Monitoring of oceanographic properties of Glacier Bay, Alaska

2004 Annual Report

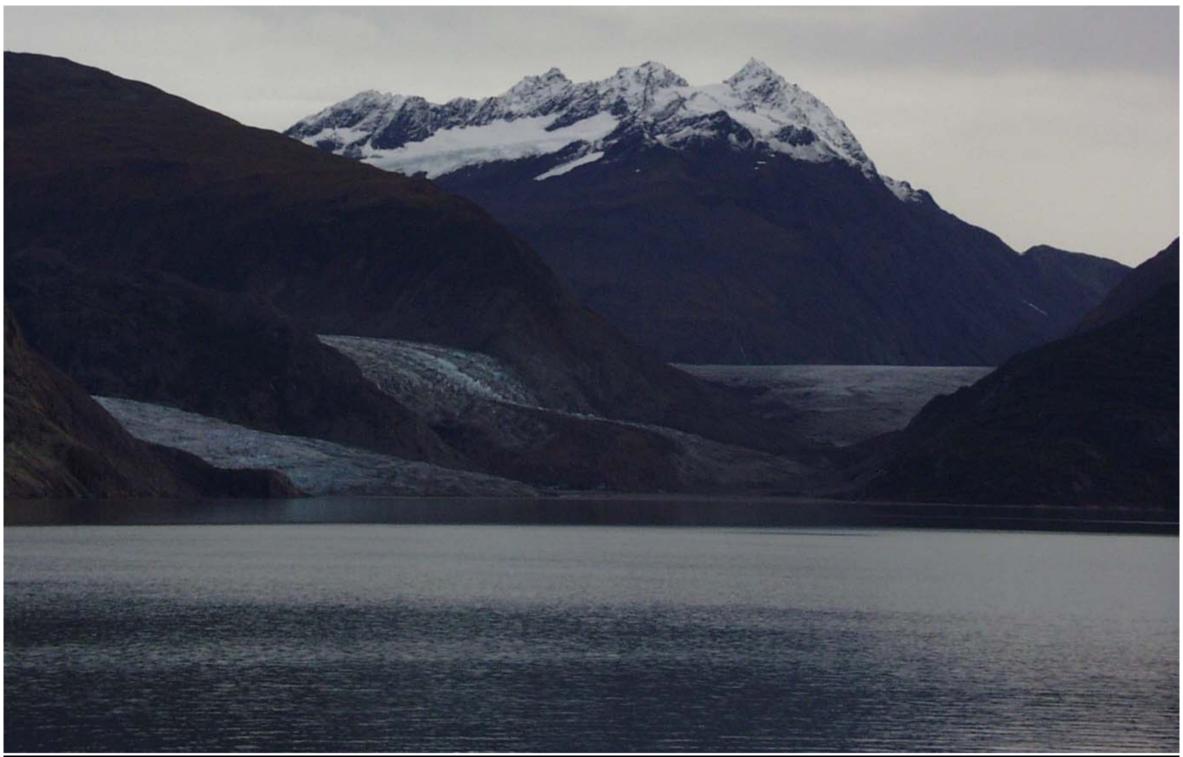

Photo by Erica Madison

Erica Madison and Lisa L. Etherington

U.S. Geological Survey
Alaska Science Center
Glacier Bay Field Station
P.O. Box 140
Gustavus, AK 99826

Prepared for Glacier Bay National Park (Gustavus, AK)

June 2005

Introduction

Glacier Bay is a recently (300 years ago) deglaciated fjord estuarine system that has multiple sills, very deep basins, tidewater glaciers, and many streams. Glacier Bay experiences a large amount of runoff, high sedimentation, and large tidal variations. High freshwater discharge due to snow and ice melt and the presence of the tidewater glaciers makes the bay extremely cold. There are many small- and large-scale mixing and upwelling zones at sills, glacial faces, and streams. The complex topography and strong currents lead to highly variable salinity, temperature, sediment, primary productivity, light penetration, stratification levels, and current patterns within a small area.

The oceanographic patterns within Glacier Bay drive a large portion of the spatial and temporal variability of the ecosystem. It has been widely recognized by scientists and resource managers in Glacier Bay that a program to monitor oceanographic patterns is essential for understanding the marine ecosystem and to differentiate between anthropogenic disturbance and natural variation.

