and Zaikof Bay. Large differences in temperature and salinity exist between bays at the same time of year. A temperature and salinity (and density) front is present at the mouth of Zaikof Bay in March 1996, but not at other bays. No anoxic deep layers were found in any of the bays.

Vertical sections of horizontal velocity show the currents in these bays to be extremely complex and seasonally variable. Differences exist between the head and the mouth of the bay in nearly all cases. Except for Eaglek Bay, the currents at 10 meters are generally weaker at the head than at the mouth of the bays. A strong current shear exists at the mouth of Zaikof Bay on both flood and ebb tide. The density fronts and horizontal velocity shears could be responsible for the retention of zooplankton and juvenile fish in the bay. An anticlyclonic eddy was observed at the mouth of Zaikof Bay in October 1996, which could also act as a retention mechanism.

Work in FY98

The goal of this project is to extend the nearshore measurements made by SEA Oceangraphy in FY96 and FY97 into FY98. The complete data set will cover 3 overwintering periods from October 1995 to March 1998. Measurements of temperature, salinity, dissolved oxygen, current velocities, and zooplankton densities in October 1997 and March 1998,were collected for comparison with previous years' data. Fluorescence measurements were not collected on these cruises because of instrument malfunctions. To document the variability of temperature in each bay as a function of time and depth, 3 temperature logger moorings were deployed in each bay. Finally, to verify the predictions of the larval herring drift model being developed under SEA project 320-J, 9 satellite tracked drifting buoys were deployed in Port Gravina (a reliable herring spawning site) and tracked for over 4 months.

Objectives

The main objective of this research is to extend the work done by SEA Observational Oceanography (320-M) in support of SEA Herring (320-T) into FY98. The overall goal of both SEA Oceanography and this project is to identify the dominant physical processes that influence Pacific herring production in PWS. Specific goals for FY98 are:

1. Document the seasonal and interannual changes in water mass properties (temperature, salinity, and density), and circulation patterns in Eaglek Bay, Simpson Bay, Whale Bay, and Zaikof Bay during the final year of the SEA Herring project (FY98).
2. Correlate fluorescence and zooplankton distributions with water mass properties, and current velocity.
3. Identify physical retention mechanisms (fronts, eddies, etc.) within the bays.
4. Obtain time series of temperature changes throughout the winter months (October 1997 to March 1998) in each bay for use in the herring bioenergetics model.
5. Provide data to verify the predictions of a larval drift simulation using the numerical circulation model developed under SEA project 320-J.

The only objective not met was the correlation of fluorescence with water mass properties and current velocities (task 2). The fluorometer circuit boards were sent to the manufacturer for repair twice, and both times returned inoperable. Work remains to be done validating the larval drift model predictions (task 5). Combining these data with previous years data, and correlating the biological and physical measurements is ongoing.

Methods

Oceanographic cruises were conducted in Eaglek Bay, Simpson Bay, Whale Bay, and Zaikof Bay in October 1997 and March 1998 as part of a two vessel survey. One vessel collected the oceangraphic data presented here, the other collected net samples and performed acoustic surveys (under SEA project 320-T). Stations and transects occupied were the same as in previous surveys (Vaughan et al, 1997).

The hydrographic data was collected using a SeaBird 19.03 CTD. Conductivity, temperature, and dissolved oxygen as a function of pressure were recorded at 1 dbar intervals. Salinity was calculated from conductivity using standard SeaBird software. The CTD sensors were calibrated annually by SeaBird Electronics. The CTD salinities and oxygens were not calibrated with bottle samples because of minimal annual sensor drift rate. Density was calculated from temperature, pressure, and salinity.

Instantaneous current velocity transects were collected using an RDI 150 kHz broadband acoustic Doppler current profiler (ADCP) mounted to the hull of the survey vessel. In both cruises, the vessel hull was constructed of fiberglass, so interference with the ADCP compass was minimal. Most transects were in water less than 400 m depth so that bottom tracking was available. The bin length was 4 m for most of the data. The ADCP generally measured flows from about 10 m depth to the bottom.

On previous cruises, high resolution real-time measurements of temperature, salinity, fluorescence, and zooplankton distributions were made using a Chelsea Instruments Aquashuttle towed from the vessel by a conducting cable. The Aquashuttle consists of a Focal Technologies optical plankton counter (OPC), to measure zooplankton, and a Chelsea Instruments Aquapack, which measures temperature, salinity, and fluorescence. The Aquapack was under repair during both cruises. To collect simultaneous temperature, salinity, and zooplankton measurements, a SeaBird 19 CTD was mounted to the Aquashuttle in place of the Aquapack. The modified Aquashuttle was raised and lowered vertically from the surface to about 50 meters as it was towed, sampling continuously.

To provide over-winter temperature times series data in the 4 bays, temperature logger moorings were deployed in October 1997 and retrieved in March 1998. The temperature loggers used were StowAway Tidbits manufactured by Onset Computer Corporation. Data stored internally during deployment is downloaded optically upon retrieval. The moorings consisted of a surface float, a bottom anchor, and 3 temperature loggers at depths of 5, 25 and 50 meters. Moorings were placed along the axis of each bay, near the head, middle and mouth. All moorings were retrieved successfully except two at the head and middle of Zaikof Bay, one at the head of Whale Bay.

To provide information about herring larval drift paths, nine WOCE/SVP Lagrangian drifting buoys manufactured by Technocean were deployed in Port Gravina in May 1998. The deployment schedule was 3 per day, at 3 locations in the bay, every two days. Locations were chosen on the western side of Port Gravina, between the mouth of St. Mathews Bay, and Red Head. Deployment times and locations are shown in the table below.

drifter	date	time	latitude	longitude
12073	May 13	1515	60 39.02'	146 27.06'
12068	May 13	1530	60 40.08'	146 23.97'
12067	May 13	1545	60 40.99'	146 20.02'
12066	May 15	1040	60 39.05'	146 27.01'
12071	May 15	1100	60 40.31'	146 24.00'
12072	May 15	1115	60 41.07'	146 20.06'
12070	May 17	1050	60 39.00'	146 27.14'
12069	May 17	1103	60 40.14'	146 23.85'
12065	May 17	1117	60 40.97'	146 19.92'

The buoys were satellite tracked using the ARGOS system, and were drogued with a 4 meter long cylindrical canvas 'sock', extending from about 13 meters to 17 meters below the surface. The drifters followed currents at a mean depth of approximately 15 meters. Port Gravina was chosen because of historically large areas of herring spawn. May was chosen to coincide with the appearance of the herring larvae.

Results

Water Mass Properties

Profiles of mean temperature (T), salinity (S), and dissolved oxygen (O) averaged over all stations in each bay in March 1998 and October 1997 are shown in Figure 2. Note the different axis. The March mean profiles show that the 2 bays, Simpson and Zaikof, are vertically well mixed, similar to central PWS. The fjords, Whale and Eaglek, have surface temperature and salinity stratification down to about 40 m. Similar structure was observed in March 1996 and 1997 (Vaughan et al, 1997, Figures 20-23). This could indicate that the fjords are more isolated from the Sound and from local atmospheric mixing processes in March. Early stratification in the fjords may lead to an early spring phytoplankton bloom in those regions.

In October, the fjords exhibit pronounced temperature layer maximums (Figure 2), similar to December observations in the central Sound. The bays exhibit weak maximums or none. Similar structure was observed in October 1995 and 1996 (Vaughan et al, 1997, Figures 20-23). In the bays, temperature generally decreases and salinity increases with depth.

Mean T/S diagrams averaged over all stations in each bay in October 1997 and March 1998 are shown in Figure 3. The 2 bays (Simpson and Zaikof) have simiar T/S characteristics in both October and March (Figures 3(b) and (c)). The well mixed condition of the bays in March can be seen clearly. In March, the 2 fjords have similar properties (Figure 3(d)); the fresher, slightly colder upper mixed layer is apparent. In October, the T/S properties of the fjords differ, indicating the influence of local effects.

To document the spatial variability of temperature, salinity, and density in each bay, horizontal contours of properties averaged over 5 to 10 m were created from the towed CTD for October 1997 (Figures 4-6) and March 1998 (Figures 7-9). Note the different contouring intervals. In October, surface temperatures were warmer at the heads of all 4 bays that at the mouths (Figure 4). The strongest along axis temperature gradient existed at Eaglek Bay (Figure 4(a)). The heads of Eaglek Bay and Zaikof Bay were saltier than at the mouths (Figure 5). The strongest salinity gradient was at Eaglek Bay (Figure 5(a)), and weakest at Simpson Bay (Figure (b)). Horizontal density contours (Figure 6) revealed the presence of a density front in Eaglek Bay (Figure 6(a)). Density gradients in the other bays in October were weak.

In March, surface temperatures were warmer at the heads of Eaglek Bay (Figure 7(a)) and Whale Bay (Figure 7(c)). Temperatures in the two bays, Simpson and Zaikof (Figures 7(b) and (d)) were nearly uniform. The two bays were also more uniform in salinity than the two fjords (Figure 8). Horizontal density gradients are strongest on the western side of Eaglek Bay (Figure 9(a)) and at the mouth of Whale Bay (Figure 8(c)). Density gradients in Simpson and Zaikof Bay in March are weak (Figures 9(b) and (d)).

Circulation

Velocity vectors from 10 m depth for ebb and flood tides in each bay are shown in Figures 10-13. Note the different vector length assignments. On one or both tide stages, velocities at the mouths of Zaikof Bay (Figure 13), Whale Bay (Figure 12), and Simpson Bay in October (Figure 11(a) and (b)) are stronger than velocities inside the bays. These horizontal velocity shears might contain juvenile fish within the bay. Regions with weak flows are found in all bays. Zaikof Bay has the most uniform flow field (Figure 13).

No ADCP measurements are available from March 1997. Comparison with velocities at 10 m from October 1996 and March 1996 (Vaughan et al, 1997, Figures 26 and 27) show some simiarities in all bays in October. In March, only Zaikof Bay exhibits similar patterns between 1998 and 1996.

Kenai, into Cook Inlet, past Kodiak Island, and is now in the Alaska Stream south of the Aleutians. The other (12070) meandered around Orca Inlet and exited PWS around June 2 (Figure 23). It traveled southwestward, rounded the southern tip of Montague Island, and re-entered PWS through Montague Strait. It stopped by Green Island for a week, rounded the north end of Montague Island, exited PWS through Hinchinbrook Entrance again, and ran aground near Patton Bay. A fisherman retrieved it and redeployed it south of Perry Island. It made an anticyclonic revolution around the island, and traveled to the western side of Port Nellie Juan.

Of the 3 that remained in the general area, one (12068) circulated around the Knowles Head region, and stopped transmitting prematurely after it approached the tanker lane (Figure 21). The second (12066) stopped at Knowles Head for about a month before it moved to northern PWS (Figure 19). It came south in a large anticyclonic arc, and spent a couple weeks around Smith Island. It went north, east of Naked Island, then south again to Middle Point between Rocky and Zaikof Bay, where it may have run aground. It stopped transmitting September 7.

The third drifter (12073) stayed in St. Mathews Bay for about 2 months before exiting Port Gravina on July 24 (Figure 26). It traveled diagonally across the Sound to the northern end of Knight Island. It meandered along the eastern side of Knight Island, and gradually across to the western side of Montague Island, where it ran northeastward along the coast to Port Chalmers.

Discussion

As shown in previous years' data, differences in temperature, salinity, and current veloicty exist between the 4 nearshore regions. Comparison of these data with data from 1995 through 1997, show that the spatially averaged temperature, salinity, and density vertical structure for each region is relatively constant over time. The two fjords (Eaglek Bay and Whale Bay) seem less connected to the central Sound in March, based on water mass properties, suggesting that they may be isolated during the winter. The fjords also show earlier stratification formation, which could lead to an earlier spring bloom and more food for juveniles.

Both bays and fjords often exhibit warmer surface temperatures at the heads than at the mouths. Potential retention mechanisms exist in the form of density fronts (at Eaglek Bay) and current velocity shears (at Zaikof Bay and Whale Bay). Circulation patterns within each bay are more constant in October than March. Current velocities are generally reduced within each bay, or at least some portion of each bay. Correlations with the fish data will reveal which conditions and structures enhance juvenile herring survival.

The temperature logger mooring time series show that most temperature changes are related to atmospheric cooling events. Some of the deep variability (at Simpson and Whale Bay) is not linked to the surface. More time series analysis of these temperature records is needed to relate temperature changes at each level to the atmospheric forcing.

The drifting buoy trajectories showed that 4 drifters remained in Port Gravina from May to September. It is possible that some or all may now be aground. An anticyclonic circulation was present in the central Sound. In June 1997, drifter trajectories showed a cyclonic circulation was present. Two drifters showed that the upper layer flow at Hinch-

OPC Data

Particle counts measured by the Optical Plankton Counter (OPC) were very low, averaging about 15 counts/second, in the bays sampled in October 1997 and March 1998. The particles sampled were also very small; most were less than 1 mm equivalent spherical diameter (ESD). Particles in this size range could include small zooplankton, chain-forming phytoplankton, or other detritus particles. Early stages of calanoid copepods can be found in the surface waters in early March, and small calanoid adults can persist into the fall. Phytoplankton can be sampled in the surface waters in early March and, given the proper oceanographic conditions, on into the fall months, as well. The fluorometer which is normally deployed with the OPC was under repair in both October and March, so no direct measurements of chlorophyll are available to compare with the OPC particle counts. Such a comparison might indicate if patches of slightly higher OPC particle counts in these bays were correlated with patches of chlorophyll and, thus, phytoplankton. Otherwise, the higher counts could indicate higher zooplankton abundance.

Temperature Logger Moorings

Time series of temperature from all 4 bays from October 1997 to March 1998 are shown in Figures 14-17. Generally, the greatest differences are vertically rather than horizontally. Except at Zaikof Bay, the 5m records contain more variability than the 50m records (e.g., Figure 14(c)). Cooling events at 5m can be seen in the 25 and 50m records, but the magnitudes are less (e.g., Figure 15(a)). The same cooling events can be seen at the mouth, middle and heads of the bays simultaneously (e.g., Figure 15(a)-(c)). Changes at the head of Simpson Bay are reduced in magnitude, but since the moorings at the heads of Zaikof and Whale Bay were not recovered, it is not possible to generalize this finding. The one mooring at the mouth of Zaikof Bay (Figure 17) shows less temperature variability there than in the other bays.

In the beginning of the 50m records throughout Simpson Bay and Whale Bay, a temperature increase occurs (Figures 15-16). The increase is not observed in the 5 and 25m records, and so is not linked to local atmospheric forcing. An intrusion of warm, dense or salty (at 50m) may have caused the increase. Vertical movement of the isopycnals due to some other mechanism might also be responsible. Since the increase occurs at both a bay (Simpson) and a fjord (Whale), a mechanism connected to fjord dynamics is less likely. A definite cause to this deep temperature increase has not yet been identified.

Drifting Buoy Trajectories

Trajectories of the satellite tracked drifting buoys are shown in Figures 18-26. Of the 9 released, 4 stayed in Port Gravina (12067, 12069, 12071, 12072), 2 exited Port Gravina quickly and left the Sound through Hinchinbrook Entrance (12065, 12070), and 3 remained in the Gravina/Knowles Head area for 1 to 2 months before escaping to the central Sound (12066, 12068, 12073). The 4 that stayed in Port Gravina were forced onshore or up into the bays and may have run aground (Figures 20, 22, 24 and 25).

Of the 2 that exited quickly, one (12065) made 9 anticyclonic revolutions in the central Sound, and exited PWS on June 15 (Figure 18(a)-(d)). It traveled westward past the inbrook Entrance in June was southward, as it was in 1997. One drifter went northward through Montague Strait, similar to trajectories in 1997. One or more drifters circulated in the nearshore regions around Smith Island, Green Island, and Montague Island. One drifter traveled west past the Kenai Peninsula, through Shelikof Strait, and into the Gulf of Alaska.

References

Vaughan, S.L., S.M. Gay, L.B. Tuttle, and K.E. Osgood, 1997: Water Mass Variability and Circulation in Prince William Sound. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 96320-M), Prince William Sound Science Center, Cordova, Alaska, 99574.

Figure 1

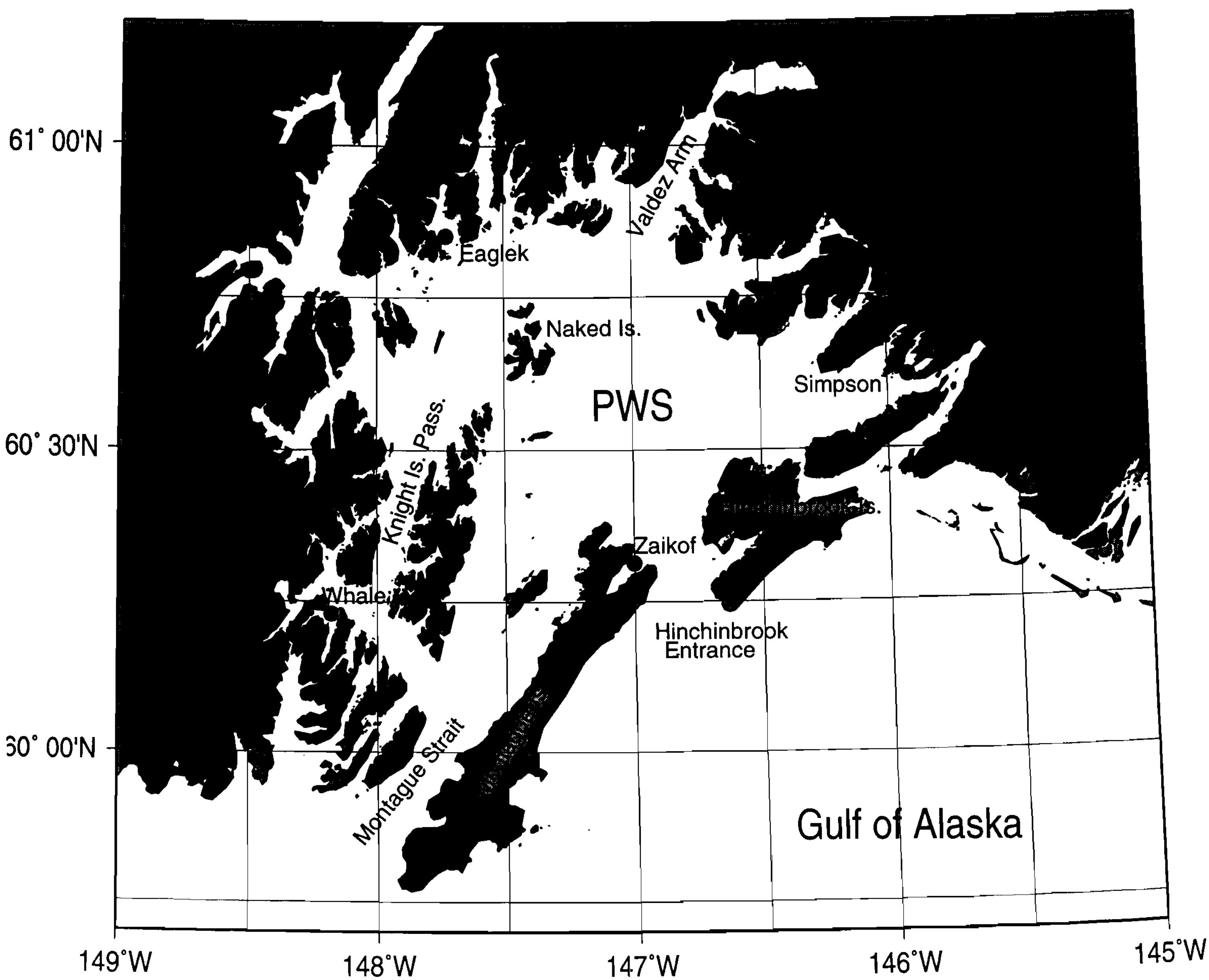
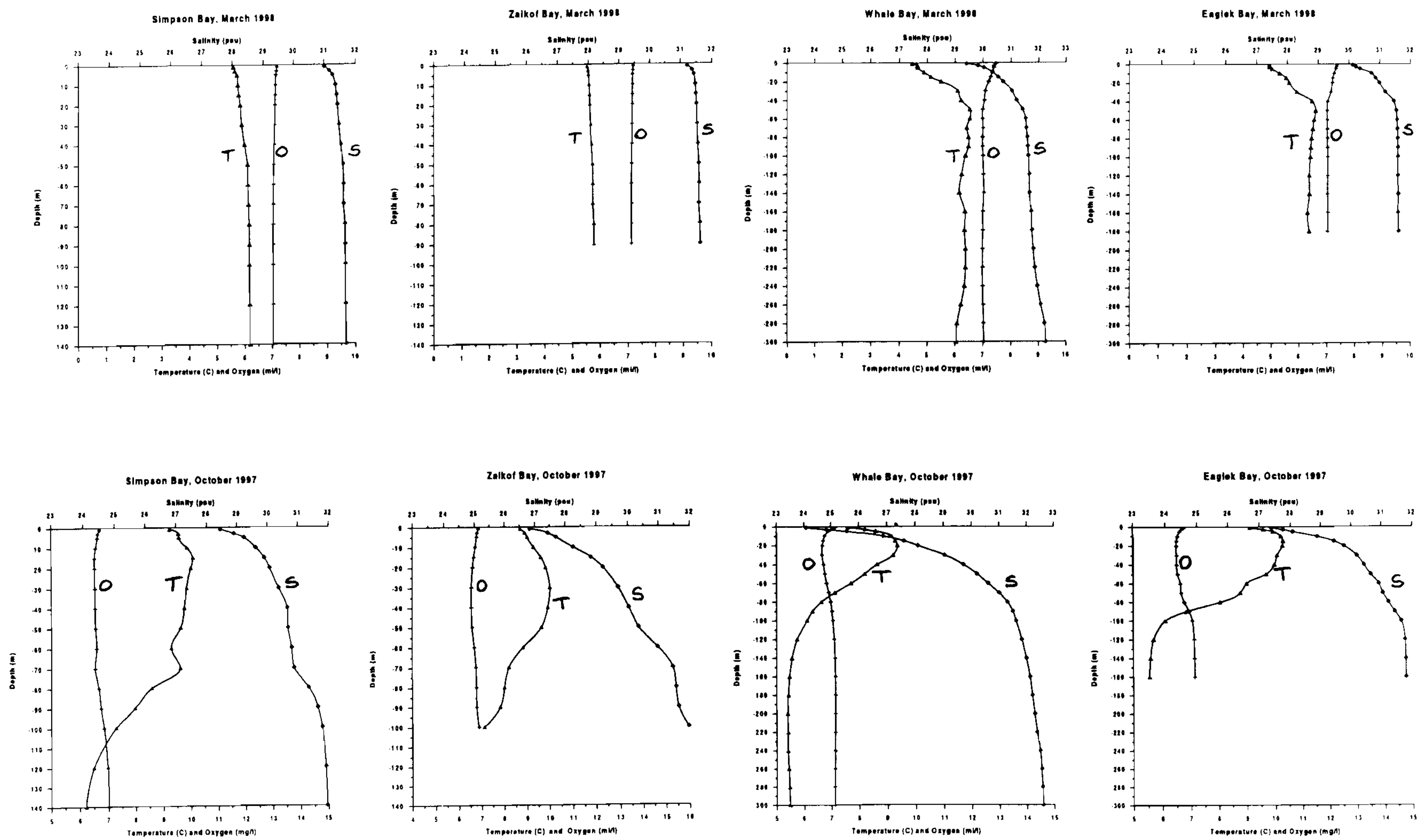

