PROJECT TITLE: Physical Oceanographic Factors Affecting Productivity in Juvenile Pacific Herring Nursery Habitats, submitted under the BAA

Project Number: 070817

Interim Progress Report

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Project Overview

The objectives of the study of physical oceanographic factors affecting productivity in juvenile herring nursery habitats are to build upon the data base within Prince William Sound (PWS) fjords started under Sound Ecosystem Assessment (SEA) to provide a more objective description of the seasonal dynamics of physical factors affecting productivity of nursery fjords and potential coupling of high recruitment of juvenile herring to broad-scale advection of Gulf of Alaska (GOA) water into PWS. It is also intended to address the limitations inherent in the SEA study, by providing a more comprehensive set of physical data that can be tested with advanced statistical methods used to discern the dominant mechanisms forcing the circulation within fjords and hence advection and/or retention of plankton and larval herring within nursery fjords. Understanding how these mechanisms vary between productive and marginally productive habitats is crucial in accessing the feasibility of restoring Pacific herring by remote rearing of juveniles within specific nurseries. In addition, temporal variation in the physical properties of these sites is important to ascertain the strength of these patterns over time in response to interannual (high frequency) and interdecadal (low frequency) climatic shifts brought about respectively by the El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), as well as gradual background changes heat flux due to Global Warming.

To meet these objectives the study has three major goals:1) to continue a time series of basic physical and biological parameters measured during the SEA project within four nursery fjords used by juvenile Pacific herring (Fig. 1), and to compare these results with similar data being collected at oceanographic moorings at Hinchinbrook Entrance (HE) and Montague Strait (MS) and during high spatial resolution hydrographic cruises conducted as part of the PWS (Ocean) Observing System (PWSOS); 2) To quantify conditions that influence advection of nutrients and plankton into two experimental nursery fjords by measuring features of hydrography and circulation pertaining to exchange of water near the mouth.; and 3) to provide descriptions of the general circulation within two nursery fjords (one per year) by obtaining high resolution physical data on the flow field and its affects on the spatial distribution of physical properties.

Results to Date

Broadscale Hydrography

The first component of this research involves the seasonal collection of hydrography data from the four fjords surveyed during SEA and stations within PWS. The data, including temperature and salinity (T/S), fluorescence, and turbidity, are being obtained through coordination with other ongoing research programs including Oil Spill Recovery Institute (OSRI) and Alaska Ocean Observing System (AOOS) sponsored oceanographic moorings, thermosalinograph (TSG) cruises within PWS, and two EVOS funded research projects: (Trends in adult and juvenile herring distribution and abundance in PWS - R. Thorne, PWSSC and Prince William Sound Herring Forage Contingency - T. Klein, PWSSC). Results of the AOOS moorings deployments are still under evaluation, but hydrography data within the four SEA fjords were collected in March and June, and additional conductivity/temperature/depth (CTD) data in Simpson were collected in June and July (Table 1). A TSG cruise planned for early August will

Table 1. Research Log for Factors Affecting Productivity in Herring Nurseries (2007)

Month	*Dates*	*Cruise, Locations & P.I.*	*Types Data Collected or Service Performed*
March	19-24	Juvenile Herring Cruise - D. Thorne	Broad scale hydrography; CTDs at 6 stations in each fjord
May	8-20	Zooplankton Cruise - T. Kline	Hydrography (Hydrobios CTDF) at discrete depths in above fjords
June	2	Trip to Simpson - S.Gay	Hydrography (6 CTDs) & wire-walker test deployment at SB
June	13-14	Cruise to Simpson - S. Gay	CTD Moorings deployed at SB (inner basin and mouth)
June	16	Trip to Simpson in Whaler - S. Gay	Checked moorings & placed kill cells on CT in N. Arm
June	20-22	Cruise to Simpson Bay (KD706)	Intensive ADCP/Hyrography transects
June	26	Trip to Simpson in Whaler - S. Gay	Collected water samples (A.Q.) & CTDs at 4 stns (20 m max.)
June	28	Trip to Simpson in Whaler - S. Gay	Download met data; zoop tows at mouth & delta (N.Arm); CTD's
July	1-5	TSG Cruise to EGB, WB, ZB	Broad scale hydrography; tsg & CTDs at 6 stations in each fjord
July	7	Trip to Simpson in Whaler - S. Gay	Download met data & attempted to deploy 2nd weather stn
July	13	Trip to Simpson in Whaler - S. Gay	setup shore met station on an island on east side of Simpson
July	15-17	Cruise to Simpson Bay (OC707)-S.Gay	Intensive ADCP/Hyrography transects
July	21	Trip to Simpson in Whaler - S. Gay	Download met data from buoy & shore stations (note-unable to establish comm. w/ buoy met station)

collect CTD data throughout PWS and at the mooring sites in Hinchinbrook Entrance and Montague Strait. This cruise will also survey the four SEA fjords as well as the outer portions of two tidewater glacial fjords also investigated during SEA (Unakwik Inlet and Icy Bay). The intent here is to determine the extent of subsurface glacial water potentially emanating from the glacial basins. During the SEA project, water advected from these fjords was found to enter Eaglek Bay and Whale Bay and produce fronts (i.e. differing fish habitat) within the main basins (Gay and Vaughan, 2001).

Fig. 1. Locations of four fjords surveyed during the SEA herring research project conducted from 1995 to early 1998.

Results from March 2007 Cruise

The physical properties of the four SEA fjords surveyed in March 2007 are shown in Figure 2. The conditions observed in 1996 are shown in Figure 3 to provide a comparison over 10+ years. From these data it is quite evident that local spatial variation in late winter is greater among these four sites in 2007 in comparison to 1996. Note, however, that the plots for 2007 go only to 100*m* depth whereas the 1996 data show nearly the entire water column. Comparing the T/S data to this depth limit shows profiles in 2007 to be generally colder and saltier in comparison to 1996. This is expected on the basis of the extreme weather conditions that occurred in March 2007 in comparison to 1996. For example mean air temperatures over PWS in March 1996 were ~ 2^{o}C (Gay and Vaughan, 2001) whereas in March 2007 high pressure over the continent created strong seaward katabatic winds and air temperatures fell to -17 ^{o}C (Dick Thorne, personal comm.).