This year's sampling marks the 12th continuous year of monitoring the oceanographic conditions at 23 stations along the primary axes within Glacier Bay, AK, making this a very unique and valuable data set in terms of its spatial and temporal coverage.

Methods

The Glacier Bay oceanographic monitoring project was designed for the acquisition, analysis, and modeling of fjord-estuarine oceanographic data in Glacier Bay, Alaska. In 2004, sampling of Glacier Bay's oceanographic conditions was conducted four times, including the months of March, June, July, and October (Table 1). Repeated sampling of the lower Bay stations during both peak flood and slack high conditions was conducted in the month of June. Recent compilation and analysis of Glacier Bay's oceanographic data set led to suggestions for sampling consistency among years, by concentrating the core sampling on March, July, October and either December/January (time period of low variability), with June and/or August noted as additional beneficial time periods (Etherington et al. 2004).

Oceanographic sampling was conducted using the standard protocol for the Glacier Bay oceanographic monitoring program (Hooge et al. 2004). Sampling consisted of performing a single CTD (conductivity, temperature, depth) cast at each station (Fig. 1). Data were collected for each 1 m depth bin of the water column from the surface to within 10 m of the bottom, or to a maximum depth of 300 m. This specific model of Seabird CTD is limited to depths of 300 m. Some stations are located at depths greater than 300 m. From each depth bin, the following parameters were measured: 1) salinity (psu) –calculated from conductivity; 2) temperature (ºC); 3) irradiance (microEinsteins m^{-2}) – measure of photosynthetically active radiation (PAR); 4) optical backscatterance (OBS) (mg L^{-1}) – measure of turbidity; 5) fluorescence (mg m^{-3}) – a proxy for chlorophyll-a concentration; 6) density of water (σ_t) – derived from salinity and temperature.

Euphotic depth was defined as the depth at which the amount of PAR equals 1% of that measured at the surface (thus, euphotic depth measures the depth at which light availability becomes minimal). An index of stratification was calculated to describe the stability of the water column. Differences in the density of the water column between consecutive 1 m depth bins were calculated so that an overall mean of density change could be determined ($\Delta\sigma_t$ m^{-1}) for a specified stratum of the water column. Similar stratification indices have been used in other studies to quantify water column stability (e.g., Bowman and Esaias 1981, Sime-Ngando et al. 1995).

Oceanographic characteristics were defined for the top 15 m of the water column. Means of temperature, salinity, stratification, OBS, and chlorophyll-a were calculated over the surface stratum of 0-15 m for each cast. This depth stratum was chosen because it is the most dynamic region of the water column within Pacific fjords (the density typically reaches 90% of the deep water value by 10-15 m; Pickard and Stanton 1980), including Glacier Bay (Hooge and Hooge 2002). Additionally, the depth stratum of 0-15 m is a zone of high biological production in southeast Alaska estuarine systems (Ziemann et al. 1991, Hooge and Hooge 2002). For example, temporal patterns of chlorophyll-a concentrations within Auke Bay, AK varied only slightly when depth-integrated values for 0-15 m were compared to those for 0-35 m (Ziemann et al. 1991), suggesting that almost all of the phytoplankton occurred in the top 15 m. Further, Robards et al. (2003) demonstrated that the most forage fish biomass within Glacier Bay was found within the shallowest water layer (<25 m), irrespective of bottom depth.

Results and Discussion

Salinity

In 2004, regional and seasonal patterns of surface water salinity generally followed the average spatial and temporal salinity patterns over the years 1993-2002 presented in Etherington et al. (2004) (Fig. 2). There was a decline in salinity of surface waters as you move from the mouth to the head of the Bay. June sampling data describes a high salinity concentration at the mouth and central parts of the bay (e.g., stations 0, 1,2, 3, 4), and a decrease in salinity as you move to the head of the West Arm (e.g., stations 16, 17, 19, 20). Salinity differences among stations were more apparent in the summer and fall months compared to spring sampling (Fig. 2). Greater standard errors were evident for June, July, and October compared with sampling done in March. These higher standard errors calculated from the top 15 meters of the water column represent a large variation of salinity within depth layers. This variation within the top 15m suggests high freshwater input at surface layers. Since water density is mainly a reflection of salinity, rather than temperature in Glacier Bay (Hooge and Hooge 2002, Etherington et al. 2004) and other high latitude systems, these large variations in salinity suggest highly stratified waters. Standard errors of salinity are higher as you move towards the head of the bay, indicating greater freshwater input and stratification. In October 2004, there was high variation in salinity within the top 15 m in the upper portions of the East and West Arms as well as in Geikie Inlet. This amount of variation in salinity or stratification was not as apparent in October of 2003 (Etherington, 2004). In addition, salinity values were considerably lower in October 2004 compares with October 2003. These results suggest a change in rainwater or melt water patterns for the fall of 2004 and an increase in freshwater input to these regions.