61° 00'N
60° 30'N
60° 00'N
149°W
148°W
147°W
146°W
145°W
Valdez Arm
Eaglek
Naked Is.
PWS
Simpson
Knight Is. Pass.
Zaikof
Whale
Hinchinbrook
Entrance
Montague Strait
Gulf of Alaska

Figure 2: Temperature, salinity and dissolved oxygen profiles for bays and fjords.



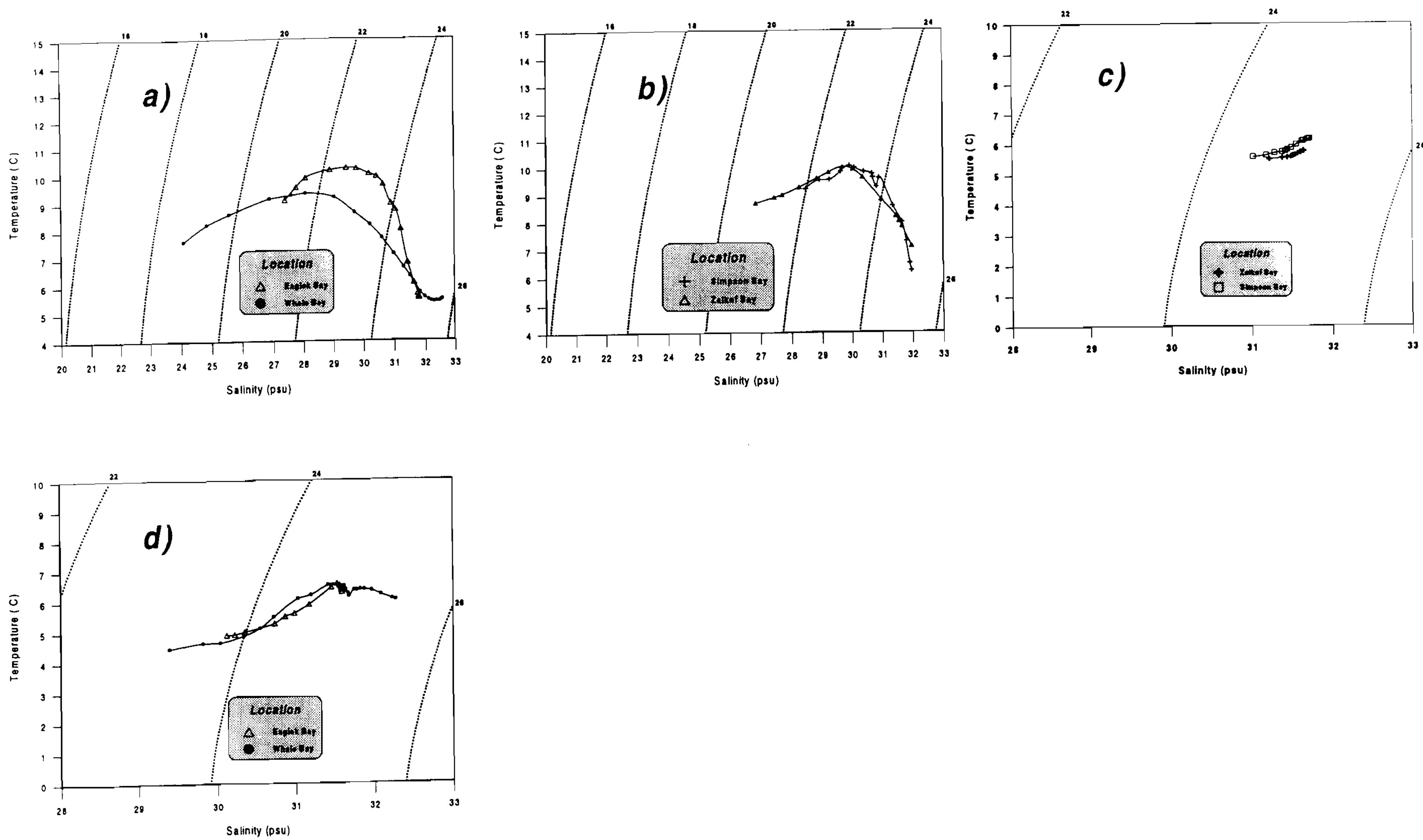


Figure 3: Temperature vs. salinity plots for locations sampled in October, 1997 (a and b), and March, 1998 (c and d).

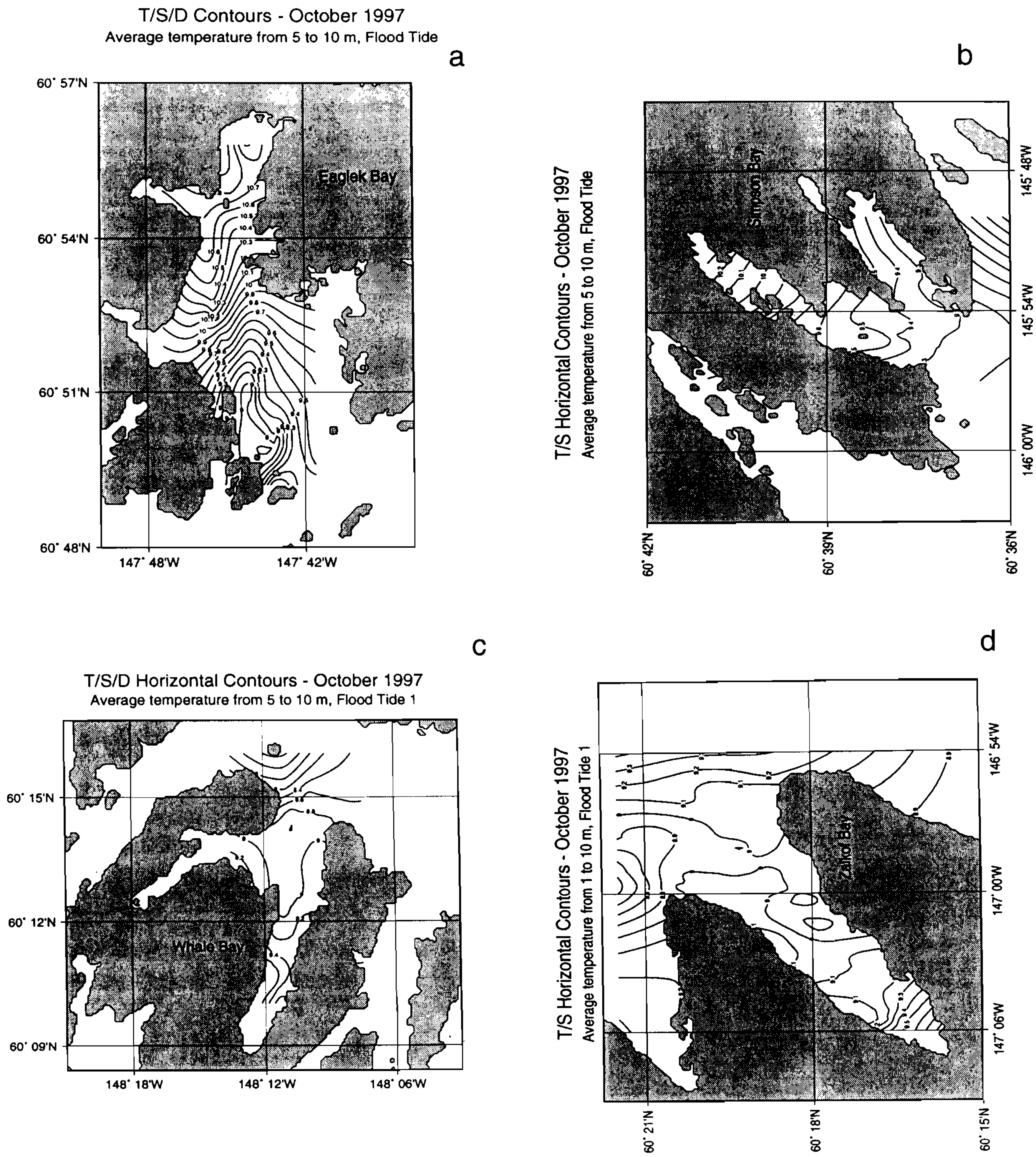


Figure 4: Average temperature from 5 to 10m on flood tide in October 1997 from (a) Eaglek Bay, (b) Simpson Bay, (c) Whale Bay, and (d) Zaikof Bay.

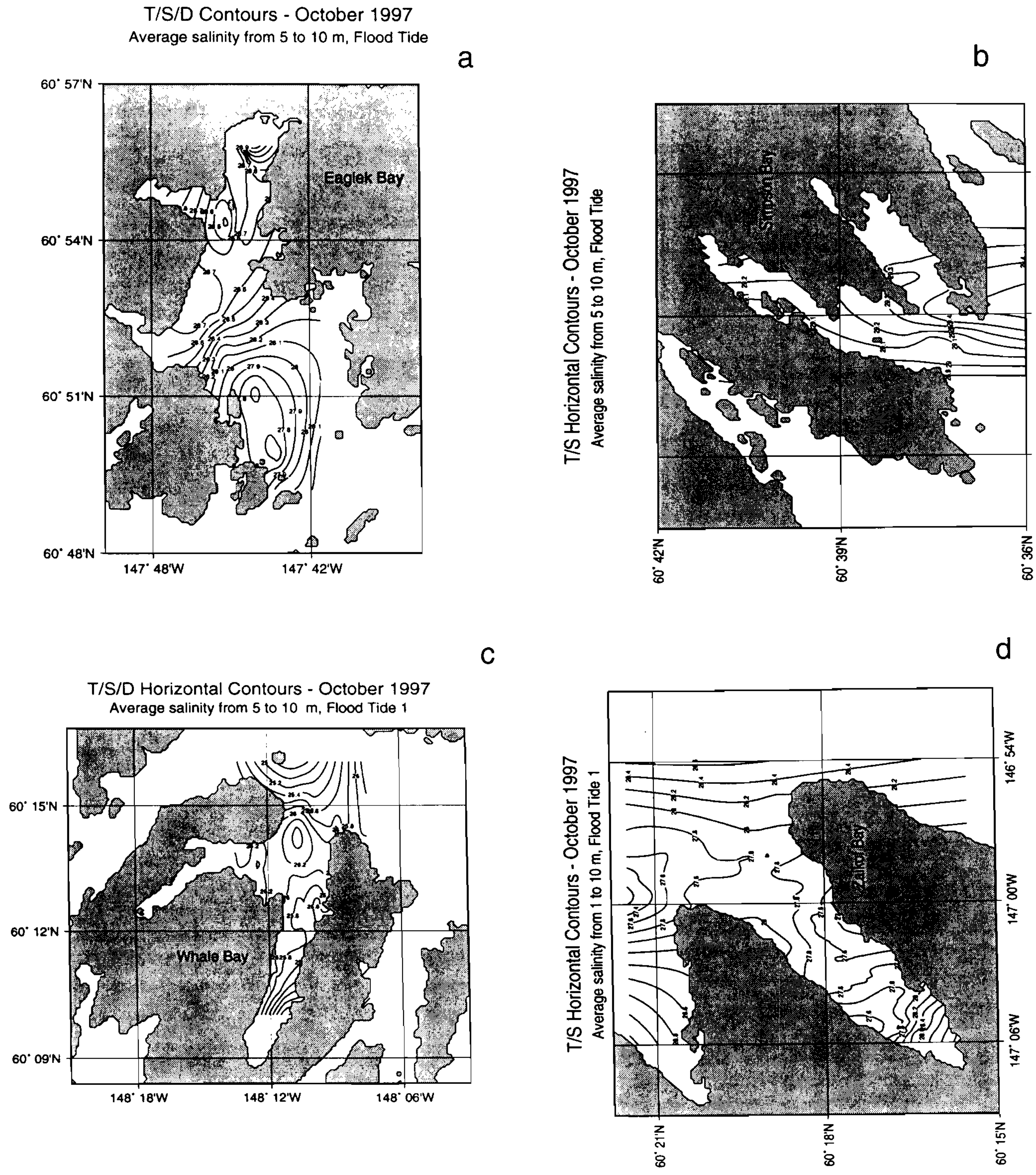


Figure 5: Average salinity from 5 to 10m on flood tide in October 1997 from (a) Eaglek Bay, (b) Simpson Bay, (c) Whale Bay, and (d) Zaikof Bay.

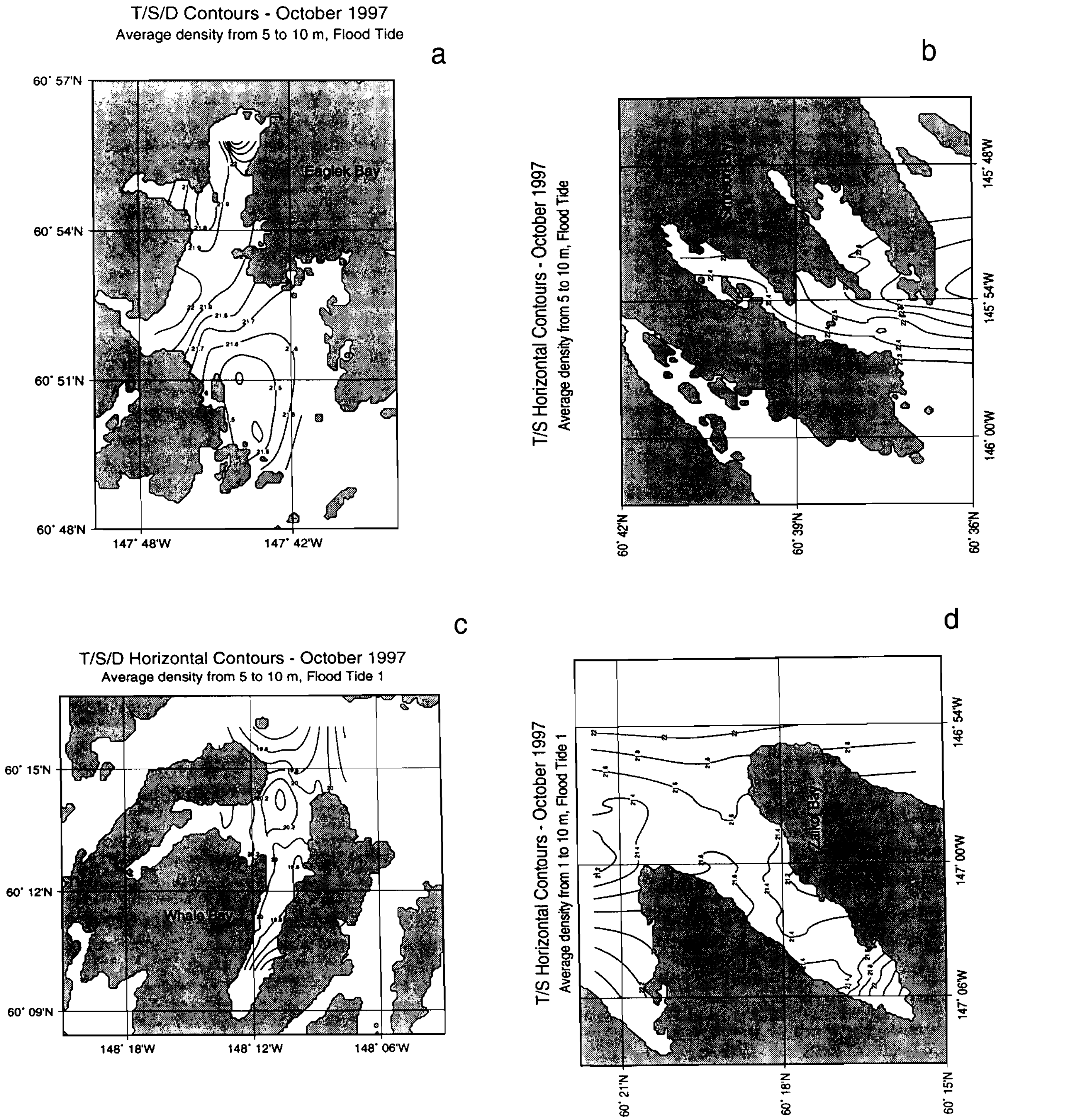


Figure 6: Average density from 5 to 10m on flood tide in October 1997 from (a) Eaglek Bay, (b) Simpson Bay, (c) Whale Bay, and (d) Zaikof Bay.