One interesting difference between these years, however, is the marked spatial heterogeneity that occurred in 2007 despite the strong mixing processes that prevailed that year. This appears to reflect both local variation in winter climatic conditions and differences in water mass conditions between the inner and outer regions of these fjords, particularly at stations located at the mouths. The fjord exhibiting the most consistent vertical pattern in mixing of heat and freshwater is Whale. The depth of upper layer mixing in 2007 is much greater (40-50m) in comparison to all other fjords as well as to conditions within Whale in 1996 (Fig. 3b). In fact, 1996 exhibited the coldest winter water conditions during the SEA years (1996-1998), and yet in 2007 the entire upper 50m layer is significantly colder and fresher by comparison. This suggests that 2007 is an anomaly, and illustrates the need for long-term data collection if highly variable interannual events are to be distinguished from low frequency changes occurring in the background, such as ENSO and PDO.

Exprimental Bay

The second component of this project involves intensive collection of physical data in Simpson Bay (Fig. 1b), an experimental nursery fjord selected for 2007. Whale Bay will be surveyed in 2008. The various cruises and trips (non-chartered) made to Simpson since the beginning of June are listed in Table 1. These trips have involved both intensive acoustic Doppler current meter (ADCP)/hydrography cruises conducted in June and July and various half-day trips in my personal skiff to download weather data (described below) and collect water and plankton samples. Additional data collected during the intensive cruise in July include water for nutrient and chlorophyll analyses and zooplankton net-tows. The water samples will be analyzed by Antonietta Quigg, who is concurrently investigating phytoplankton production in Simpson Bay, whereas the zooplankton samples will be processed qualitatively for species composition by Dr. Robert Campbell (PWSSC).

Currents. Examples of ADCP data collected during the intensive cruise in June are given in Figures 4 to 6. Figure 4 shows a vertical section of the *u* velocity component during the first flood tide and Figure 5 shows the near surface (2*m*) current vectors for the same set of transects. Note that during this tide phase strong currents occur in the upper 10*m* over the entire main basin. These flows appear to force a flow reversal along the eastern side of the fjord thus forming an eddy at the mouth (Fig. 5). These results are consistent with ADCP data collected later in July 2007 and during a flood tide in 1996 (see Fig. 5 in Revised DPD). In contrast, the Northern Arm (inner basin) has very limited flows during the flood tide. However, during ebb tide (Fig. 6) the outflows increase in strength apparently due to the topographic obstruction caused by the reef (sill) guarding the entrance to this basin. This reef also causes a topographic obstruction to deep flows and hence appears to set up a subsurface reversal (Fig. 6), which was also observed within the N. Arm during the SEA project.

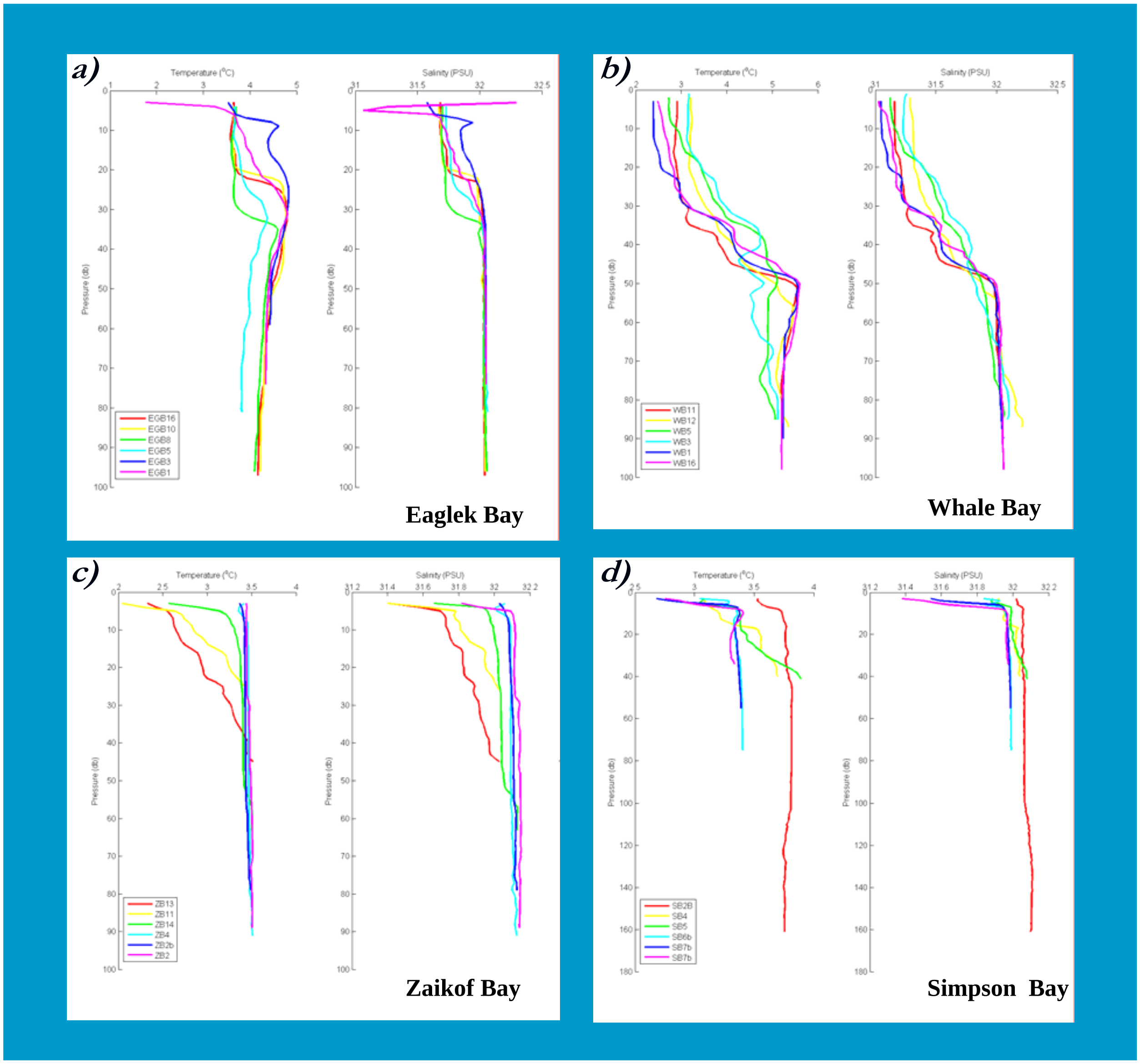

Fig. 2. Spatial variation in hydrography within the four SEA nursery fjords in March 2007. (*Plots courtesy of Rob Campbell, PWSSC.*)