Temperature

In 2004, surface water temperatures generally followed the average spatial and temporal temperature patterns over the years 1993-2002 presented in Etherington et al. (2004) (Fig. 3). Similar to salinity patterns, temperature generally decreased as you move from the mouth of the Bay to the head of the Bay, with more variation among stations in the summer compared with the fall, and spring months (Fig. 3). Unlike the surface water salinity patterns, water temperatures did not show much variation with depth as indicated by the relatively small standard errors. Freshwater input to the surface layers within the upper portions of Glacier Bay (evident from salinity variation within casts; Fig. 2) is of similar temperature to those waters at greater depths. In addition, there was not a large difference in the degree of variation within the surface waters across seasons or stations. Of the months sampled, March illustrated the least amount of variation and had the coldest temperatures, which was in concordance with averaged data from 1993 to 2002.

Stratification

In 2004, regional and seasonal patterns of surface water stratification generally follow the average spatial and temporal stratification patterns from the years 1993-2002 presented in Etherington et al. (2004) (Fig. 4). Stratification was greater in the summer months compared with spring, and generally increased as you move from the mouth to the head of the Bay (except for lower stratification levels at stations 13 and 14, which are located within shallower, more mixed areas). In June, July, and just within the upper portions of the Bay in October, there was a large variation in stratification levels across the surface waters within each cast. Most likely the highest degree of difference in adjoining depth bins is occurring at the uppermost surface layers. As suggested previously, time periods and stations with the highest stratification corresponded to the highest variance in surface water salinity (compare Figs. 2 & 4).

Chlorophyll-a

In 2004, regional and seasonal patterns of surface water chlorophyll-a levels generally follow the average spatial and temporal chlorophyll-a patterns found from the years 1993-2002 presented in Etherington et al. (2004) (Fig. 5). Of the months sampled in 2004, July had the highest levels of chlorophyll-a, with the highest reading being at station 7, west of Tidal Inlet. Within the summer months, the central Bay and the lower reaches of the East and West Arms showed the highest levels of chlorophyll-a. In contrast, during the fall sampling in October, the highest levels of chlorophyll-a were found in the upper reaches of Geikie Inlet followed by stations within the Central Bay. (Fig. 5D). From the years 1993 to 2002 June sampling data contained the highest levels of chlorophyll-a (Fig. 5F). Unfortunately we do not have chlorophyll-a data from all stations in June 2004 to examine spatial patterns throughout the Bay. The spring sampling in March 2004 described low levels of chlorophyll-a at all stations that differed from the general increase observed in March (Fig 5F).

The plot of average levels of chlorophyll-a from 1993-2002 by station indicates that the highest levels of chlorophyll-a in surface waters was found at stations 22 and 23

(Fig. 5E). Results from 2004 demonstrate that levels of chlorophyll-a at station 22 and 23 were not remarkably high, with the exception of higher levels in October (Fig. 5D). One thing to note, is that stations 22 and 23 were only recently added to the sampling program in 1999, and that it is possible that conditions may have been different in the most recent years (1999-2002), compared with average patterns over ten years (1993-2002). Therefore, the higher levels of chlorophyll-a in Geikie Inlet compared to the other stations that have been sampled consistently since 1993 could be an artifact of our sampling frequency (Etherington et al. 2004). The moderate to high levels of chlorophyll-a within Geikie Inlet in 2004, as opposed to the exceptionally high levels demonstrated from the averaged 1993-2002 plots, support this notion of a sampling artifact.