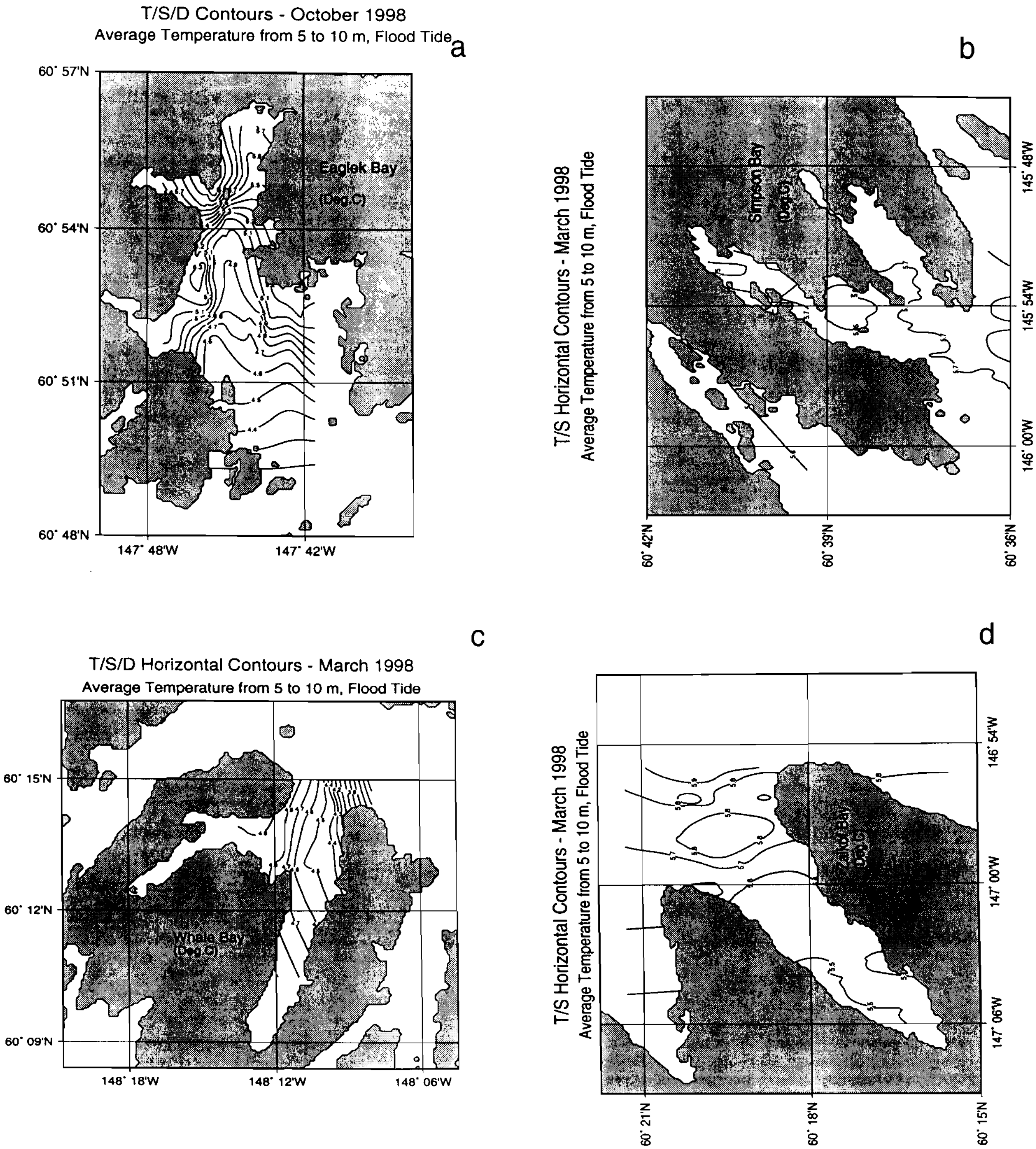


Figure 7: Average temperature from 5 to 10m on flood tide in March 1998 from (a) Eaglek Bay, (b) Simpson Bay, (c) Whale Bay, and (d) Zaikof Bay.

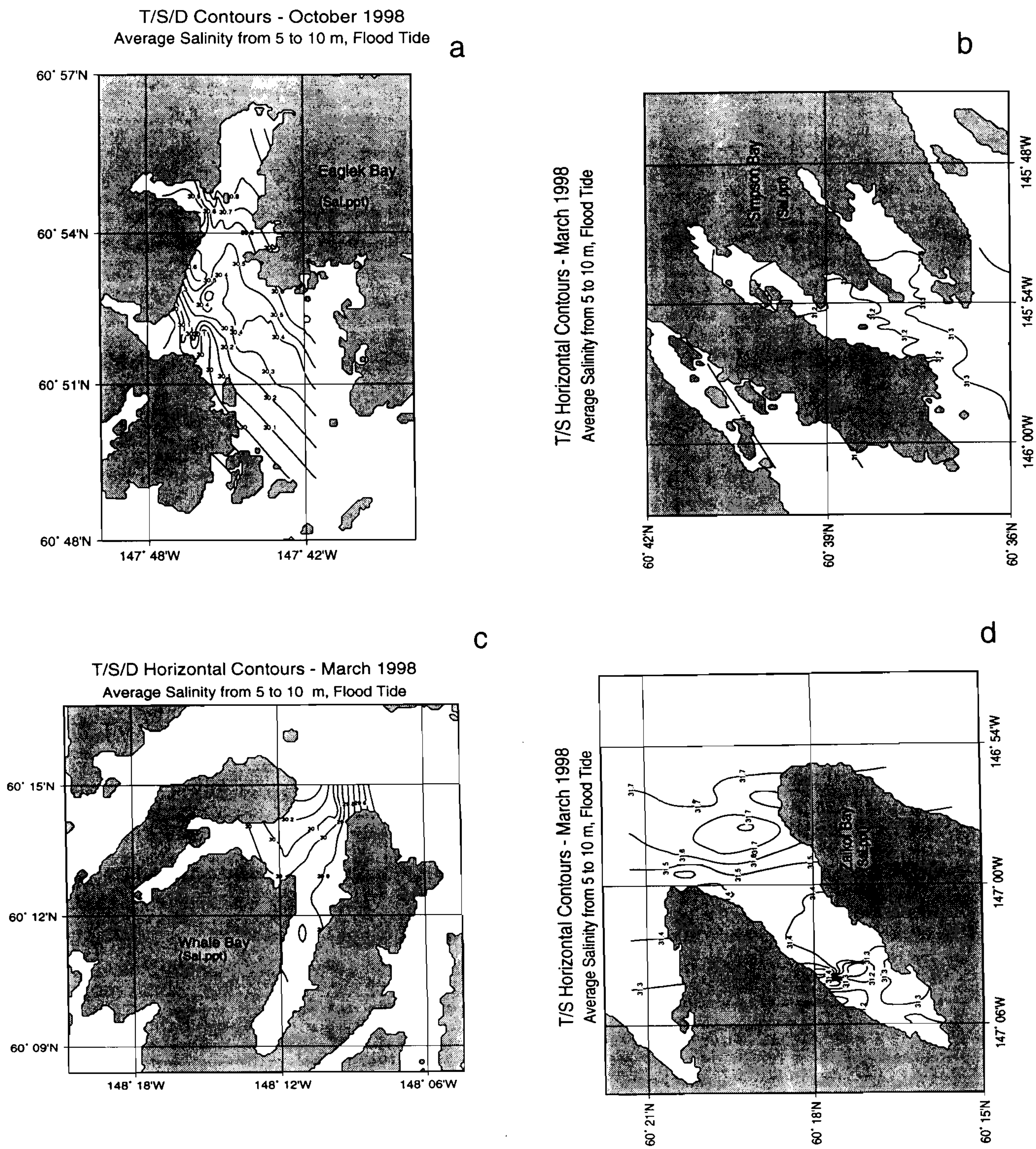


Figure 8: Average salinity from 5 to 10m on flood tide in March 1998 from (a) Eaglek Bay, (b) Simpson Bay, (c) Whale Bay, and (d) Zaikof Bay.

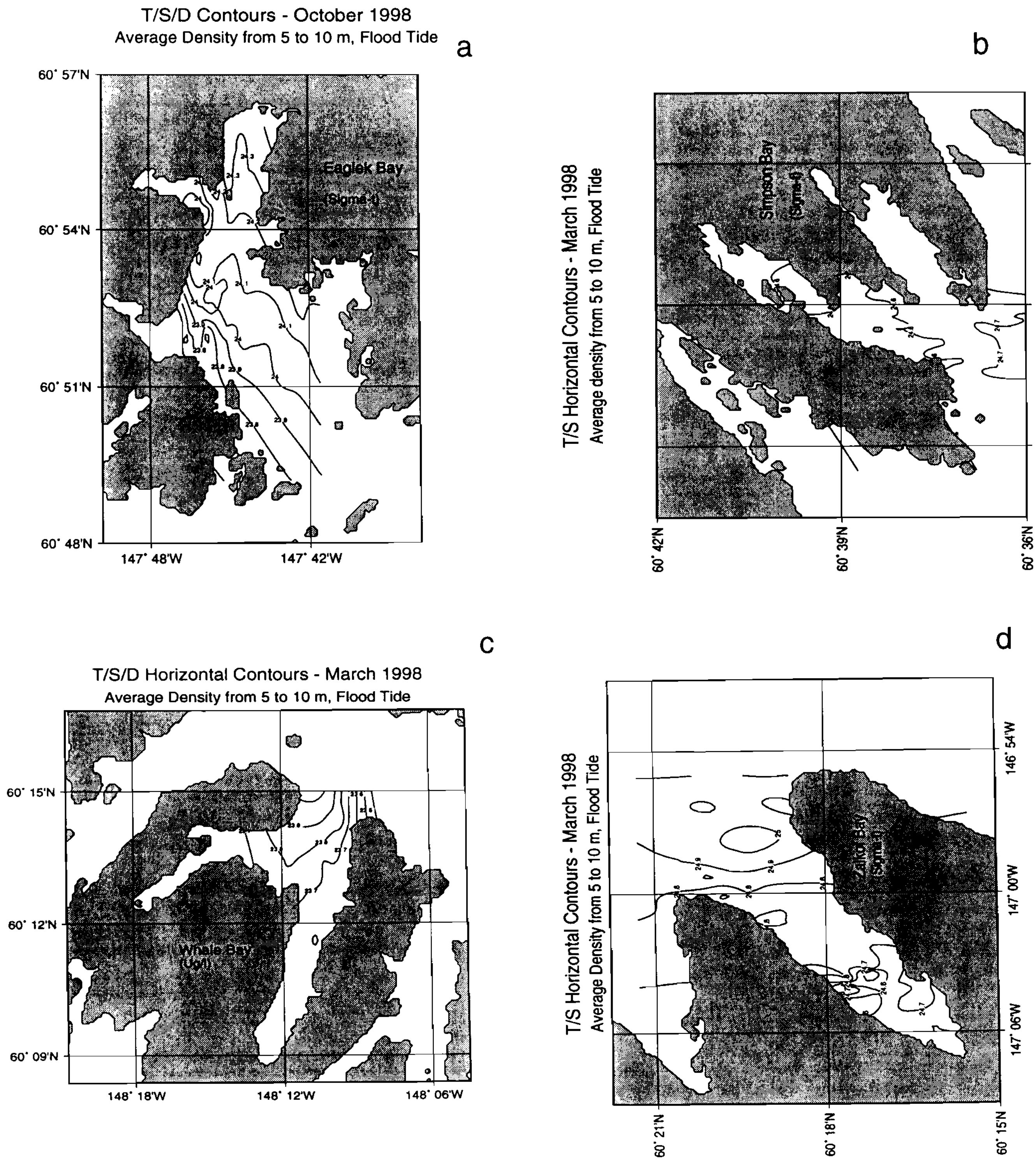


Figure 9: Average density from 5 to 10m on flood tide in March 1998 from (a) Eaglek Bay, (b) Simpson Bay, (c) Whale Bay, and (d) Zaikof Bay.

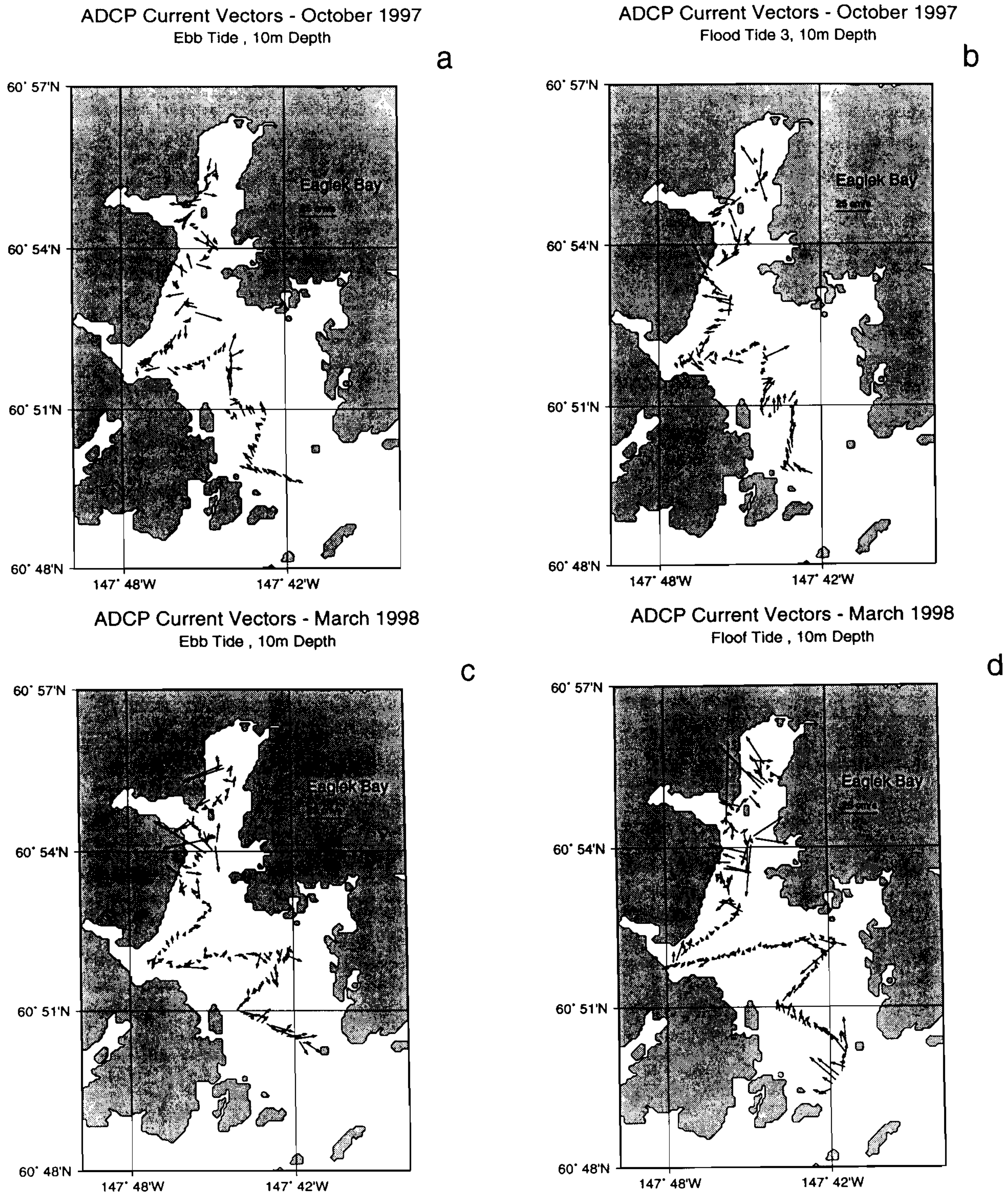


Figure 10: Velocity vectors at 10m in Eaglek Bay for (a) ebb tide October 1997, (b) flood tide October 1997, (c) ebb tide March 1998, and (d) flood tide March 1998.

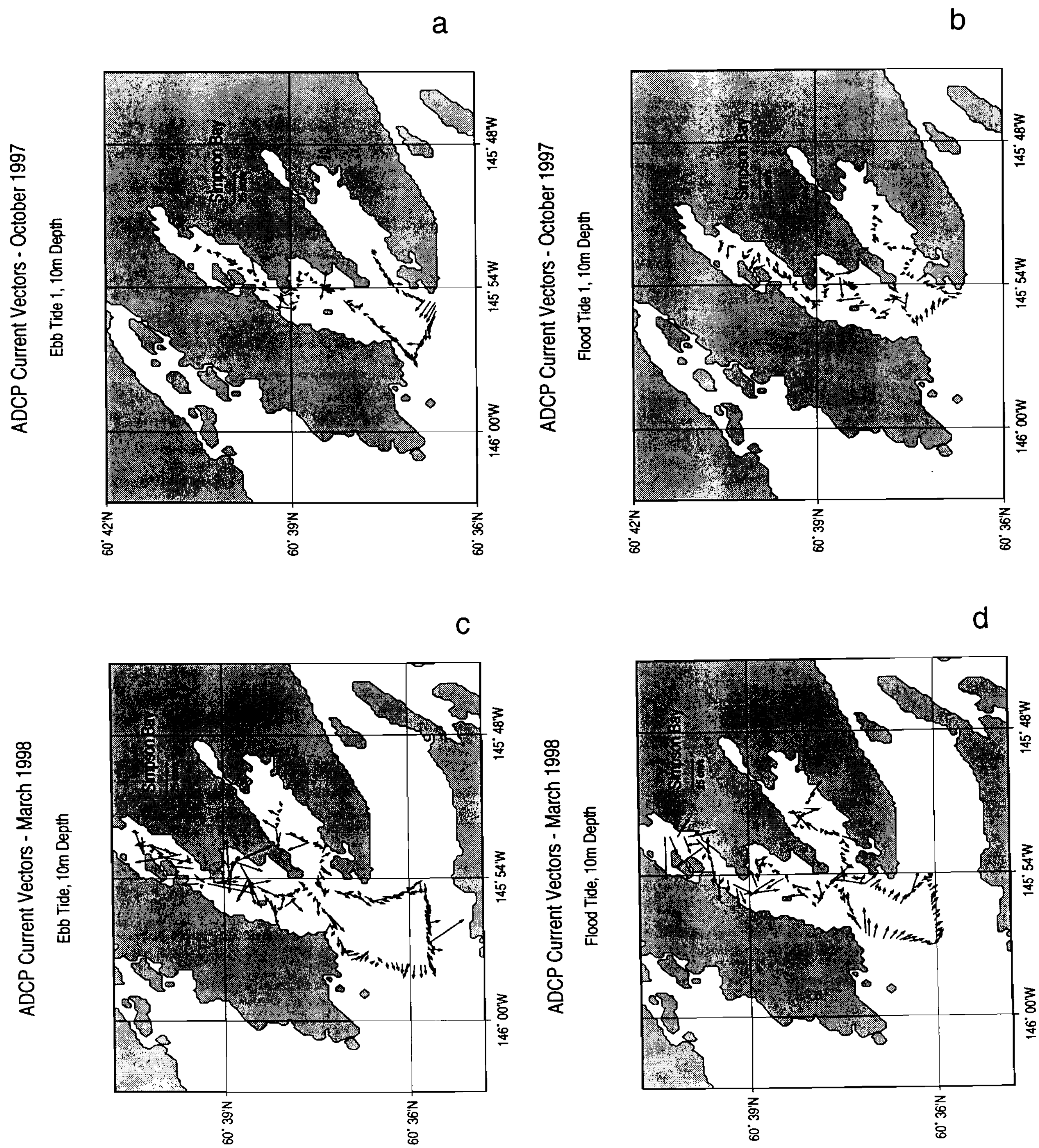


Figure 11: Velocity vectors at 10m in Simpson Bay for (a) ebb tide October 1997, (b) flood tide October 1997, (c) ebb tide March 1998, and (d) flood tide March 1998.