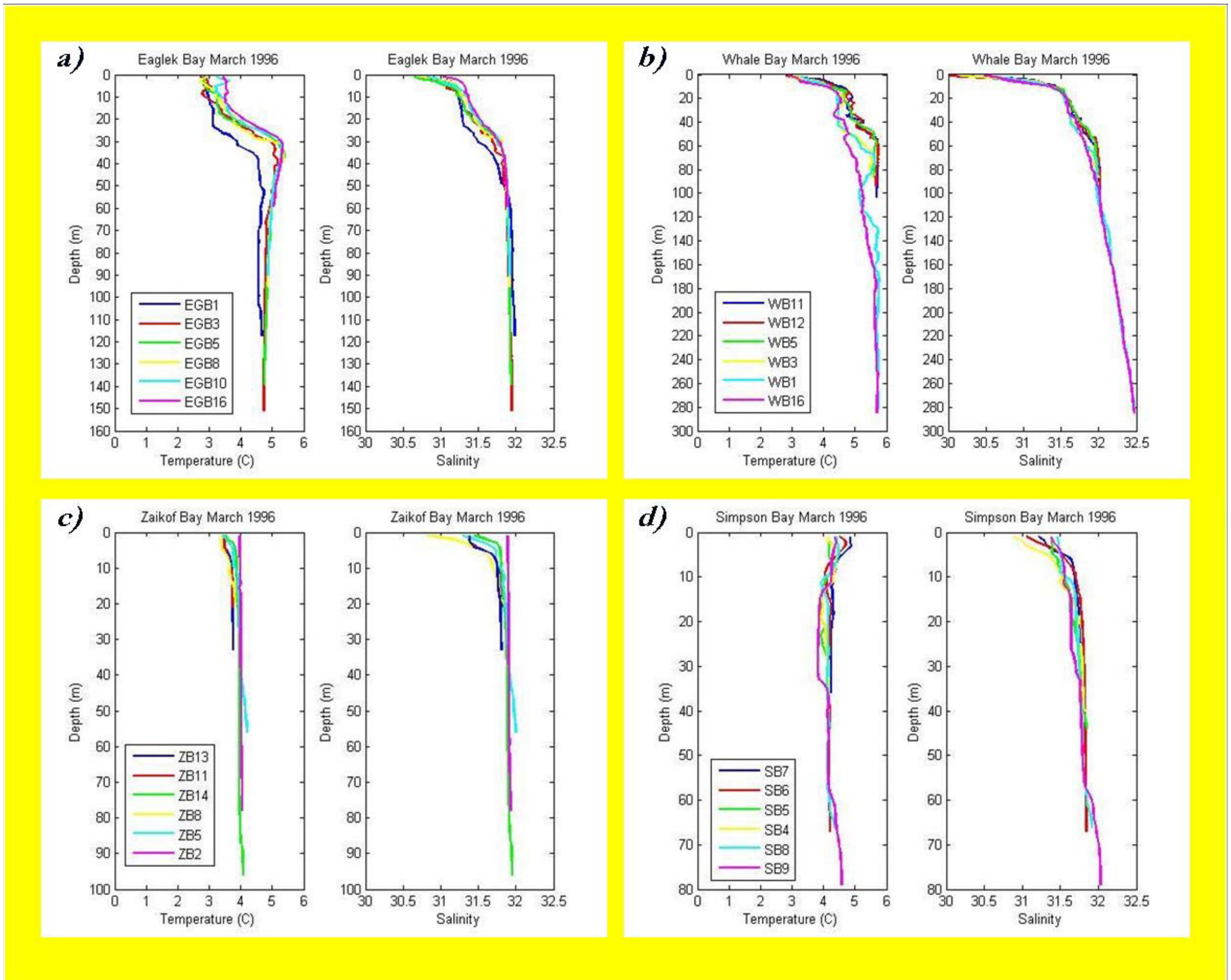

Fig. 3. Spatial variation in hydrography within the four SEA nursery fjords in March 1996.

Ancillary data collected in Simpson Bay include a time series of meteorological data consisting of winds and air temperatures (Fig. 7). These data are being collected by a weather station placed on the mooring buoy at the mouth and also by a second station, which has been set up on shore on an island located on the eastern side of the mouth (Fig. 8).

Figure 7 shows a subset of the total time series for the period covering the first intensive cruise (June 20-22). The shaded area of the plot indicates the period over which transects were surveyed in Figures 4 to 6. Note that the although the winds were generally low during this period there is a burst of winds from the west-southwest exceeding 5*m/s* (~ 10*kts*) during the flood tide. Many of these westerly wind bursts have been evident in the wind data this summer. They are typically generated by high barometric pressure to the west and intensify in the afternoon due to sea-breeze effects. These winds probably enhanced the inflowing currents during the first flood tide slightly. However, the primary forcing of these flows was due to the tidal prism and effects of bathymetry. The same pattern was observed during the first flood tide in July, which had a similar tidal height change (~ 3*m*). In contrast to June, however, the winds from the west were stronger (~8-10*mps*) and this appeared to enhance the surface inflow and the eddy formation at the mouth. These observations tend to confirm a supposition made during the SEA project regarding surface transport from central PWS into Simpson Bay.