Optical backscatterance

Patterns of optical backscatterance for each station and each month highlight the extreme concentrations at particular times and locations compared with values averaged over month or station (compare Figs. 6A-D with 6E-F, and notice differences in scale and magnitude). The highest turbidity levels are found nearest to tidewater glacial sources of high sediment loads, specifically stations 18, 19, 20, 12 and 21. Of the months sampled in 2004, June, July and October had the highest turbidity levels. Specifically, the highest OBS reading in 2004 was detected at station 20 in October. This high value contrasts with the overall seasonal pattern (1993-2002) and coincides with the noticeable change in salinity and stratification observed in October 2004. Stations 12 and 21 located at the head of the West Arm were also locations of high turbidity, due to a large amount of glacial sedimentation in the water. March demonstrates low OBS readings, with little variation between stations due to low levels of glacial melting during this time period (Fig 6A).

Euphotic depth

In 2004, regional and seasonal patterns of euphotic depth generally follow the average spatial and temporal euphotic depth patterns found from the years 1993-2002 presented in Etherington et al. (2004) (Fig. 7). Euphotic depth was deeper in the spring and shallowed as we moved into summer and fall months. The month of June had a deep euphotic depth at station 22 most likely due to its protection within Geikie Inlet and distance from any glacial sedimentation (Fig. 7B). Euphotic depth was lowest at stations nearest glacial inputs or at the head of the East and West arms. Euphotic depth relates closely to OBS; in areas with high OBS concentrations, lower euphotic depths occur (compare Figures 6 and 7).

2004 Products (papers and presentations) related to oceanographic monitoring program

Etherington, L.L., P.N. Hooge, E.R. Hooge. 2004. Oceanographic patterns in a glacially-fed fjord estuary: Implications for biological patterns and productivity. Glacier Bay Science Symposium, Juneau, AK.

Etherington, L.L. 2004. Monitoring of Oceanographic properties of Glacier Bay, Alaska 2003 Annual Report. U.S. Geological Survey, Anchorage, AK. 37pp.

2004 other products:

In addition to our own analyses of the data, we continue to provide these oceanographic data to the interested public and fellow researchers who use these data in interpreting their own data and formulating new research questions and programs. Glacier Bay oceanographic data was delivered to the following colleagues during 2004: Ned Cokelet (NOAA/PMEL, Seattle, WA), Won Park (University of Alaska Fairbanks, Juneau, AK), Martin Robards (University of Alaska Fairbanks, Fairbanks, AK), and Leesa Wingo (South Anchorage High School, Anchorage, AK).

Acknowledgements

We appreciate the assistance of Belinda Burch, Jim de La Bruere, Karen Platt, Peg Redford, Jennifer Scott, Greg Streveler, and Leesa Wingo in field sampling. Funding for this work was provided by Glacier Bay National Park and the United States Geological Survey.

Table 1. 2004 Glacier Bay oceanographic sampling schedule. Shaded areas represent months in which oceanographic sampling was conducted. Asterisks denote where repeat sampling was conducted to obtain data on both the slack high and peak flooding conditions within the lower Bay stations. It should be noted that station 15 has been removed from the sampling protocol.