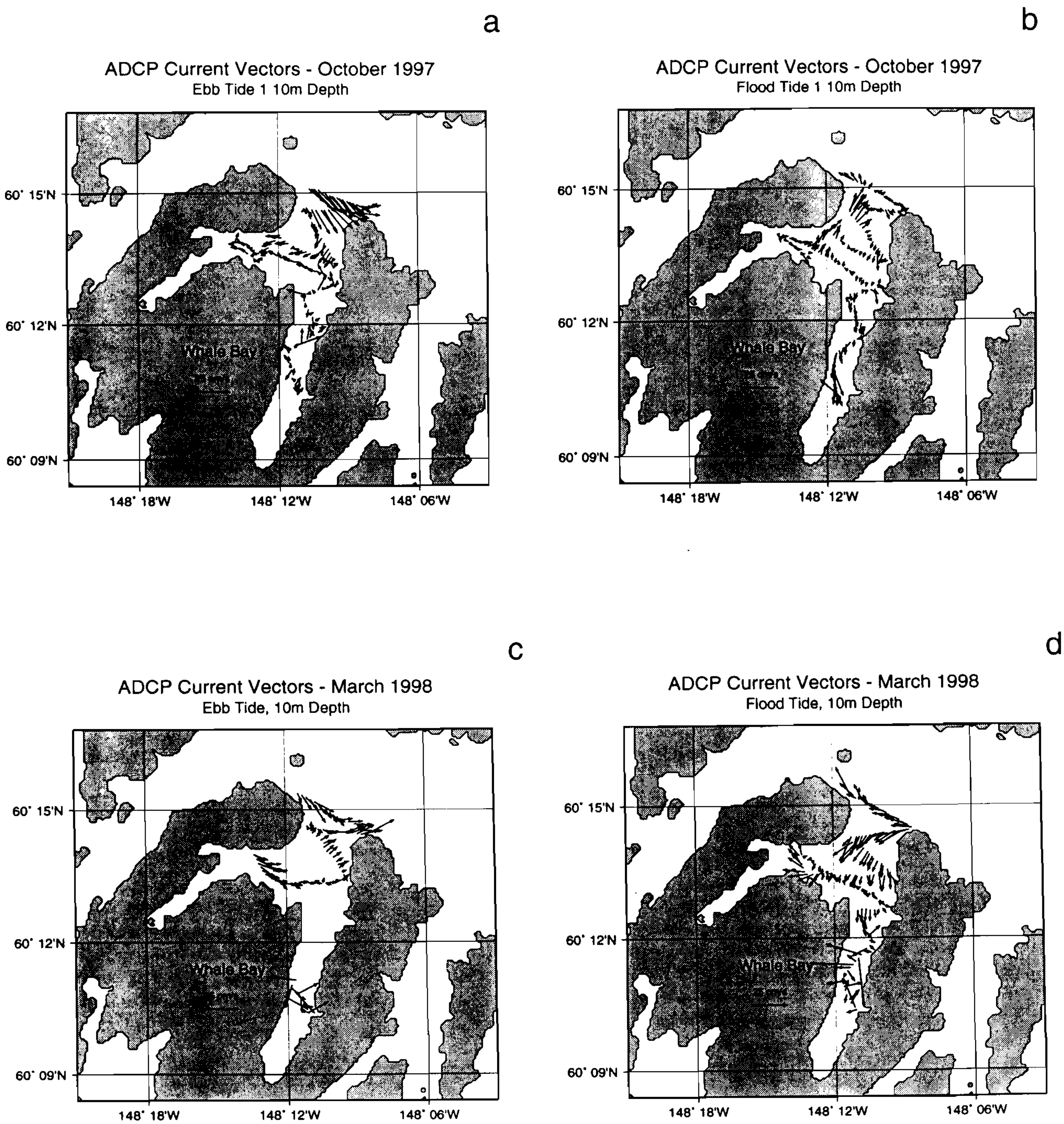


Figure 12: Velocity vectors at 10m in Whale Bay for (a) ebb tide October 1997, (b) flood tide October 1997, (c) ebb tide March 1998, and (d) flood tide March 1998.

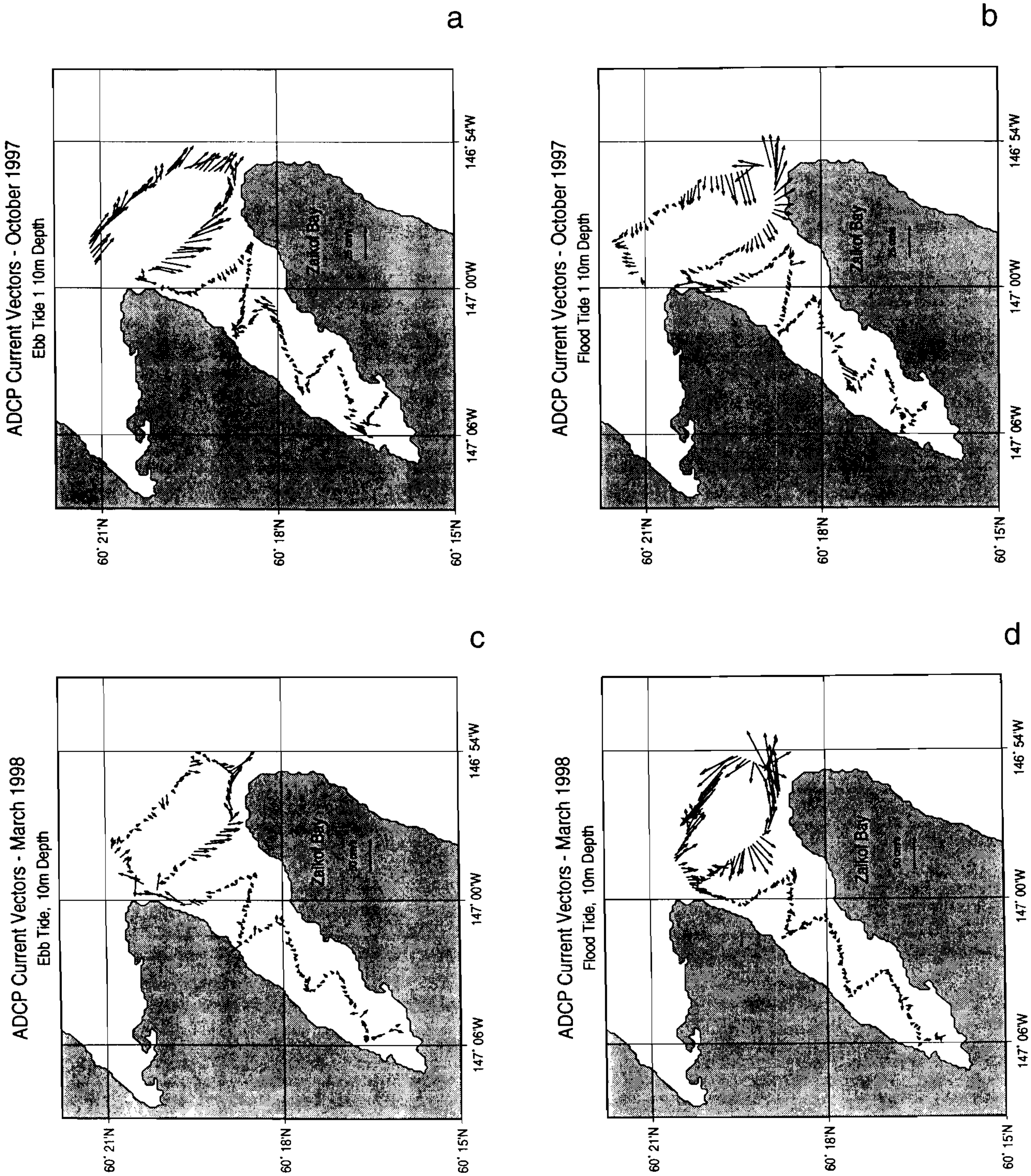
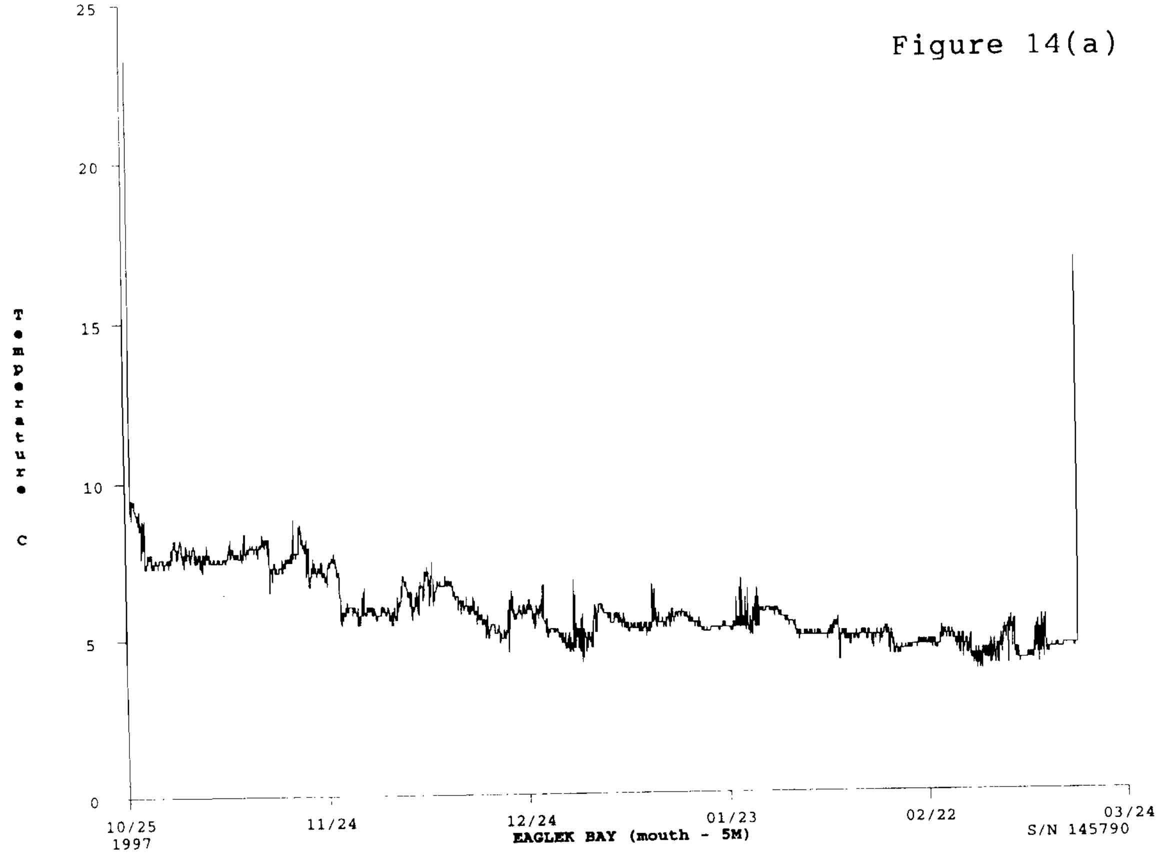
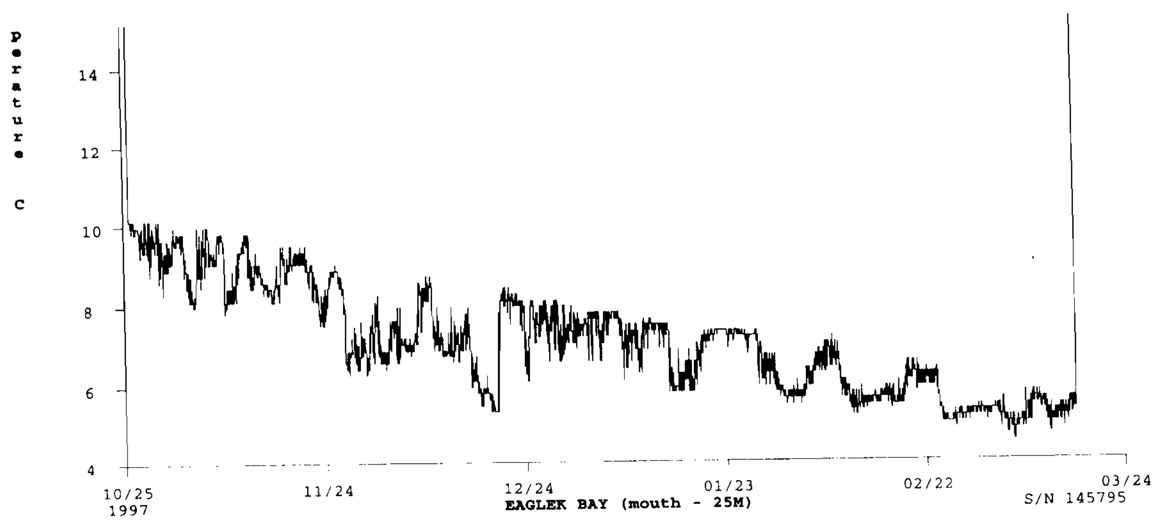


Figure 13: Velocity vectors at 10m in Zaikof Bay for (a) ebb tide October 1997, (b) flood tide October 1997, (c) ebb tide March 1998, and (d) flood tide March 1998.

Figure 14(a)

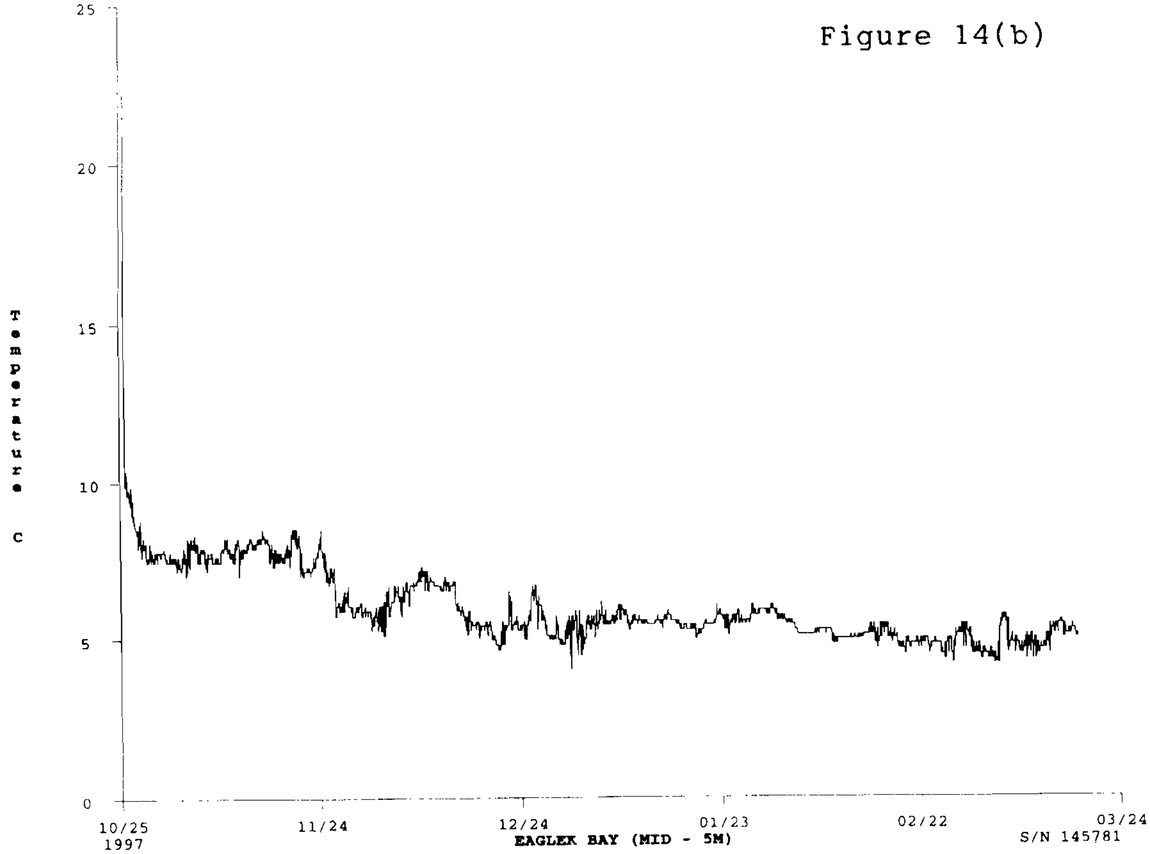


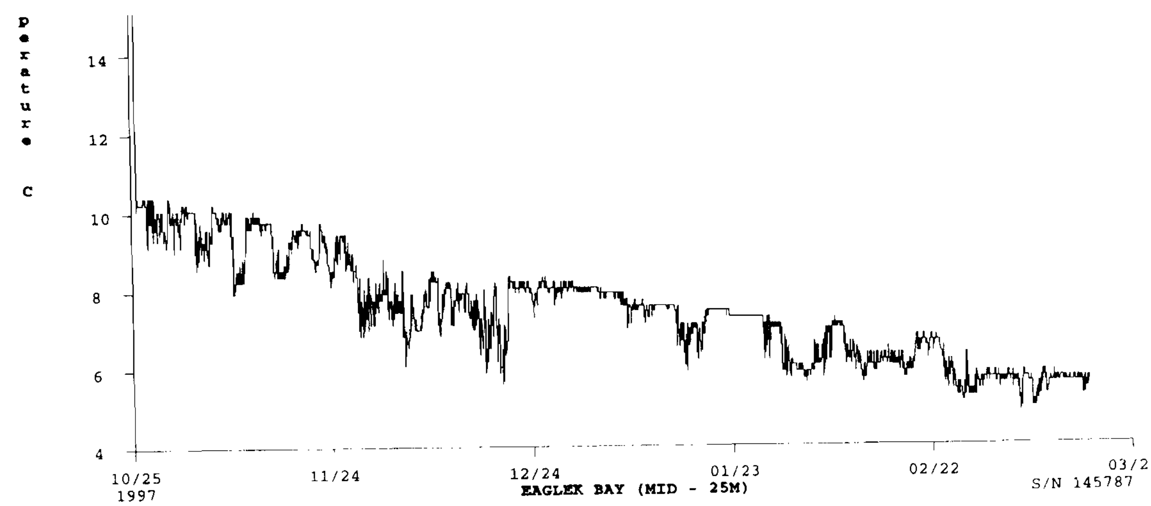
25
20
15
10
5
0
Temperature C
10/25 1997
11/24
12/24
01/23
02/22
03/24
EAGLEK BAY (mouth - 5M)
S/N 145790



14
12
10
8
6
4
perature C
10/25 1997
11/24
12/24
01/23
02/22
03/24
EAGLEK BAY (mouth - 25M)
S/N 145795

Figure 14(b)


25
20
15
10
5
0
Temperature C
10/25
1997
11/24
12/24
01/23
02/22
03/24
EAGLEK BAY (MID - 5M)
S/N 145781


14
12
10
8
6
4
perature C
10/25
1997
11/24
12/24
01/23
02/22
03/24
EAGLEK BAY (MID - 25M)
S/N 145787