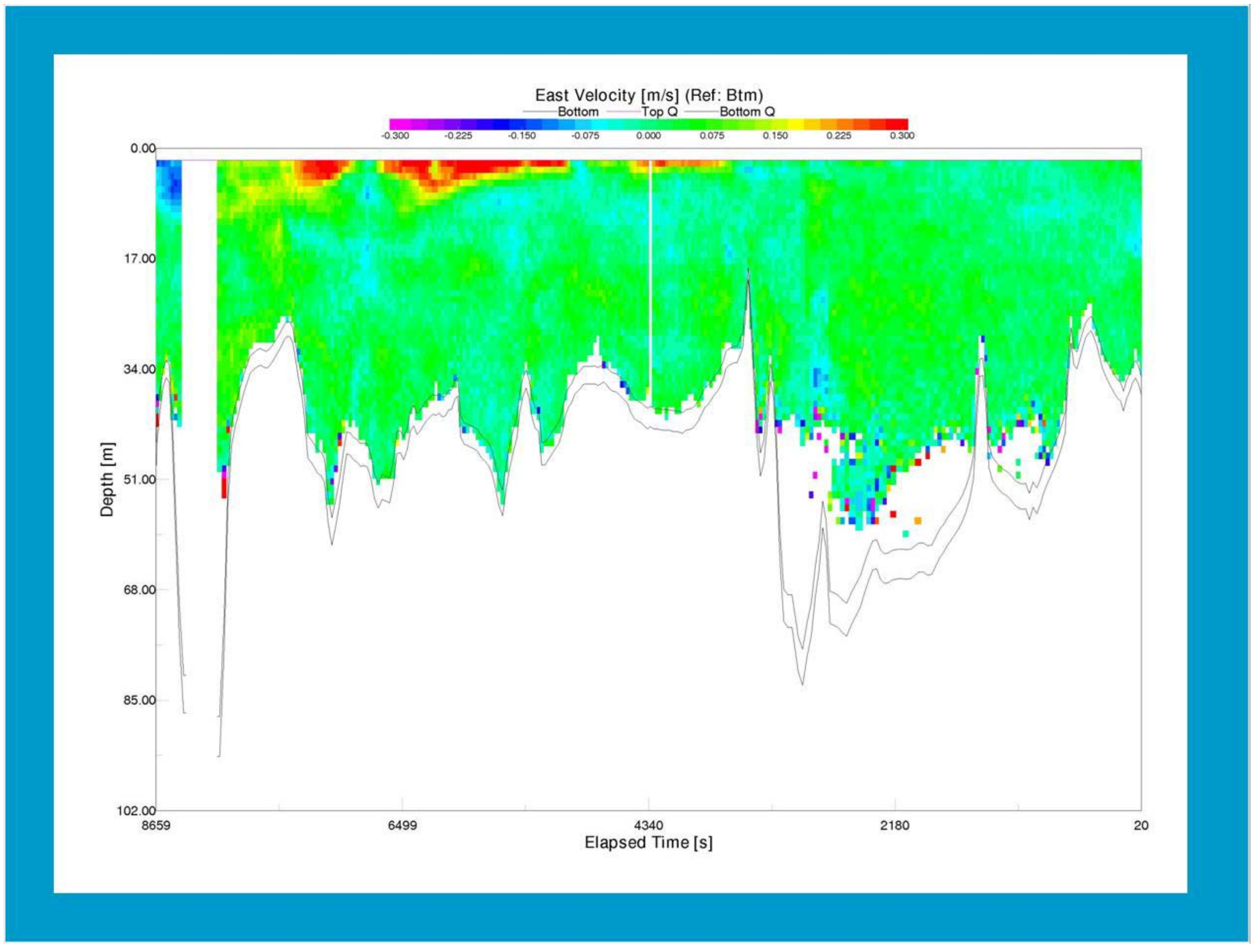

Fig. 4. East velocity (*u*) component of currents during the first flood tide in Simpson Bay, June 21, 2007.

Hydrography. During the first intensive cruise in June hydrography data were collected initially with an undulating tow-body. Because of a problem with the Chelsea Instruments (CI) Aquapack these data were collected with an SBE911 CTD mounted to a tow-sled. This instrument was providing very high resolution T/S data, but unfortunately the sled struck bottom in the deep channel on the eastern side of the mouth. The impact sheered off the power bulkhead connector and disabled the instrument for the remainder of the cruise. To compensate for this loss, CTD casts were repeated at standard stations from the N. Arm to the main basin and a series of 5 stations were surveyed across the mouth. The repeated casts were performed on every other set of transects, thus allowing uninterrupted current data collection on every other set. This same protocol was followed during the July cruise, as the vessel used for the survey was not capable of operating the hydraulic winch required for the undulating CTD. At present, the minimum size vessel for collecting these data is a 15*m* (50*ft*) seine type vessel equipped with 220 VAC 3-phase power. Due to the escalation in fuel and charter costs it is anticipated that only one more cruise of this type may be feasible this summer due to budgetary constraints.