Stations	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0			■			■	■			■		
1			■			■ *	■			■		
2			■			■	■			■		
3			■			■ *	■			■		
4			■			■	■			■		
5			■			■	■			■		
6			■			■	■			■		
7			■			■	■			■		
8			■			■	■			■		
9			■			■	■			■		
10			■				■			■		
11			■				■			■		
12			■			■	■			■		
13			■			■	■			■		
14			■			■	■			■		
16			■			■	■			■		
17			■			■	■			■		
18			■			■	■			■		
19			■			■	■			■		
20						■	■			■		
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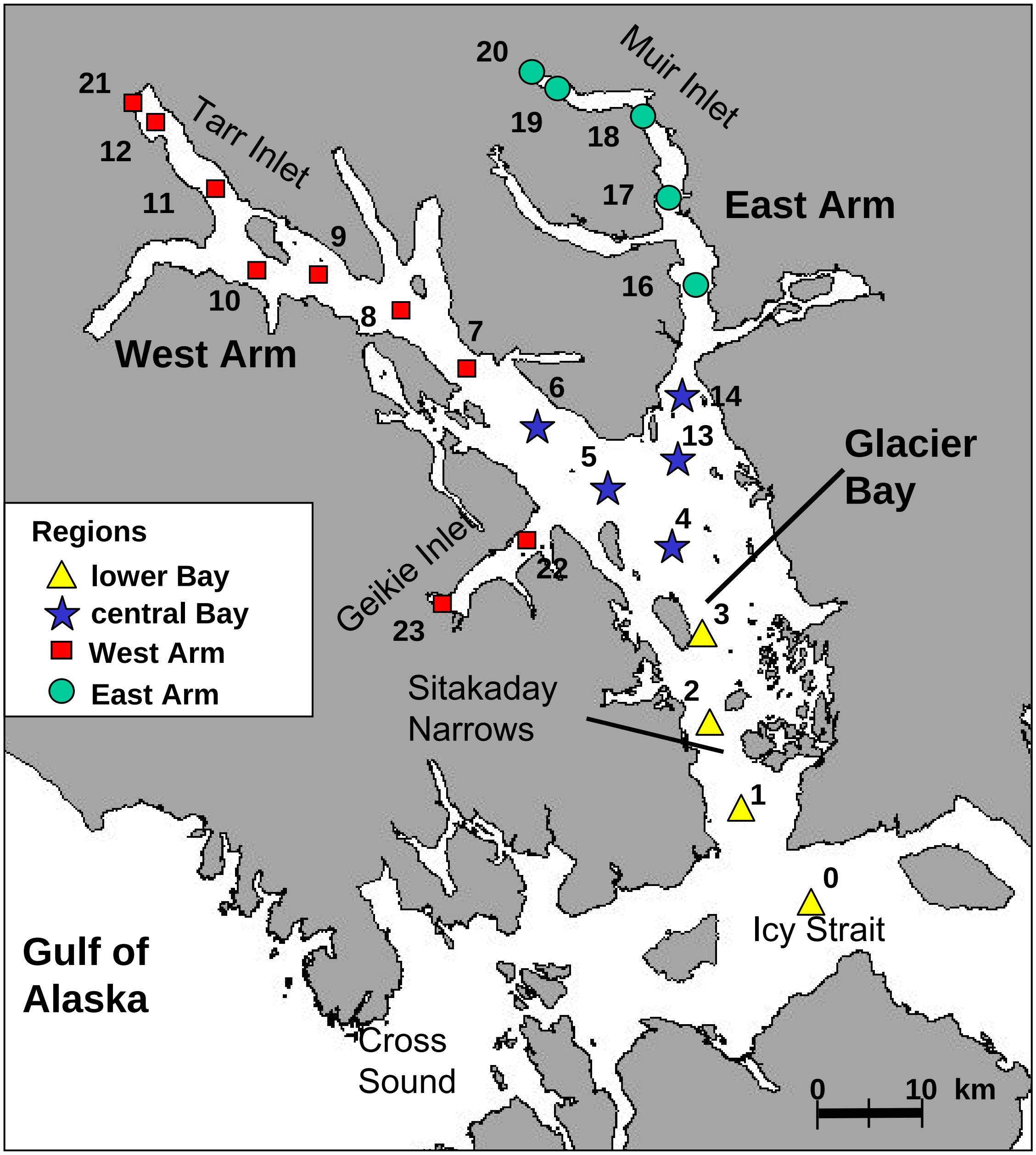

Figure 1. Glacier Bay, Alaska, and the oceanographic sampling stations. The regions indicated here were used to describe spatial variability in the oceanographic patterns within Etherington et al. (2004). Stations were grouped into regions based on similarities in bathymetry, relative position to glaciers and source of oceanic waters, and general examination of oceanographic patterns. It should be noted that station 15 is no longer sampled, due to redundancy with data from station 14.