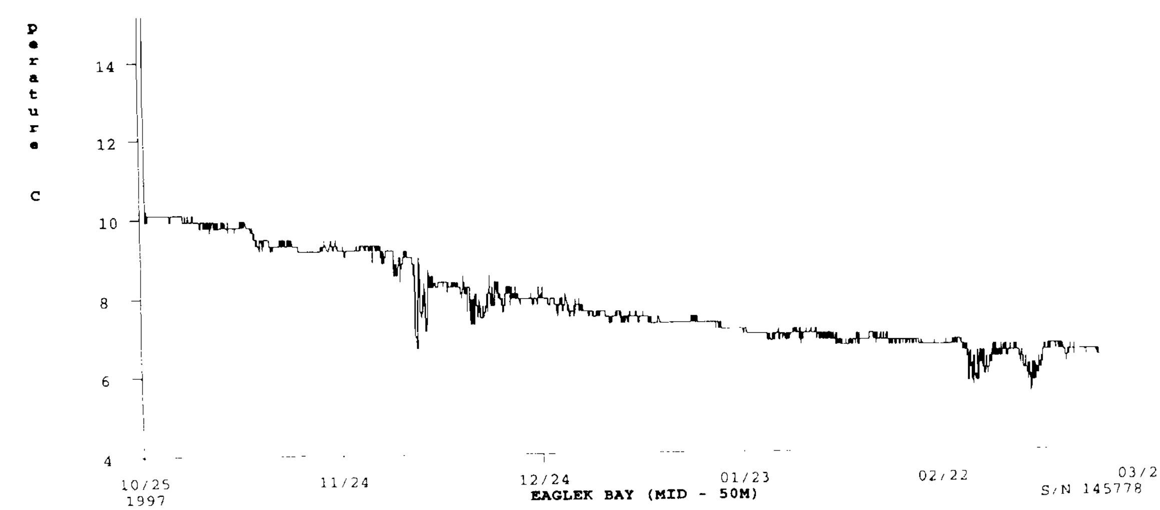
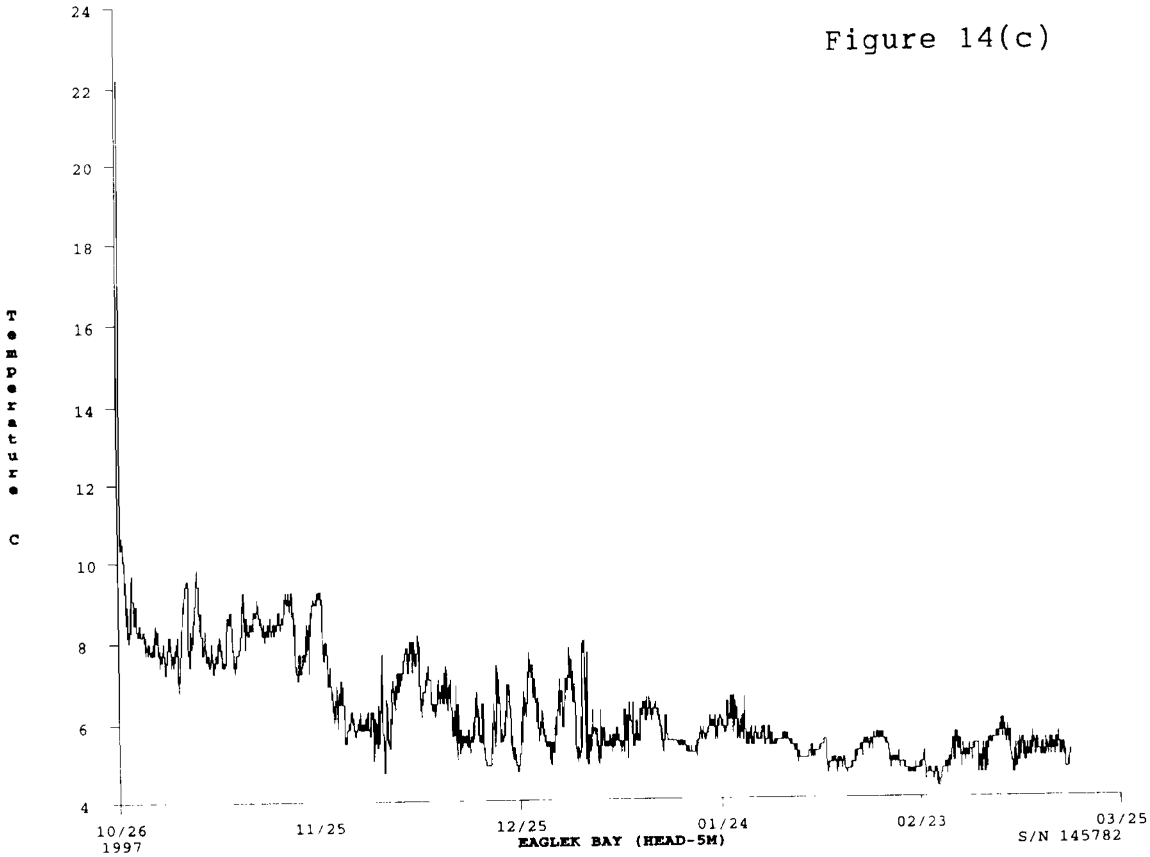
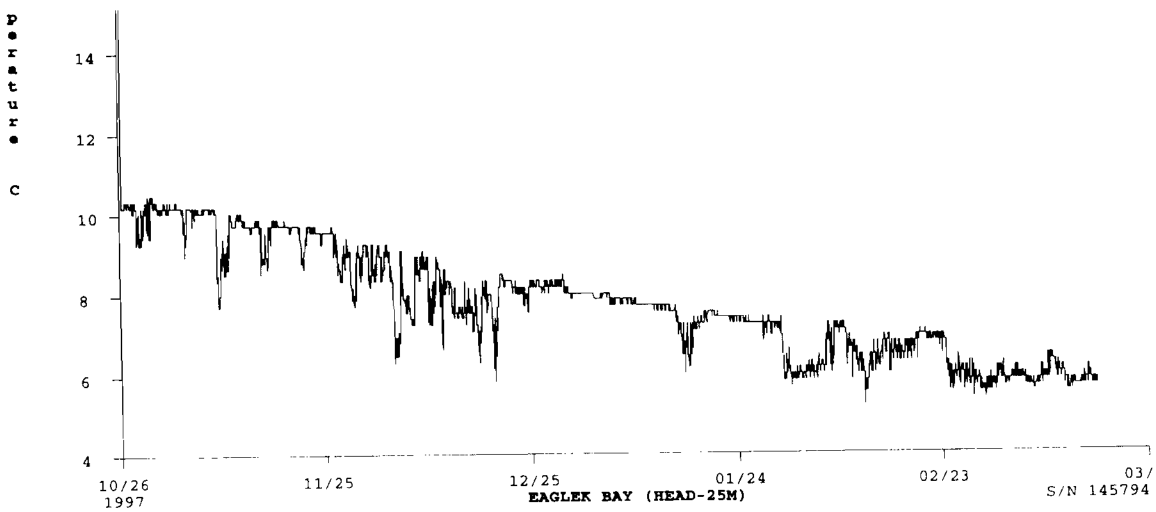

14
12
10
8
6
4
perature C
10/25
1997
11/24
12/24
01/23
02/22
03/24
EAGLEK BAY (MID - 50M)
S/N 145778

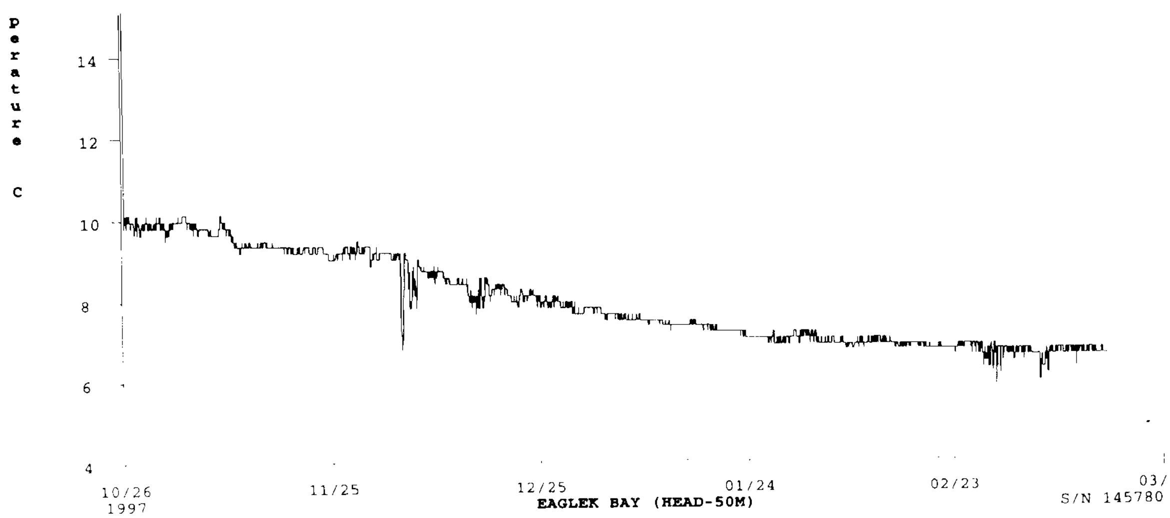
Figure 14(c)



24
22
20
18
16
14
12
10
8
6
4
Temperature C
10/26 1997
11/25
12/25
01/24
02/23
03/25
EAGLEK BAY (HEAD-5M)
S/N 145782

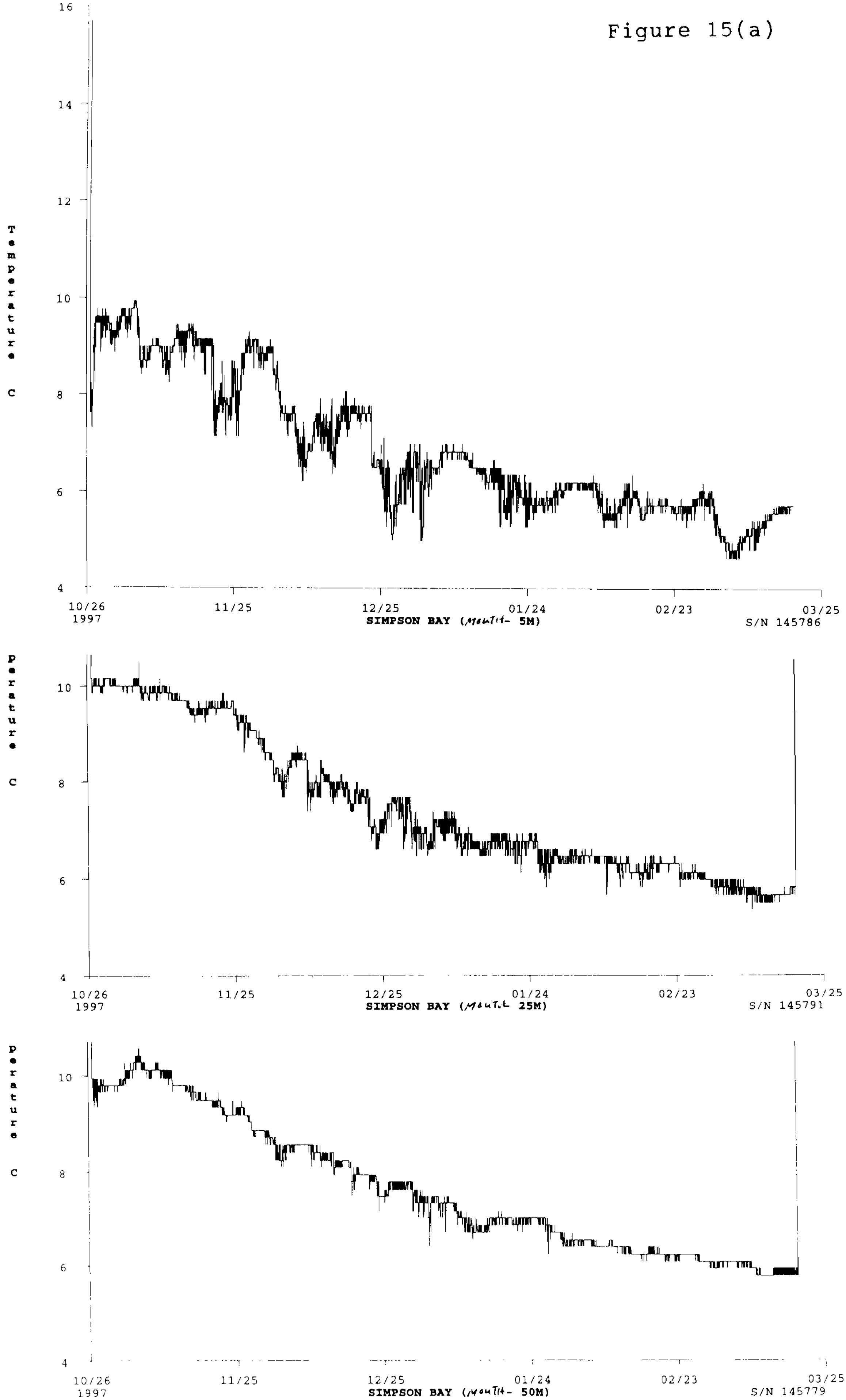


perature C
14
12
10
8
6
4
10/26 1997
11/25
12/25
01/24
02/23
03/25
EAGLEK BAY (HEAD-25M)
S/N 145794



perature C
14
12
10
8
6
4
10/26 1997
11/25
12/25
01/24
02/23
03/25
EAGLEK BAY (HEAD-50M)
S/N 145780

Figure 15(a)



Temperature C
16
14
12
10
8
6
4
10/26
1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (MOUTH - 5M)
S/N 145786
perature C
10
8
6
4
10/26
1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (MOUTH 25M)
S/N 145791
perature C
10
8
6
4
10/26
1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (MOUTH - 50M)
S/N 145779

Figure 15(b)

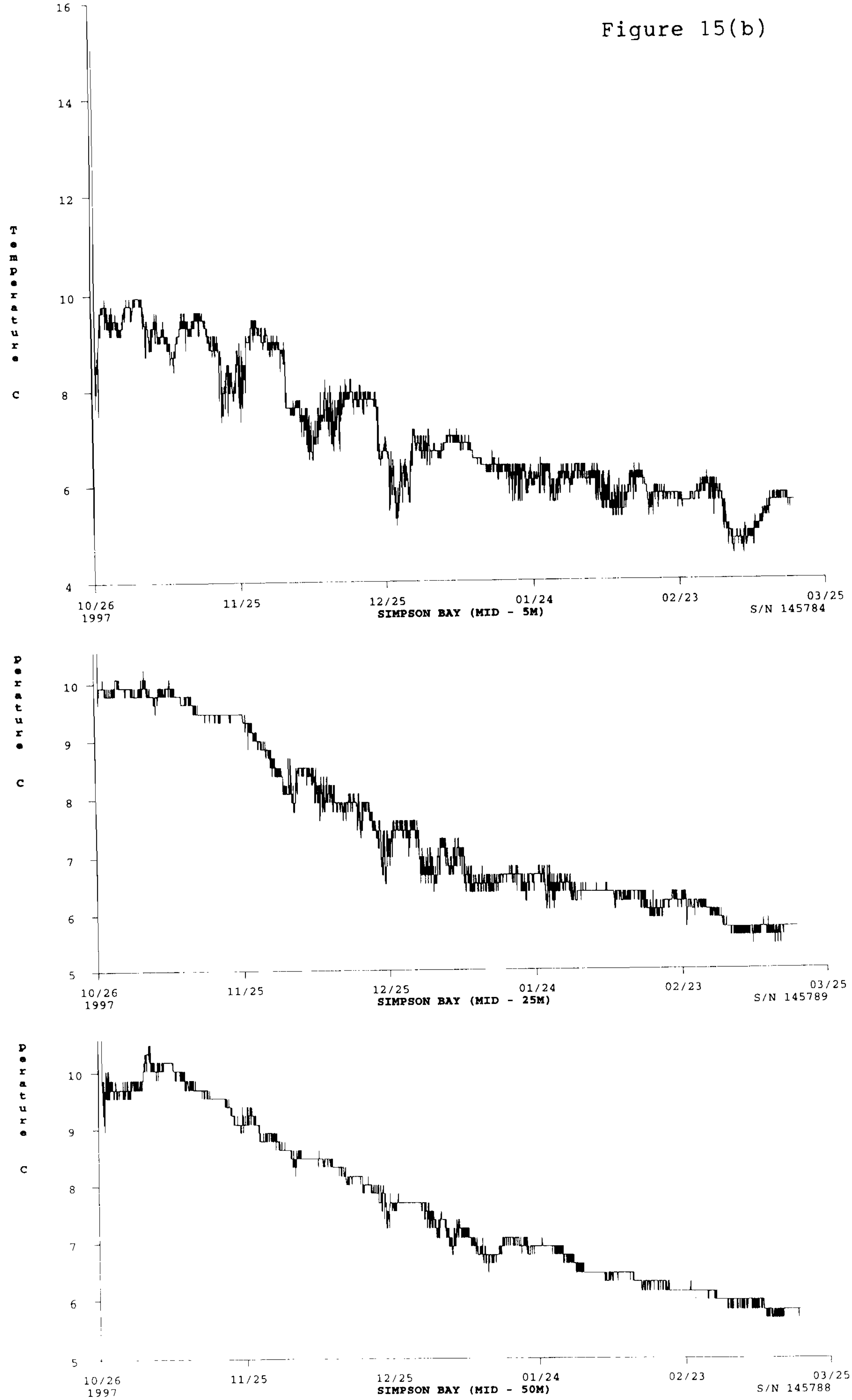
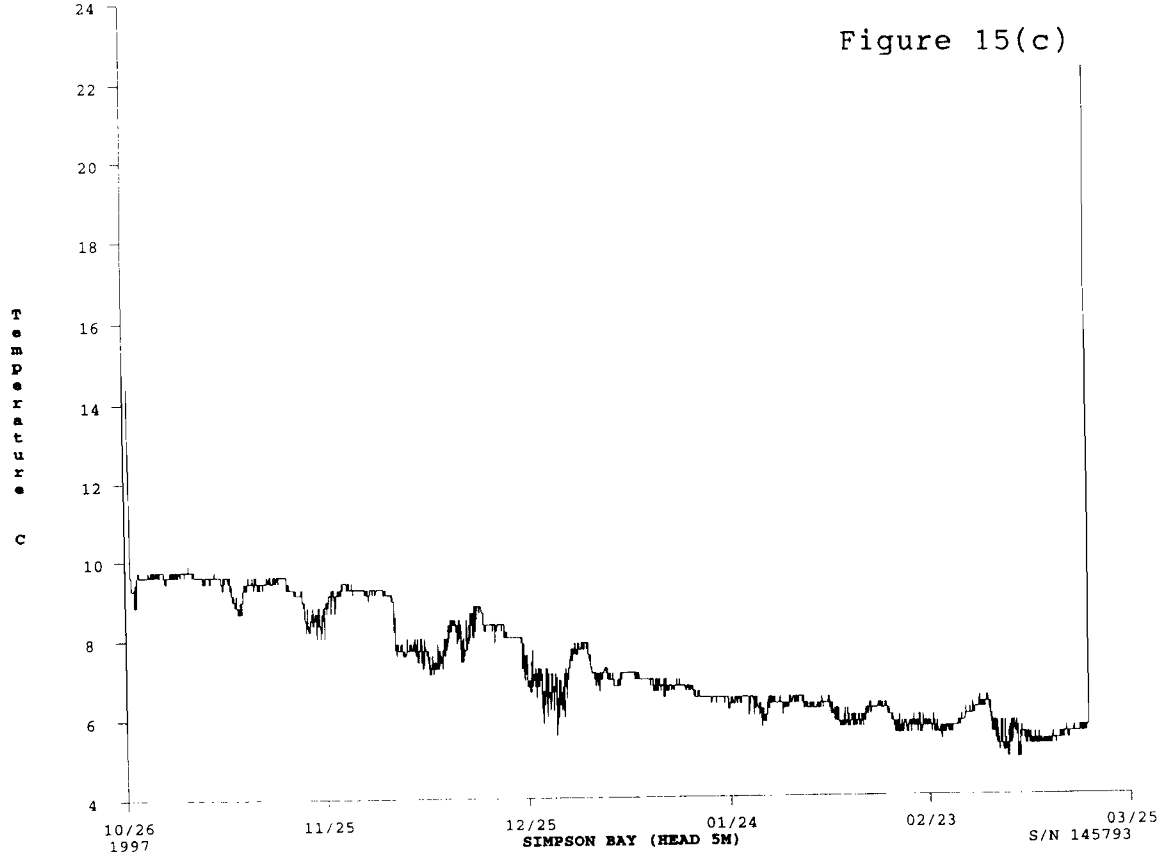
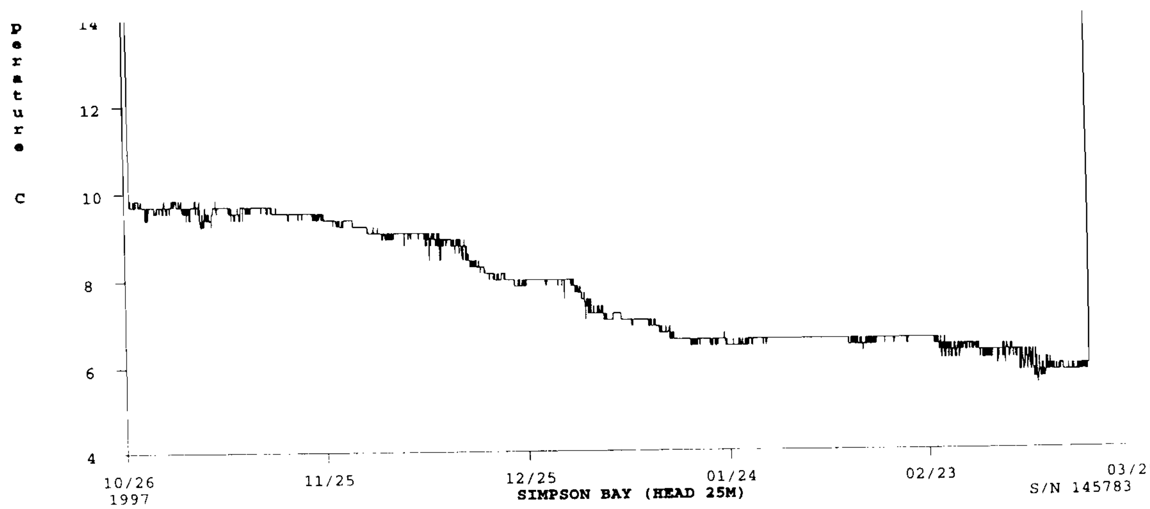