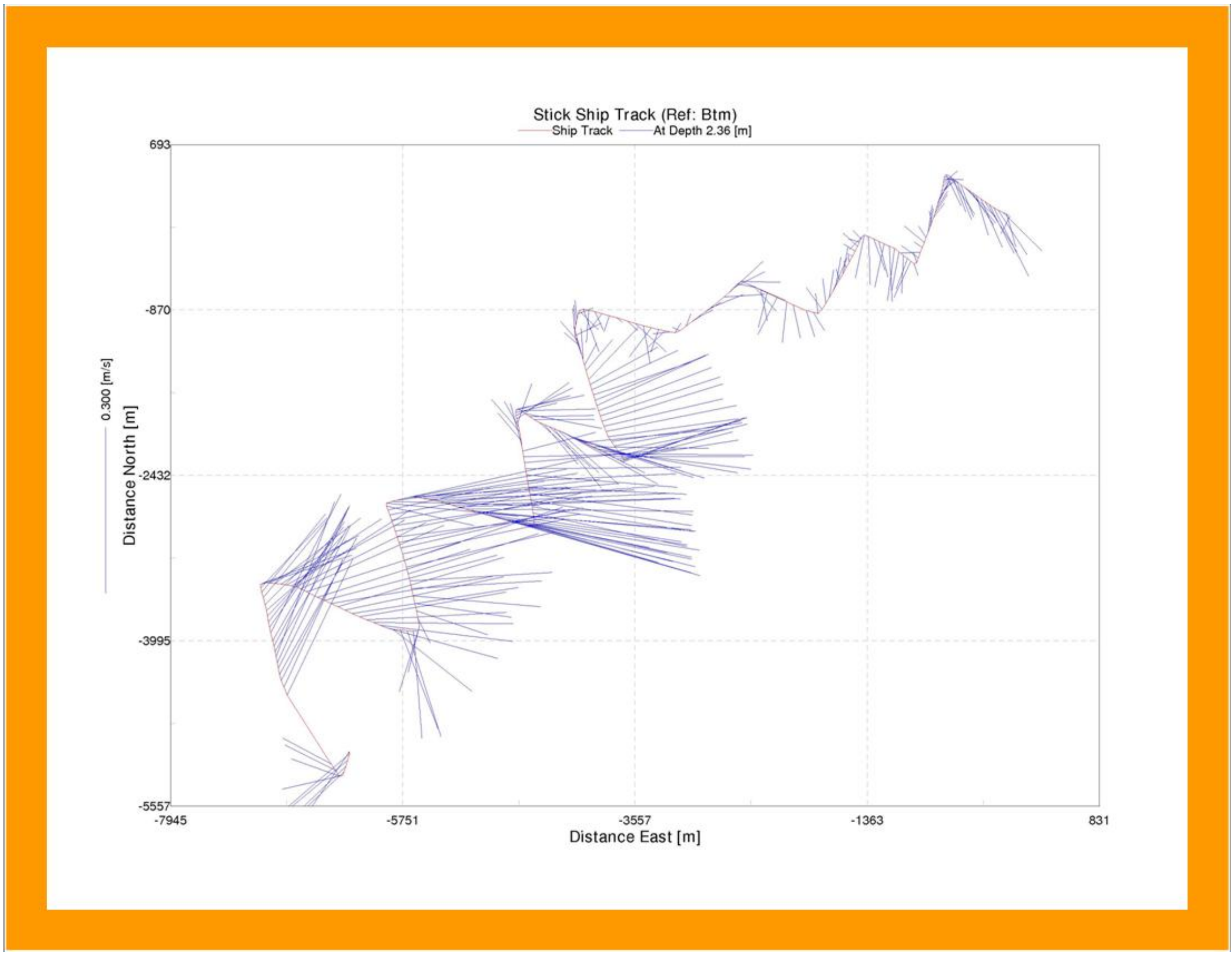

Fig. 5. Surface (2m) currents during the first flood tide in Simpson Bay, June 21, 2007.

An example of T/S data collected at the standard stations just prior to the intensive transects surveyed in June is shown in Figure 9. These CTD casts span between the N. Arm and the mouth (SB7b to Sb2b), and include two stations in the SE Arm (SB8 and 9). The data were collected during a flood tide on June 20. Although there is some spatial variation evident in the subsurface physical properties, the main feature that stands out is the progressive increase in salinity from the inner basin (N. Arm) and the outer basin and mouth. The surface water is warmest within the upper main basin (SB5) and coolest within the inner basins (at both SB7b and SB8). The conditions within the N. Arm remained the same during the ebb tides with the exception that station 7 exhibited low surface salinity (<10) due to discharge from the river moving southward.

This water also tended to be significantly cooler during the ebb since it primarily originates from glacial melting in the watershed. Station SB8 and 9 also exhibited cooler surface conditions, but the water was also saltier in comparison to the other arm. This appears to be the result of both surface mixing in this region of the fjord and less freshwater input. For example the westerly winds that affect the main basin continue unhindered into the SE Arm where the long fetch produces breaking and mixing far up into the arm.

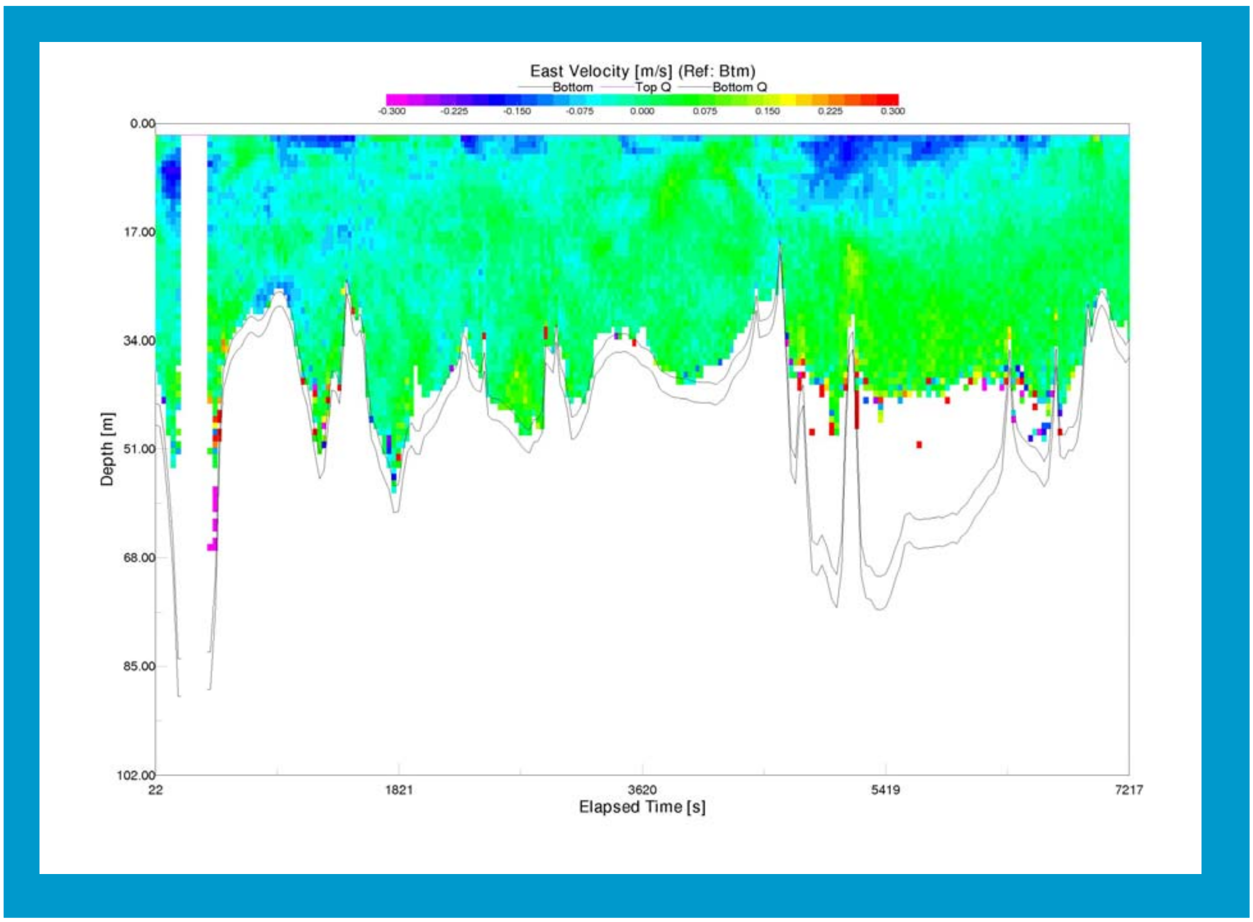

Fig. 6. East velocity (*u*) component of currents during the first ebb tide in Simpson Bay, June 21, 2007.