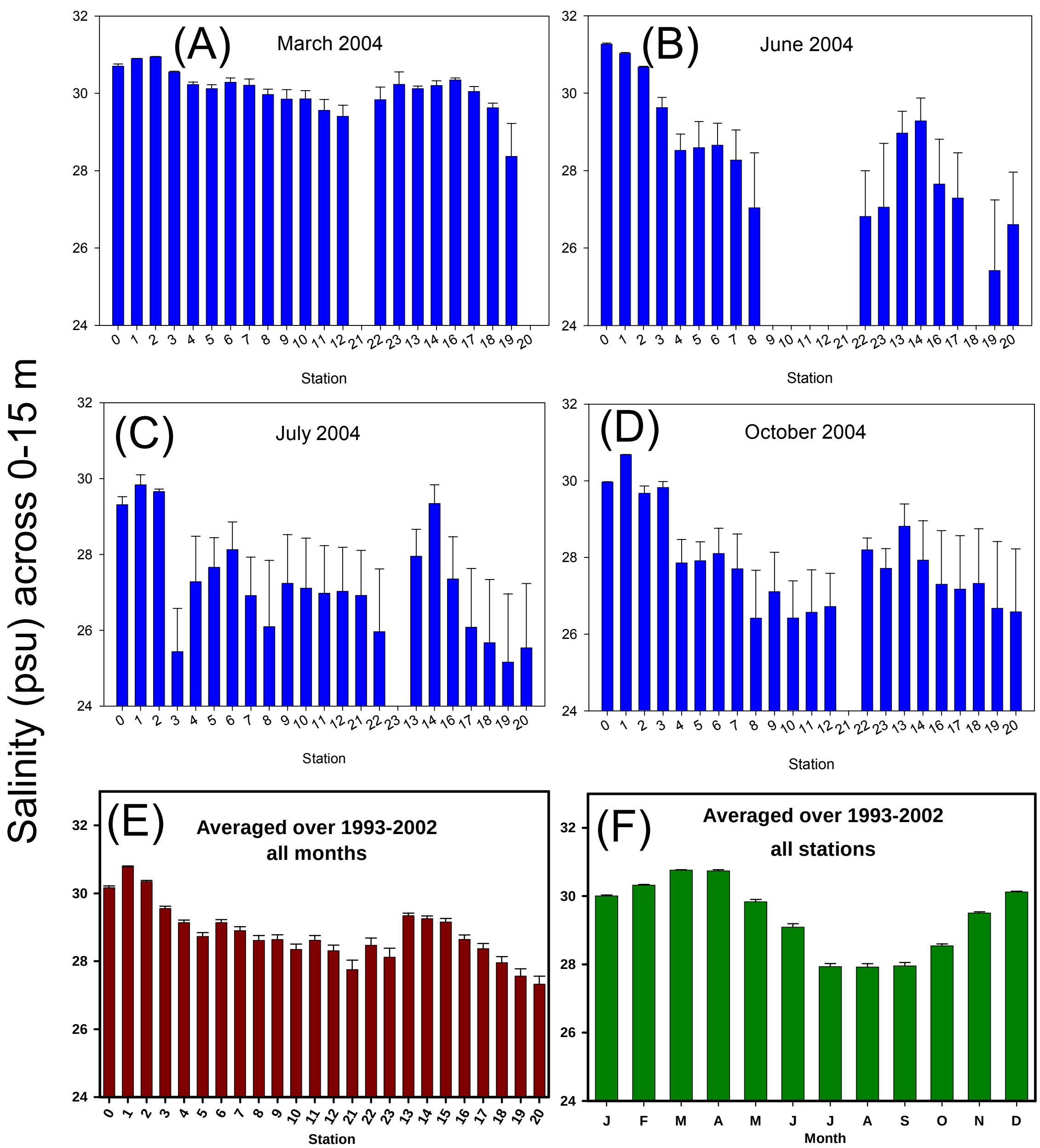

Fig. 2. Salinity patterns observed at Glacier Bay oceanographic monitoring stations. Values represent means (+ standard error) of salinity averaged over the top 15 m of the water column. Panels A-D represent 2004 values by month and station with each data point representing one cast. Zero data is presented where sampling was not conducted during that month (see Table 1 for stations sampled each month during 2004). Panel E represents salinity patterns for each station averaged over all months during the years 1993-2002. Panel F represents salinity patterns for each month averaged over all stations during the years 1993-2002. Stations are oriented from the mouth to the head of the Bay, with stations 0-12, 21 representing the axis of the Bay from Icy Strait to the head of Tarr Inlet (West Arm), stations 22 and 23 characterizing Geikie Inlet, and stations 13-20 representing the Muir Inlet (East Arm) axis.