16
14
12
10
8
6
4
Temperature
C
10/26
1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (MID - 5M)
S/N 145784
10
9
8
7
6
5
perature
C
10/26
1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (MID - 25M)
S/N 145789
10
9
8
7
6
5
perature
C
10/26
1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (MID - 50M)
S/N 145788

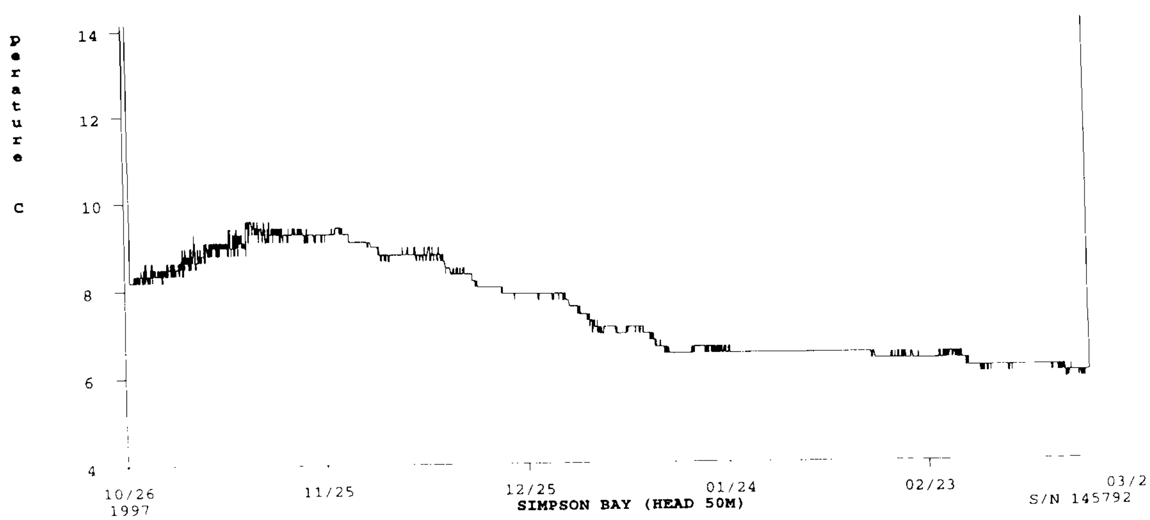
Figure 15(c)



Temperature C
24
22
20
18
16
14
12
10
8
6
4
10/26 1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (HEAD 5M)
S/N 145793

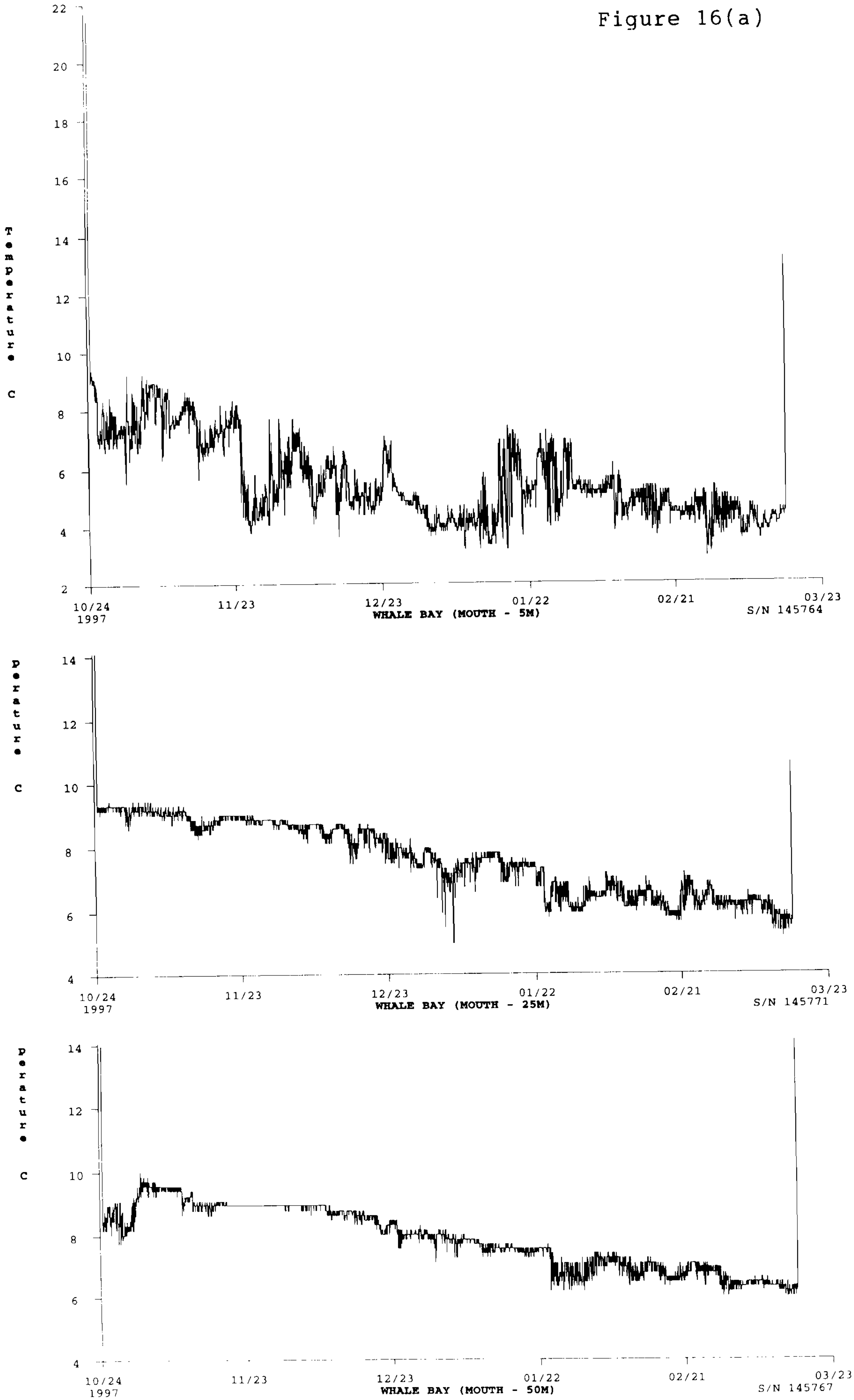


perature C
14
12
10
8
6
4
10/26 1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (HEAD 25M)
S/N 145783



perature C
14
12
10
8
6
4
10/26 1997
11/25
12/25
01/24
02/23
03/25
SIMPSON BAY (HEAD 50M)
S/N 145792

Figure 16(a)



22
20
18
16
14
12
10
8
6
4
2
Temperature C
10/24
1997
11/23
12/23
01/22
02/21
03/23
WHALE BAY (MOUTH - 5M)
S/N 145764
14
12
10
8
6
4
perature C
10/24
1997
11/23
12/23
01/22
02/21
03/23
WHALE BAY (MOUTH - 25M)
S/N 145771
14
12
10
8
6
4
perature C
10/24
1997
11/23
12/23
01/22
02/21
03/23
WHALE BAY (MOUTH - 50M)
S/N 145767

Figure 16(b)

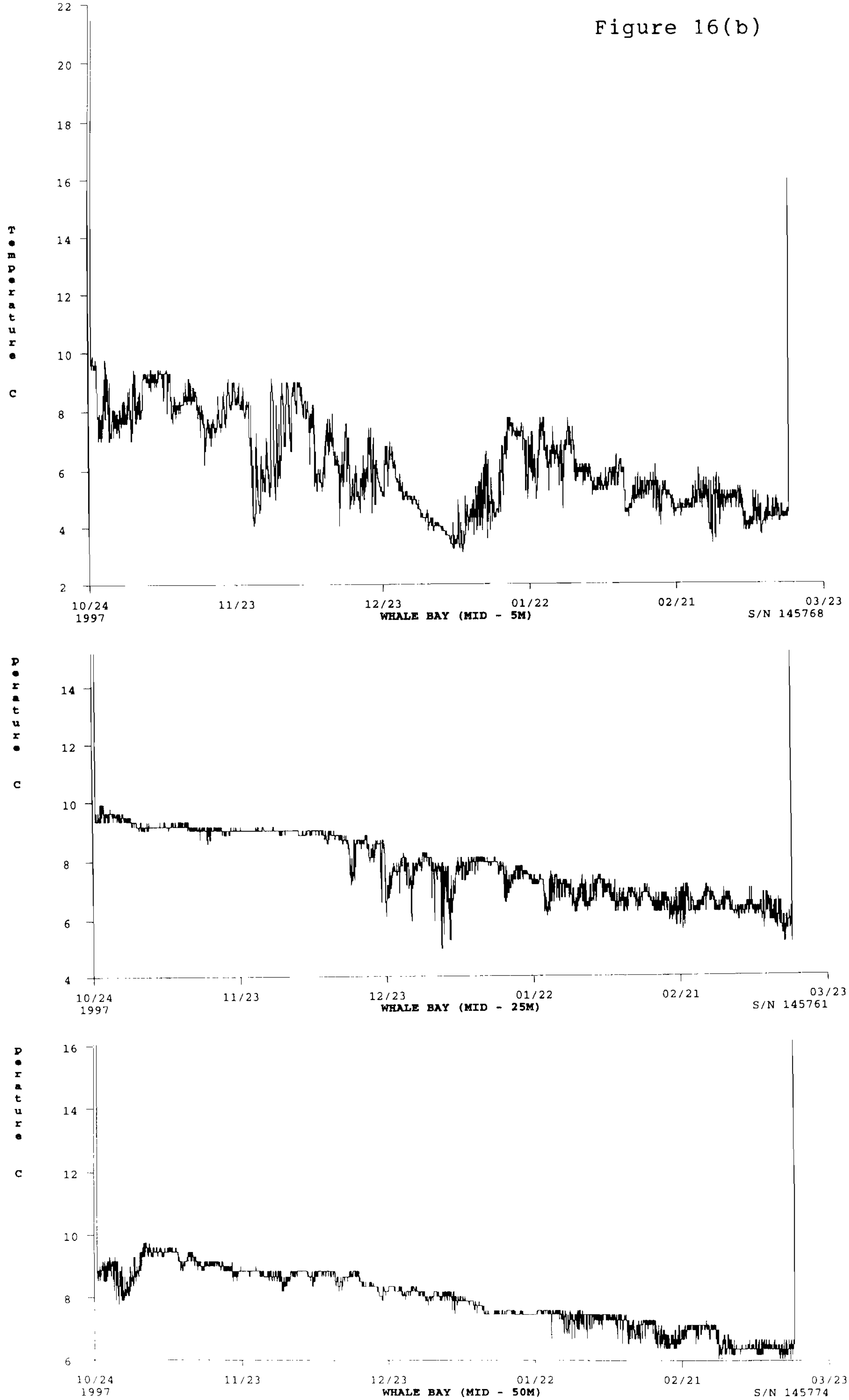
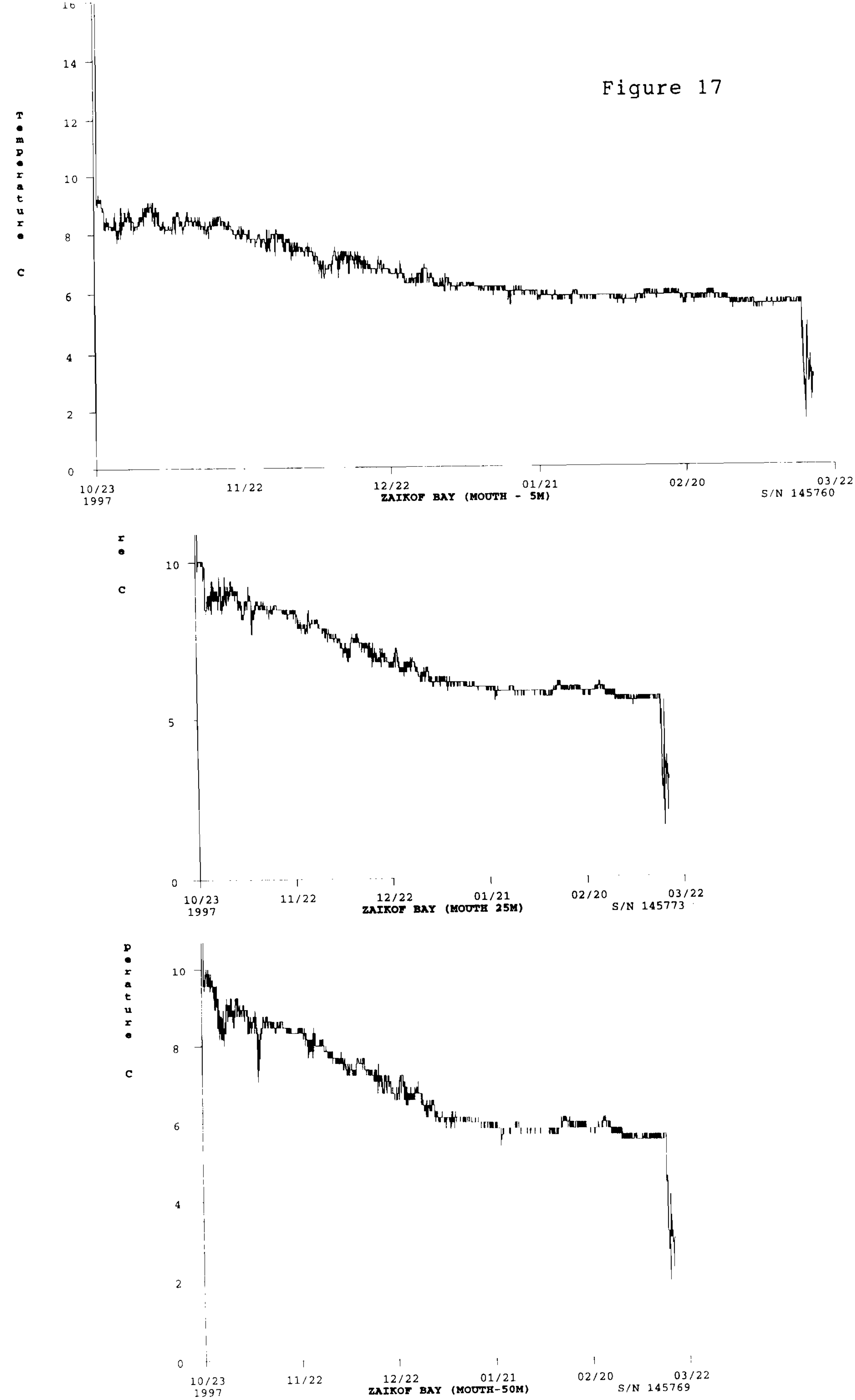
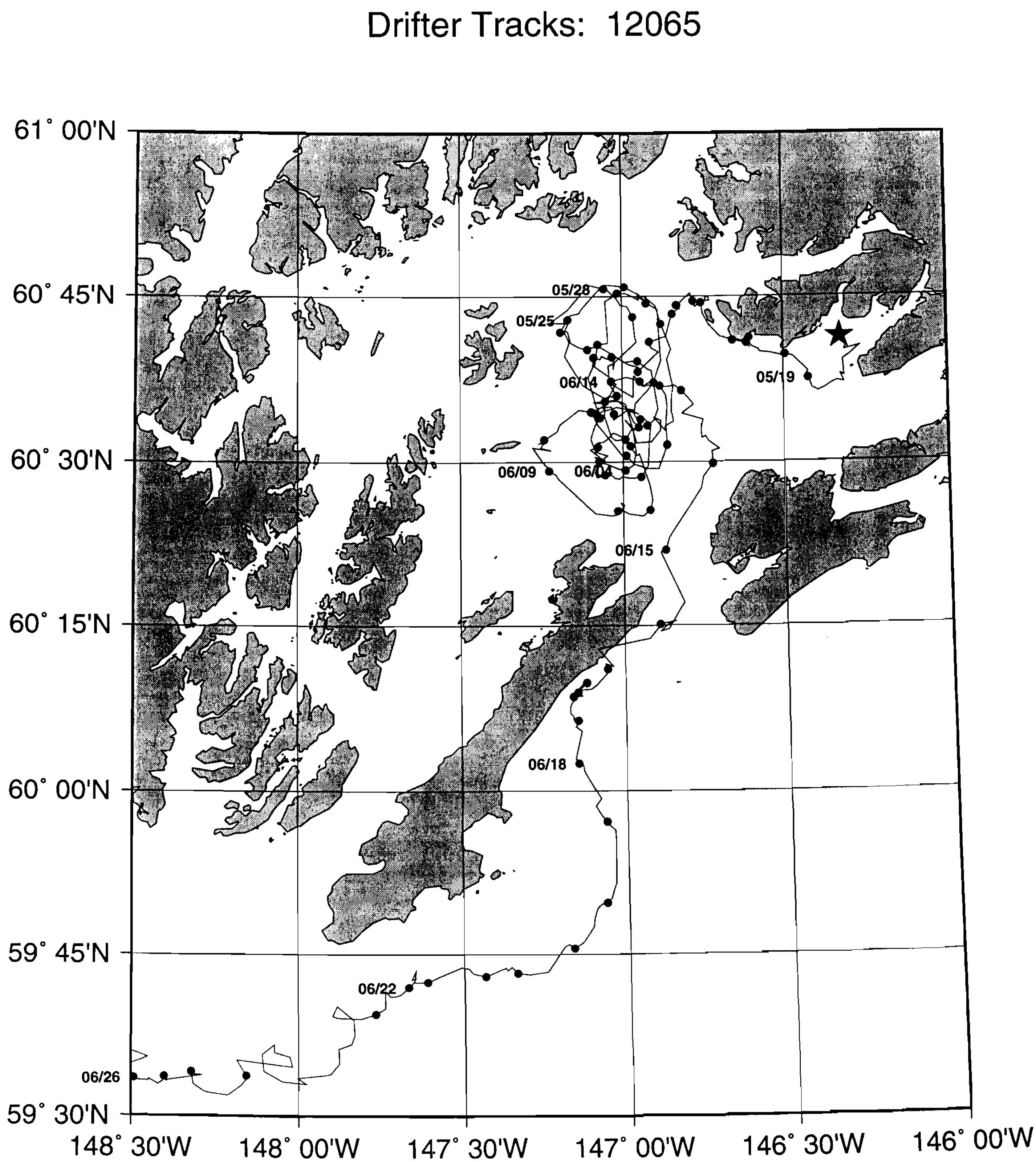

Temperature C
22
20
18
16
14
12
10
8
6
4
2
10/24
1997
11/23
12/23
01/22
02/21
03/23
WHALE BAY (MID - 5M)
S/N 145768
perature C
14
12
10
8
6
4
10/24
1997
11/23
12/23
01/22
02/21
03/23
WHALE BAY (MID - 25M)
S/N 145761
perature C
16
14
12
10
8
6
10/24
1997
11/23
12/23
01/22
02/21
03/23
WHALE BAY (MID - 50M)
S/N 145774

Figure 17



Temperature C
16
14
12
10
8
6
4
2
0
10/23
1997
11/22
12/22
01/21
02/20
03/22
ZAIKOF BAY (MOUTH - 5M)
S/N 145760
re
C
10
5
0
10/23
1997
11/22
12/22
01/21
02/20
03/22
ZAIKOF BAY (MOUTH 25M)
S/N 145773
perature
C
10
8
6
4
2
0
10/23
1997
11/22
12/22
01/21
02/20
03/22
ZAIKOF BAY (MOUTH-50M)
S/N 145769

Figure 18(a)



Drifter Tracks: 12065
61° 00'N
60° 45'N
60° 30'N
60° 15'N
60° 00'N
59° 45'N
59° 30'N
148° 30'W
148° 00'W
147° 30'W
147° 00'W
146° 30'W
146° 00'W
05/28
05/25
05/19
06/14
06/09
06/04
06/15
06/18
06/22
06/26

Figure 18(b)