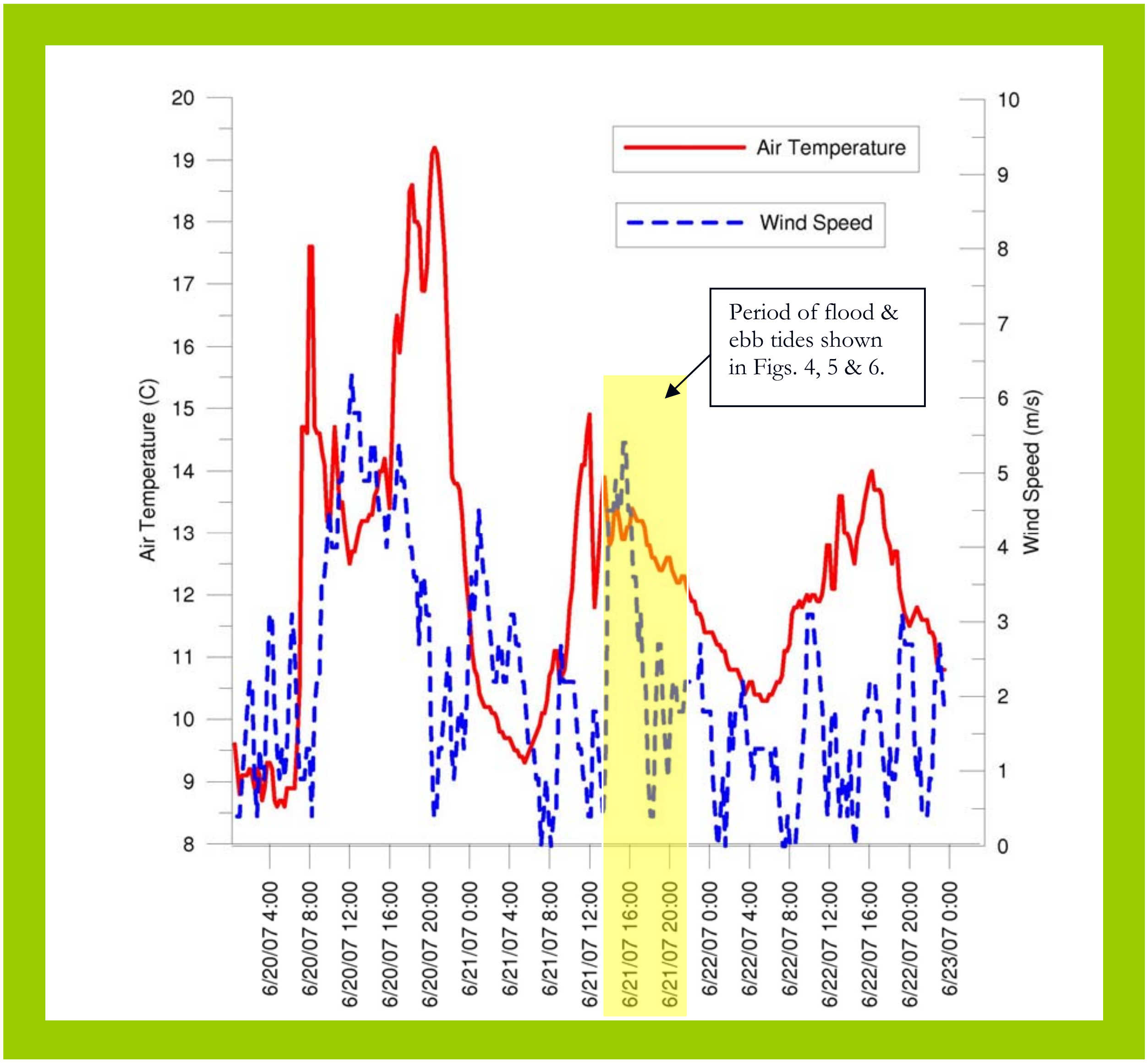

Fig. 7. Air temperatures and wind speeds during the first intensive ADCP/hydrography cruise from June 20-22, 2007. Shaded area shows period during the first flood and ebb tide for data shown in Figures 4 to 6.

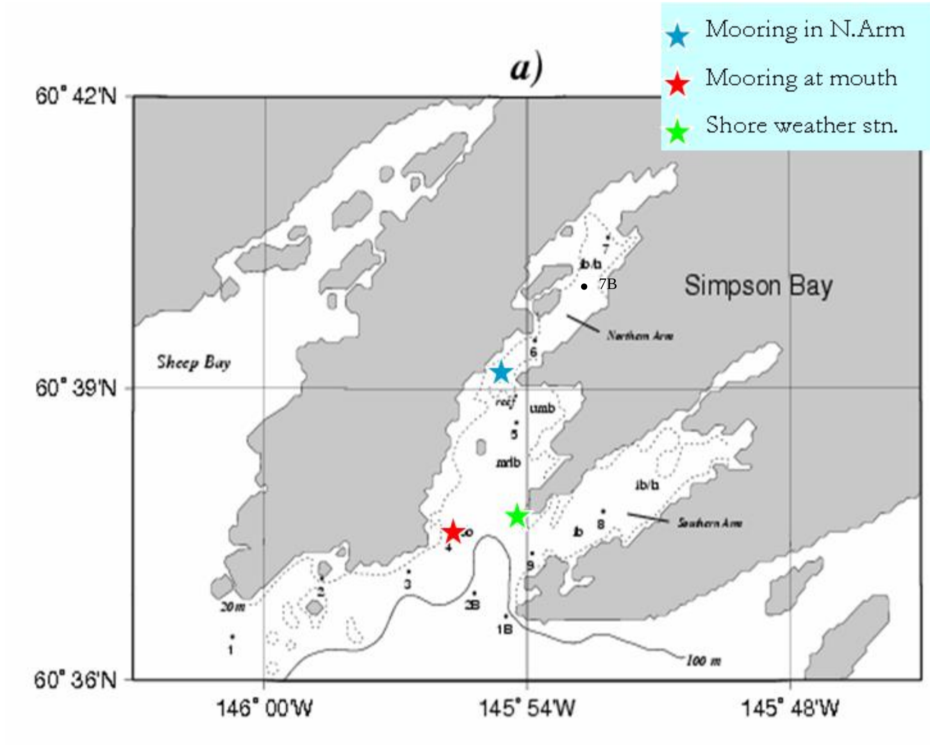

Fig. 8 Locations of oceanographic stations, CT moorings and shore weather station in Simpson Bay in 2007. Note that station 6 is close to 6b in Fig. 9.