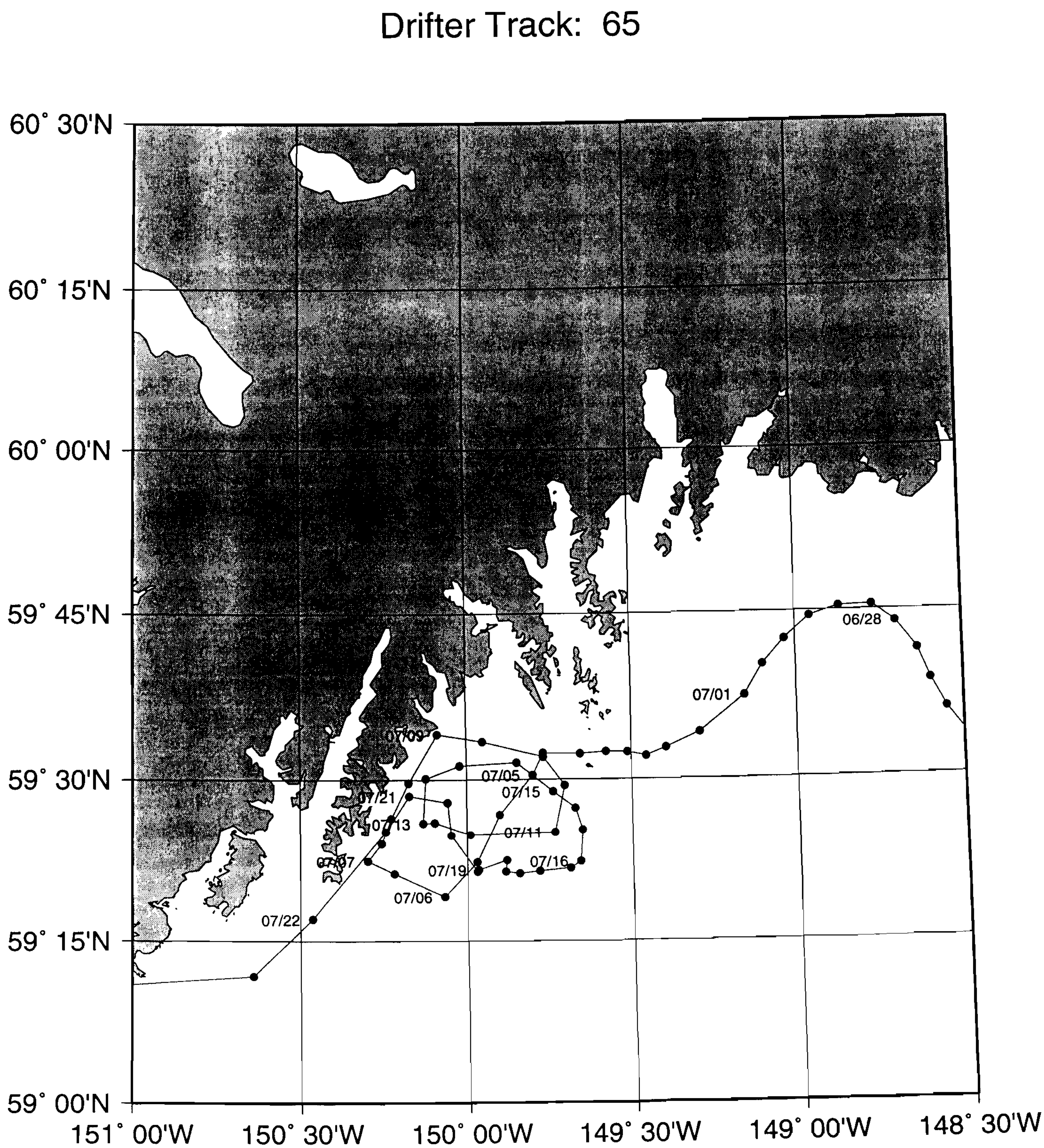

Drifter Track: 65
60° 30'N
60° 15'N
60° 00'N
59° 45'N
59° 30'N
59° 15'N
59° 00'N
151° 00'W
150° 30'W
150° 00'W
149° 30'W
149° 00'W
148° 30'W
06/28
07/01
07/09
07/05
07/15
07/21
07/13
07/11
07/07
07/16
07/19
07/06
07/22

Figure 18(c)

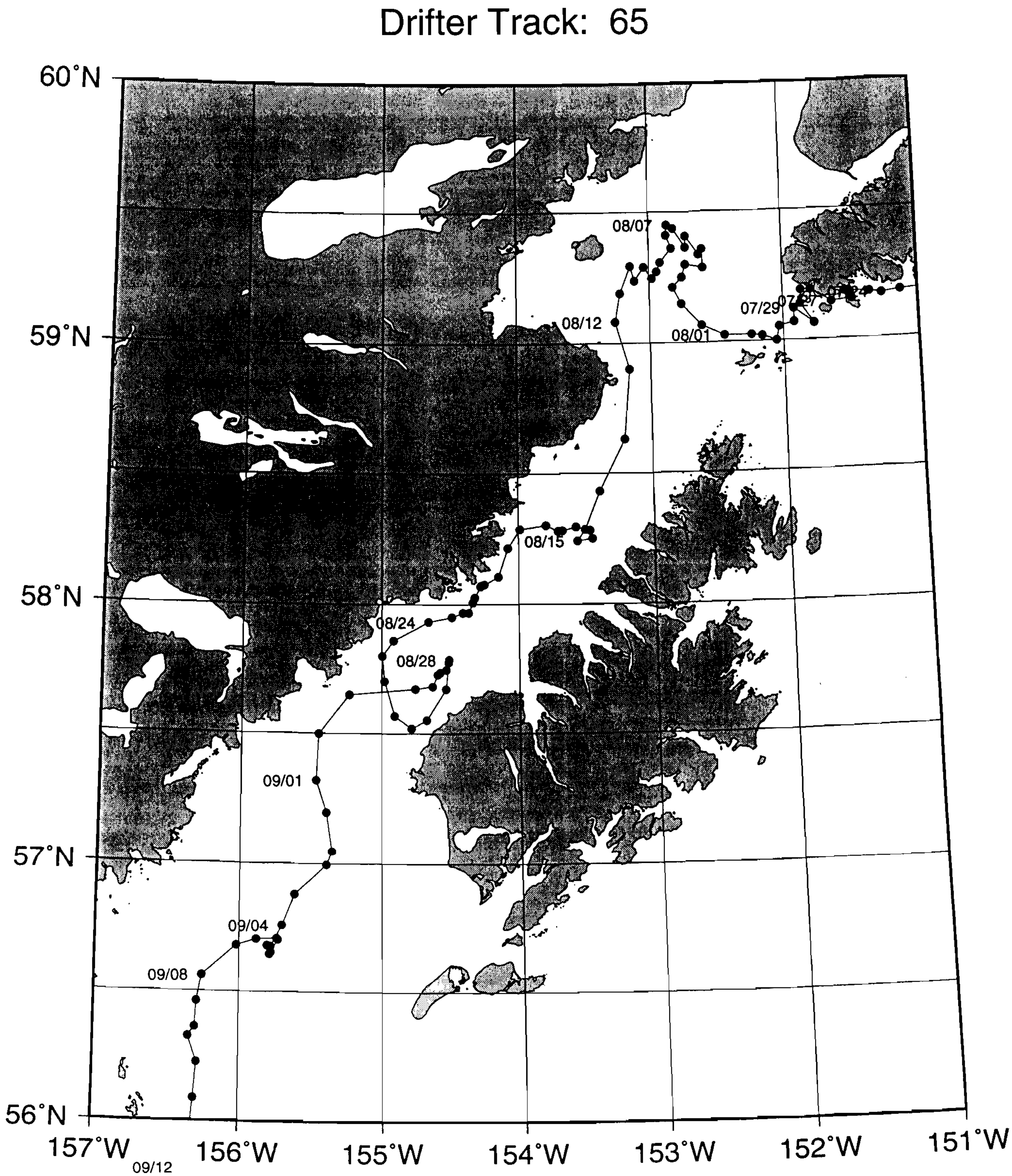
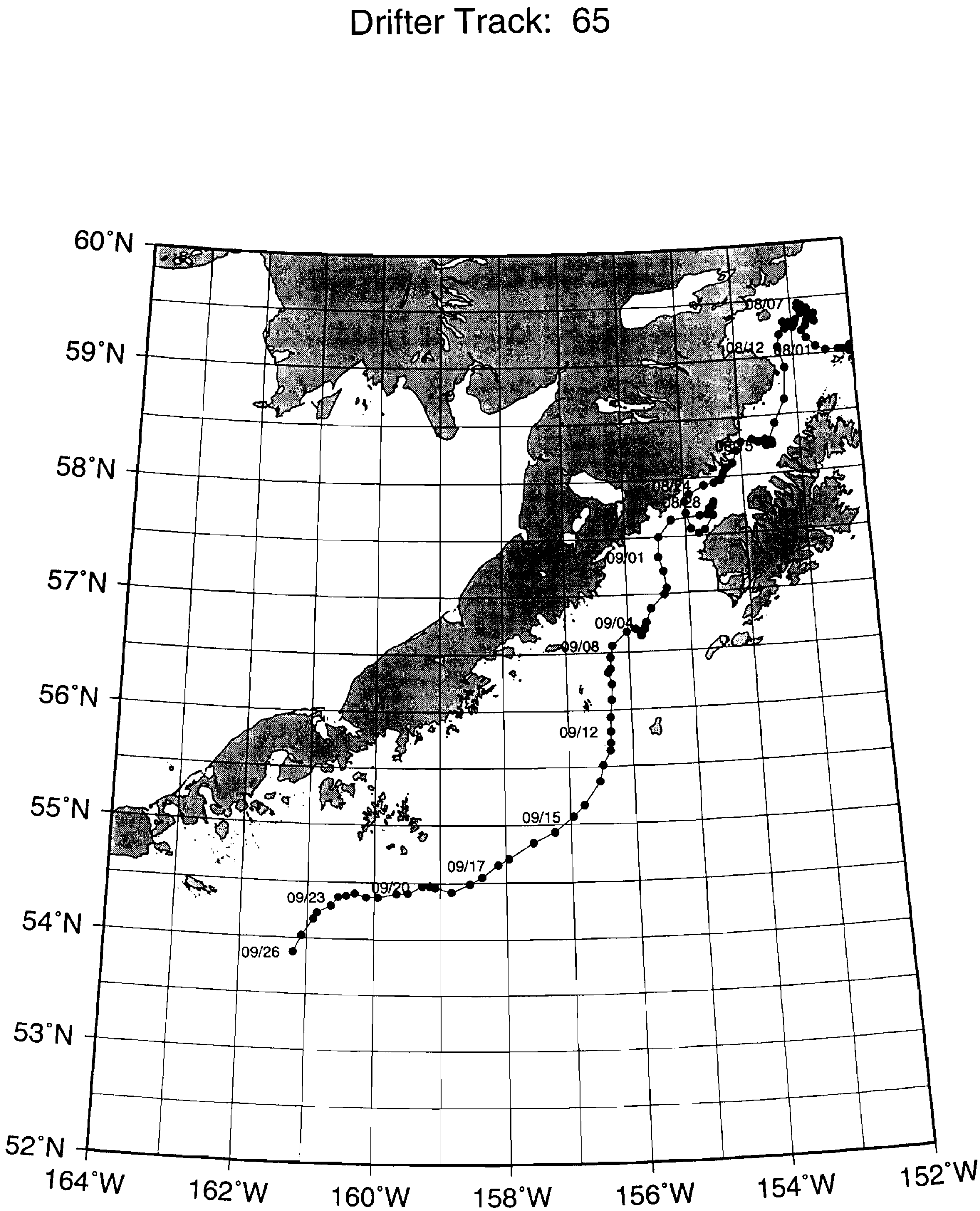
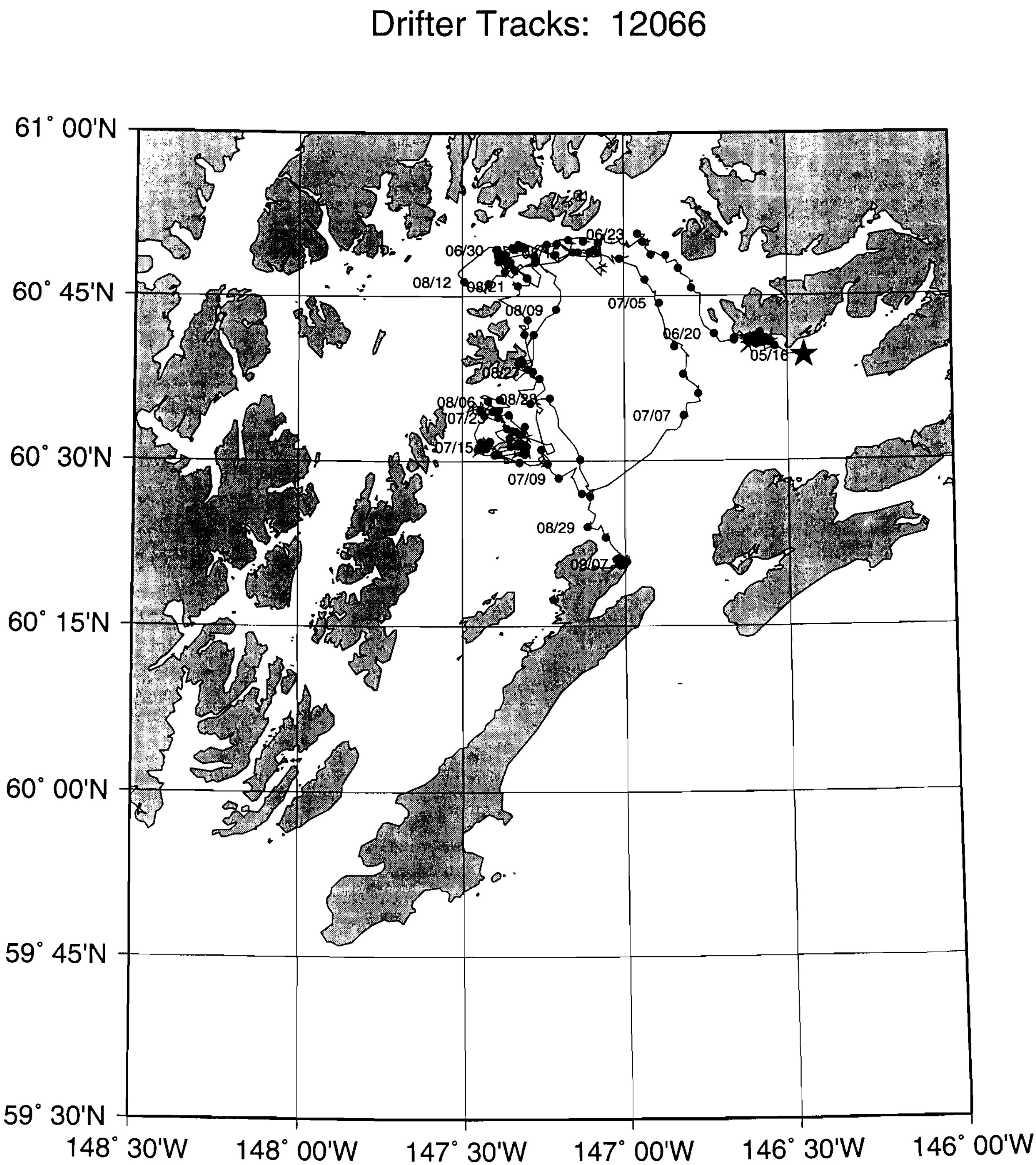

Drifter Track: 65
60°N
59°N
58°N
57°N
56°N
157°W
156°W
155°W
154°W
153°W
152°W
151°W
08/07
08/12
08/01
07/29
08/15
08/24
08/28
09/01
09/04
09/08
09/12

Figure 18(d)



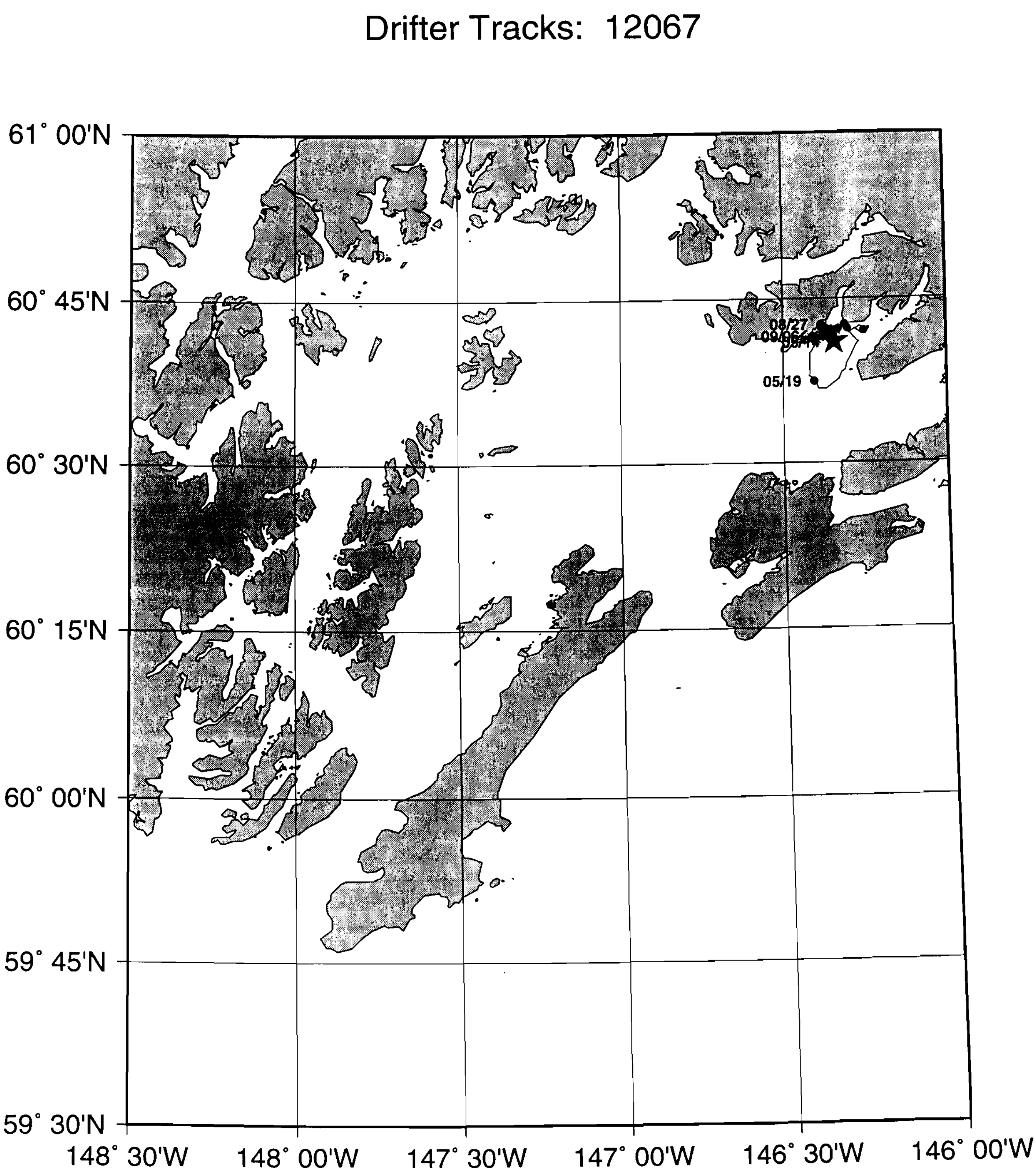
Drifter Track: 65
60°N
59°N
58°N
57°N
56°N
55°N
54°N
53°N
52°N
164°W
162°W
160°W
158°W
156°W
154°W
152°W
08/07
08/12
08/01
09/01
09/04
09/08
09/12
09/15
09/17
09/20
09/23
09/26

Figure 19



Drifter Tracks: 12066
61° 00'N
60° 45'N
60° 30'N
60° 15'N
60° 00'N
59° 45'N
59° 30'N
148° 30'W
148° 00'W
147° 30'W
147° 00'W
146° 30'W
146° 00'W
06/23
06/30
08/12
07/05
08/09
06/20
05/16
08/27
08/06
07/07
07/15
07/09
08/29

Figure 20



Drifter Tracks: 12067
61° 00'N
60° 45'N
60° 30'N
60° 15'N
60° 00'N
59° 45'N
59° 30'N
148° 30'W
148° 00'W
147° 30'W
147° 00'W
146° 30'W
146° 00'W
08/27
05/19

Figure 21

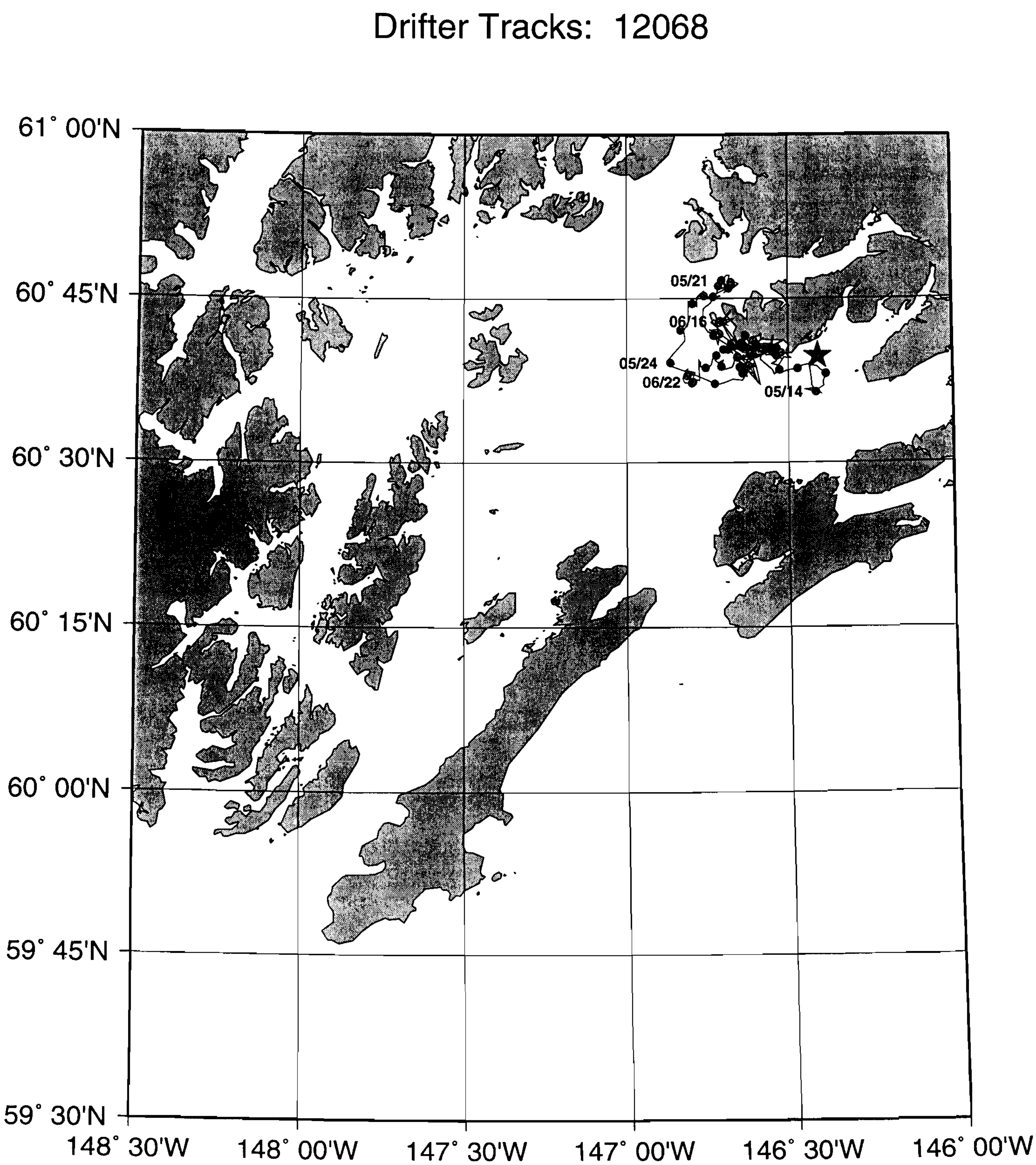

Drifter Tracks: 12068
61° 00'N
60° 45'N
60° 30'N
60° 15'N
60° 00'N
59° 45'N
59° 30'N
148° 30'W
148° 00'W
147° 30'W
147° 00'W
146° 30'W
146° 00'W
05/21
06/16
05/24
06/22
05/14

Figure 22

Drifter Tracks: 12069

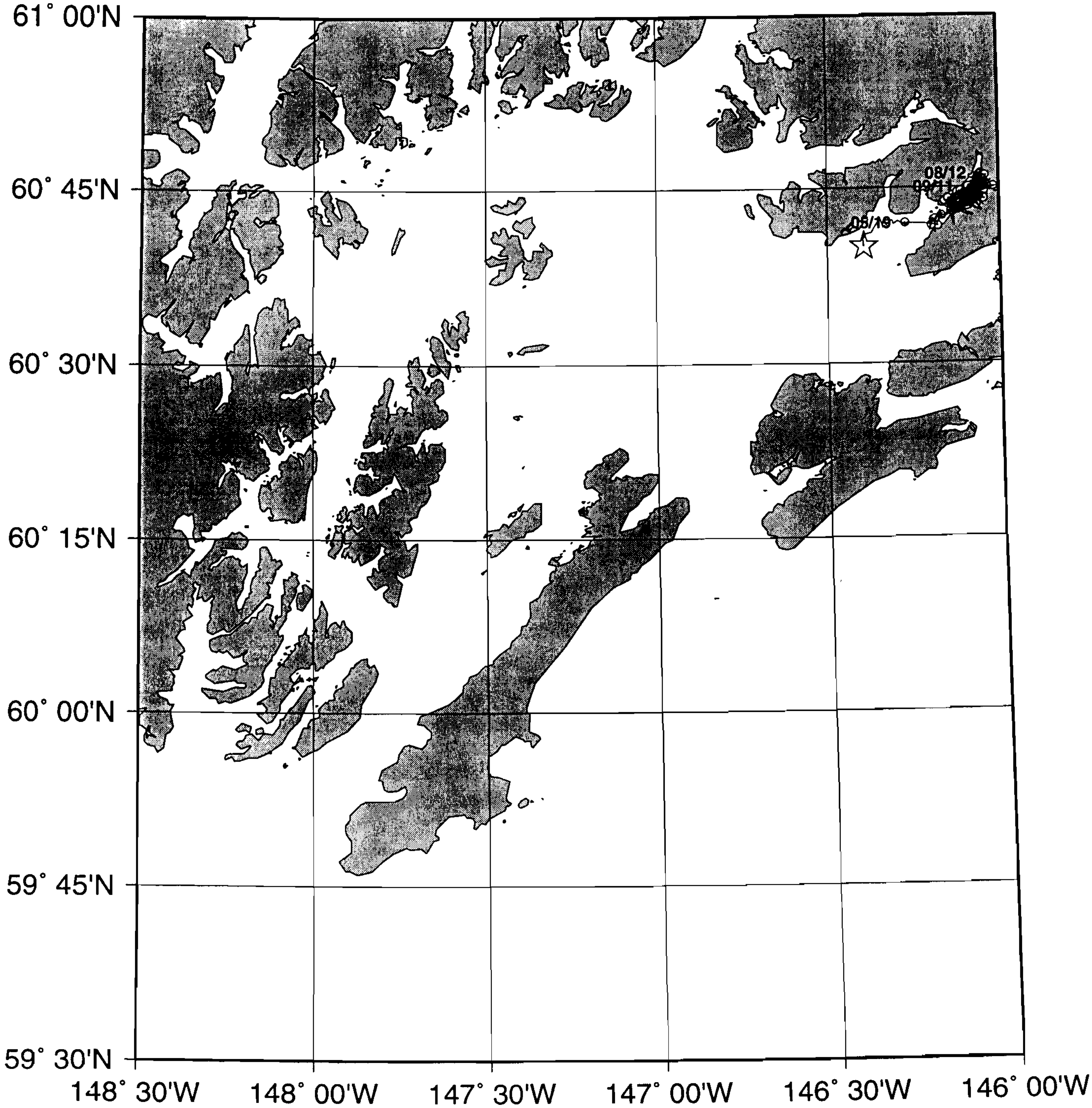


Figure 23

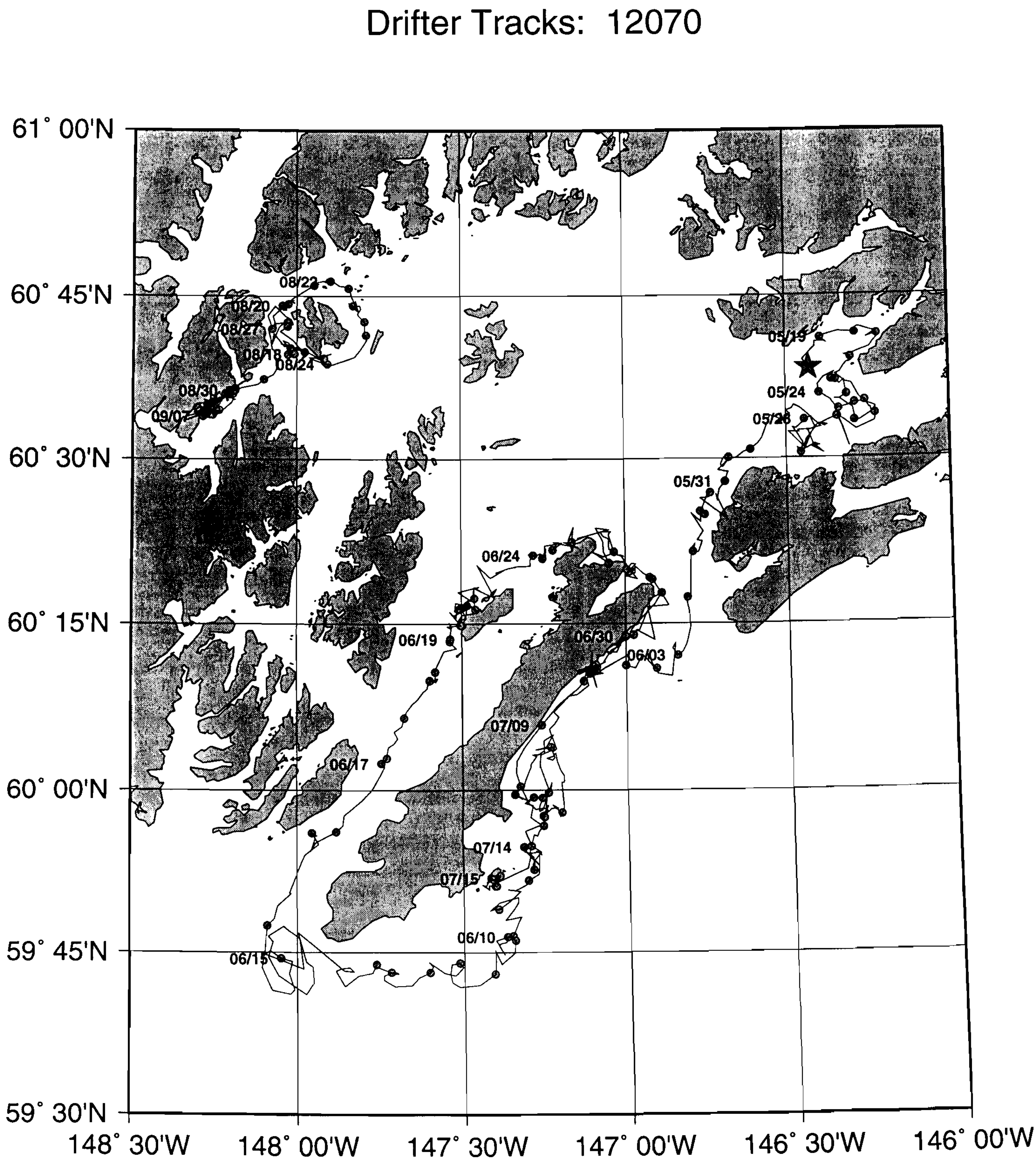

Drifter Tracks: 12070
61° 00'N
60° 45'N
60° 30'N
60° 15'N
60° 00'N
59° 45'N
59° 30'N
148° 30'W
148° 00'W
147° 30'W
147° 00'W
146° 30'W
146° 00'W
05/19
05/24
05/28
05/31
06/03
06/10
06/15
06/17
06/19
06/24
06/30
07/09
07/14
07/15
08/18
08/20
08/22
08/24
08/27
08/30
09/07

Figure 24

Drifter Tracks: 12071

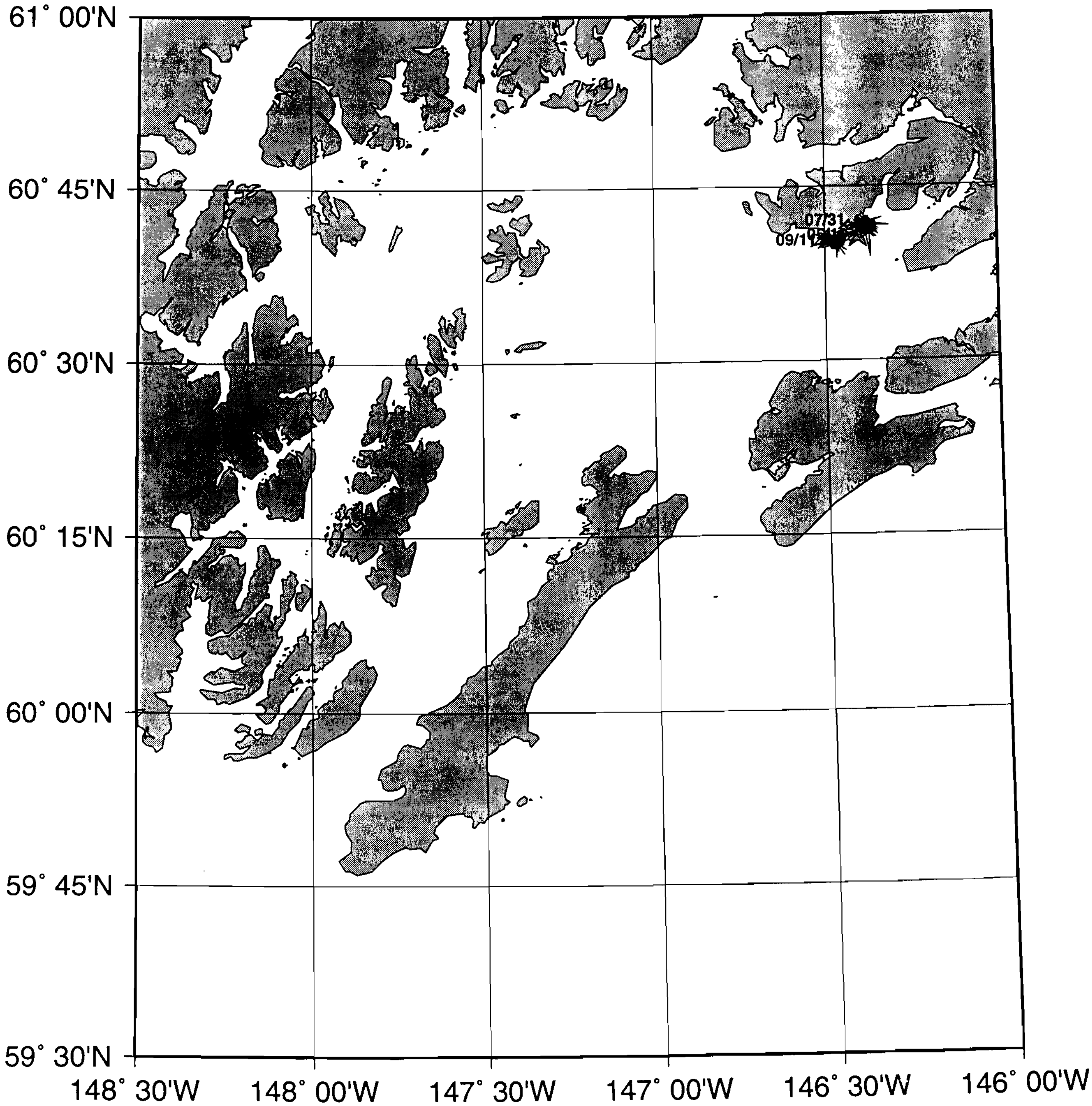


Figure 25

Drifter Tracks: 12072

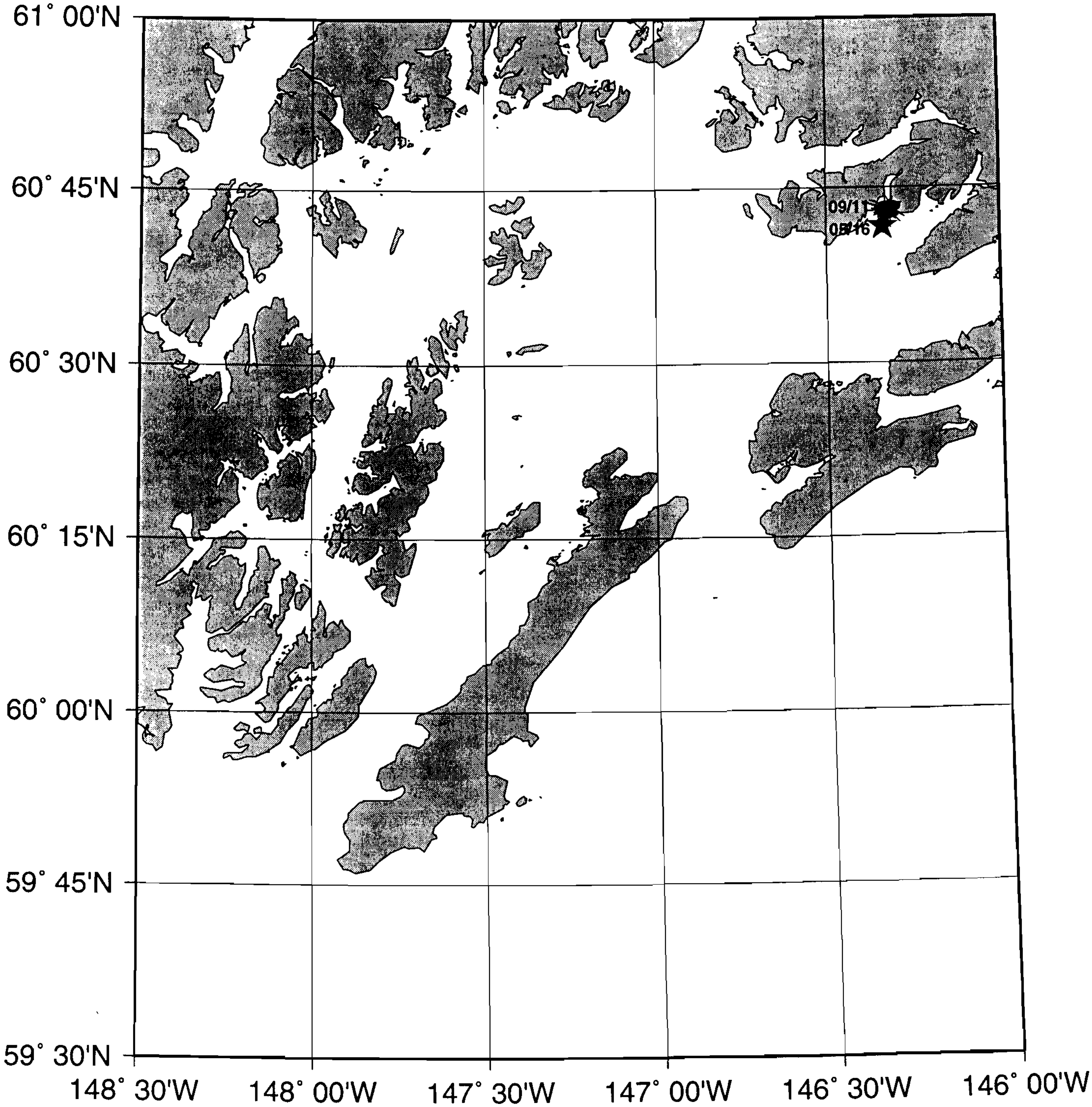


Figure 26

Drifter Tracks: 12073