CTD Moorings

The final component of the experimental fjord is comprised of time series of heat and freshwater flux obtained from two moorings equipped with near-surface (2-3*m*) and deep (40-70*m*) CTs. These moorings are deployed in the deep (70-80*m*) portion of the N. Arm (i.e. north of the sill) and near the mouth (40-50*m*) respectively (Fig. 8). The moorings were deployed in mid June, prior to the first cruise on June 20-22, and will be retrieved in the early fall. Calibrations of the CTs were performed by SBE Inc. prior to deployment to determine offset and drift in the sensors.

A schematic of the mooring located near the mouth is shown in Figure 10. Pictures of the various components of these moorings are also shown in this Figure. The basic design of the moorings includes subsurface flotation located at the top of the thermistor array. This functions to both minimize the dip in the mooring line during ebb tides and serve as a potential recovery safeguard if the surface buoys were to be lost or sunk for some reason. To reduce the lean of the mast under high winds the spar buoy at the mouth was designed with a tether (Fig. 10d). This was done to prevent an excessive vertical angle for the anemometer on the weather station. The clamping point for this tether is located at the approximate center of pressure given a 1.0 *m/s* current and a 10 *m/s* wind. The latter parameters fall well within the range of water currents and winds expected during the summer at Simpson. Note that the console and battery for operating the weather station is located inside a waterproof Pelican case attached to the buoy mast (Fig. 10b,d,e). Instead of heavy solid weights, the anchor system utilizes large Danforth style anchors with long (10m) runs of chain and a series of heavy links on the ends. This was done to ensure that minimal drag occurs under high current and wind loads and also for ease of deployment. As of this report both moorings are performing well and have remained in place.

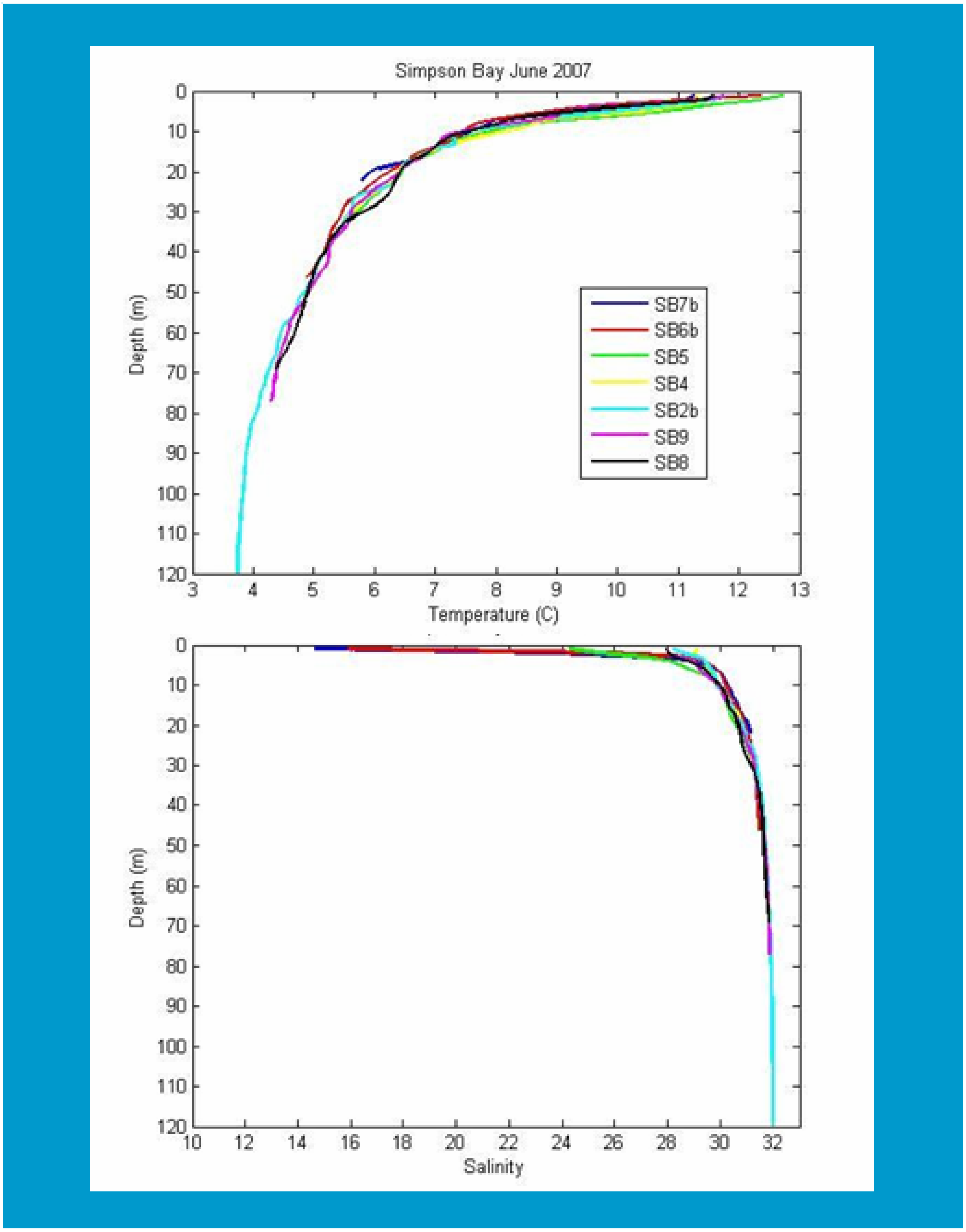

Fig. 9. Temperature and salinity profiles during a flood tide on June 20, 2007 prior to ADCP transects on June 21-22.

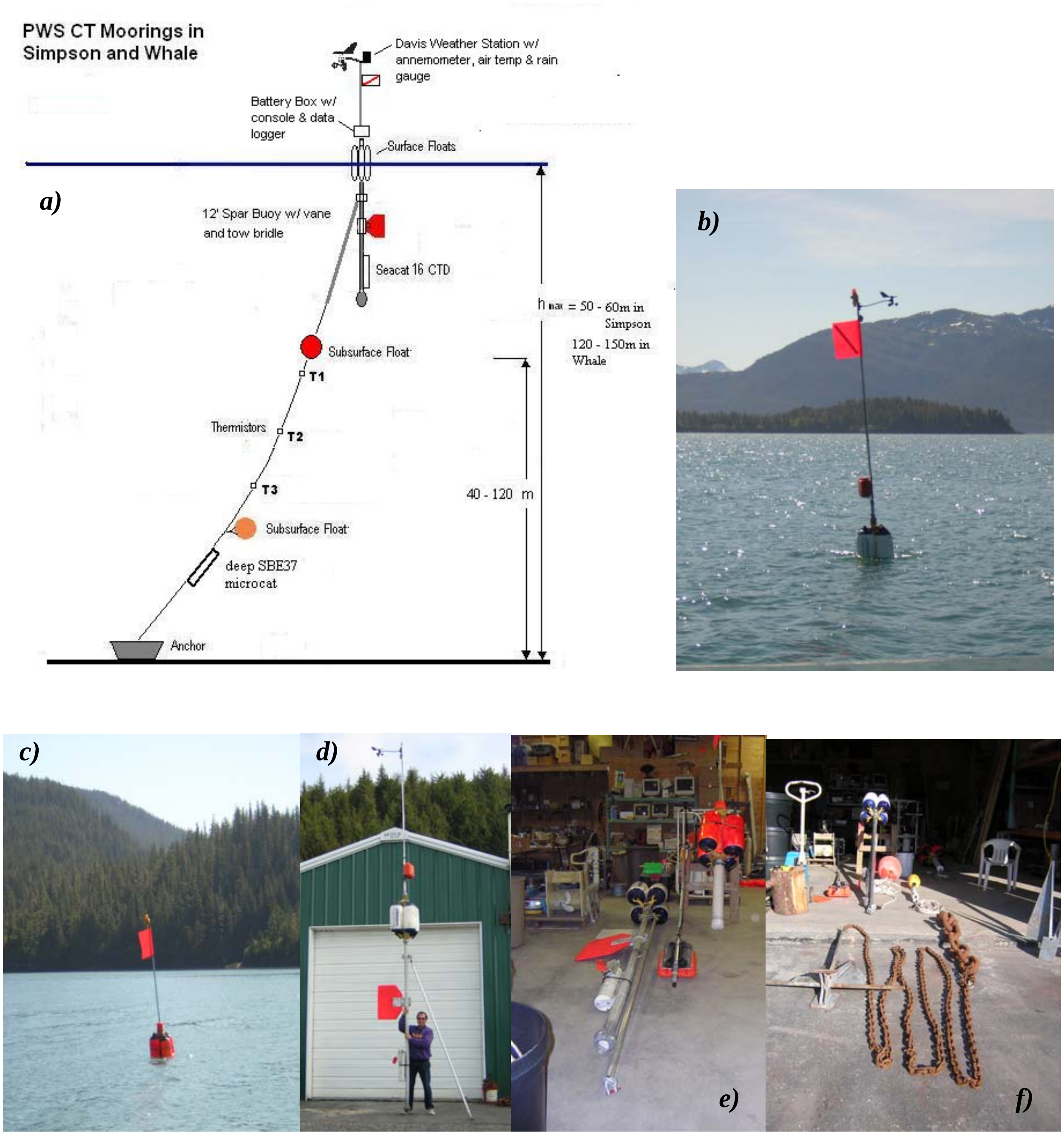

Fig. 10. Schematic and components of moorings deployed in Simpson Bay. a) schematic showing placement of CTs and thermistors; b and c) surface buoys deployed at the mouth and N. Arm respectively; d) spar buoy with weather station and tether; e and f) surface buoy components and anchor set-up. Note that anchors are 23 kg (50 lb). Danforth type weighted with ~ 10m of 3/8 in. chain and heavy chain links located at the beginning of the Spectra mooring line. The 1st CT is located 10m above this juncture.

Summary

The project investigating factors affecting productivity of juvenile herring nursery habitats has three major objectives described in the introduction. The first of these, which involves collection of hydrography data within the four SEA fjords, has been mostly successful and thus far two sets of data (March and June) have been obtained. Cast data in May were not obtained, however. This was due in part to the project just beginning and attempting to direct the initial work from Texas. After arriving in Cordova, however, these cruises are being coordinated, and a more intensive cruise is planned for early August in which all of the fjords and TSG stations will be surveyed within one week. This cruise will also include casts at HE and MS to calibrate the AOOS moorings. The last cruise to obtain CTD data from the four SEA fjords this year will likely occur when Dick Thorne's project commences to sample juvenile herring in the late fall.

The second and third objectives of the project involve intensive surveys of the physical oceanography of Simpson Bay. This work has been fairly successful thus far with two cruises completed, two sets of CT moorings deployed and two weather stations set up. At least one more intensive cruise is scheduled before the end of August. Unfortunately, the damage to the undulating tow-sled incurred during the first cruise and the lack of suitable vessels during the summer to operate the CTD winch have constrained the use of this equipment. In addition, there have been equipment problems with the Aquapack, and this instrument has also not been functional since its return. Another limitation involving logistics has been the high cost of fuel and charters. This has created significant constraints this season and is addressed further under the proposed changes to next year's budget.

Despite various set-backs this project has encountered, I believe that a comprehensive picture of the factors forcing circulation within Simpson bay are beginning to emerge from the data being collected. The number of ADCP transects obtained during the last cruise are adequate to perform the statistical analyses described in the proposal to determine the flushing rates and water exchange within the main basin and N. Arm. The hydrography from repeated casts should indicate how water masses are circulating in general with the tide stages, but I will only be able to obtain one full set of these data in late August using an undulating CTD. The next intensive cruise may focus sampling at the mouth of the main basin and SE Arm over several tide cycles to obtain a high frequency record of the currents and hydrography to pinpoint water exchange into the fjord. The water and plankton samples collected during the various cruises will be analyzed to determine the relative importance of locally derived versus allochthonous sources of nutrients and plankton to the productivity of this nursery fjord. These data along with circulation and water exchange should also indicate whether the N. Arm (the primary habitat of age-0 herring) is semi-isolated from flushing that appears to occur regularly in the main basin of the fjord.