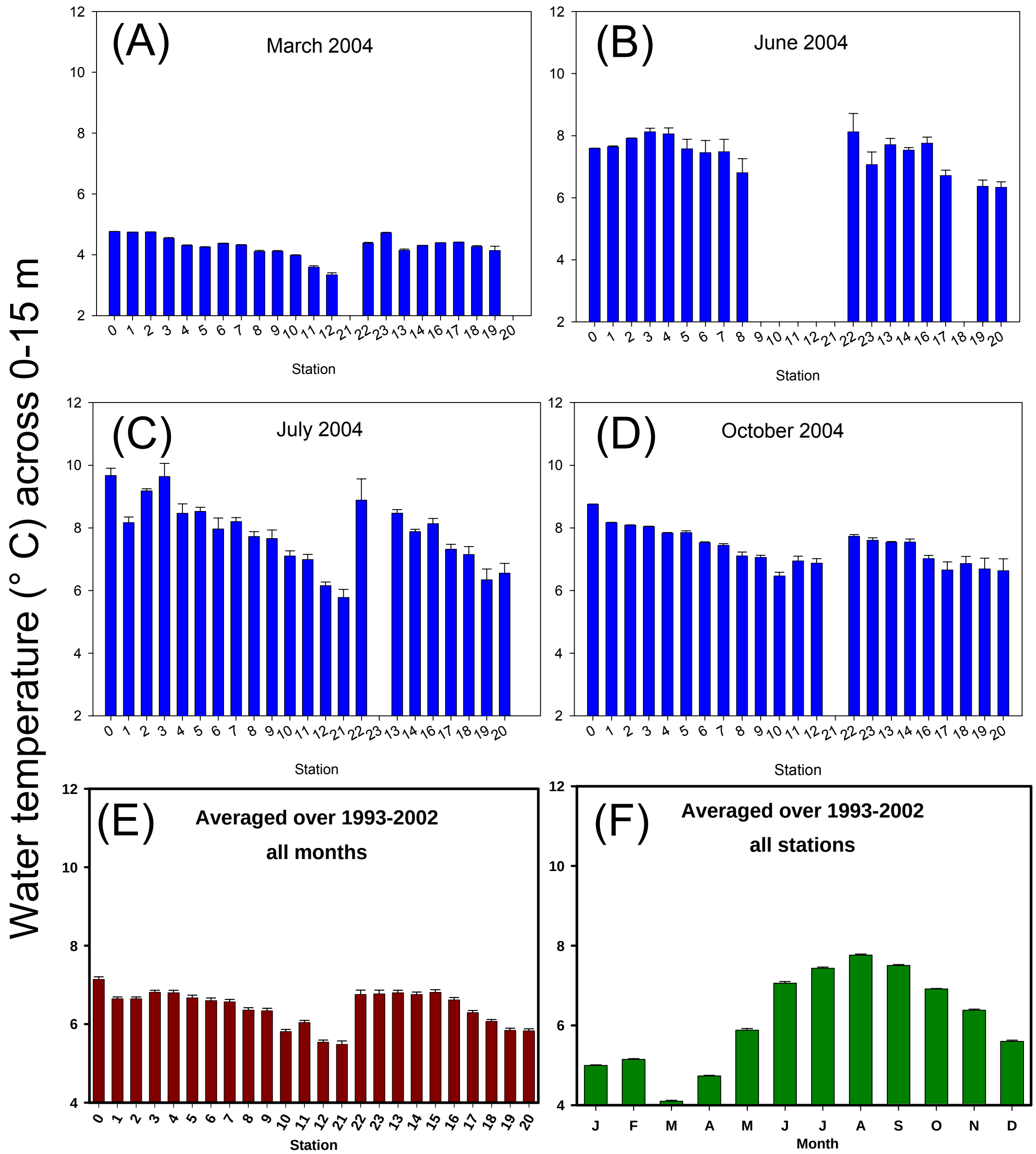

Fig. 3. Water temperature patterns observed at Glacier Bay oceanographic monitoring stations. Values represent means (+ standard error) of water temperature averaged over the top 15 m of the water column. Panels A-d represent 2004 values by month and station with each data point representing one cast. Zero data is presented where sampling was not conducted during that month (see Table 1 for stations sampled each month during 2004). Panel E represents water temperature patterns for each station averaged over all months during the years 1993-2002. Panel F represents water temperature patterns for each month averaged over all stations during the years 1993-2002. Stations are oriented from the mouth to the head of the Bay, with stations 0-12, 21 representing the axis of the Bay from Icy Strait to the head of Tarr Inlet (West Arm), stations 22 and 23 characterizing Geikie Inlet, and stations 13-20 representing the Muir Inlet (East Arm) axis.

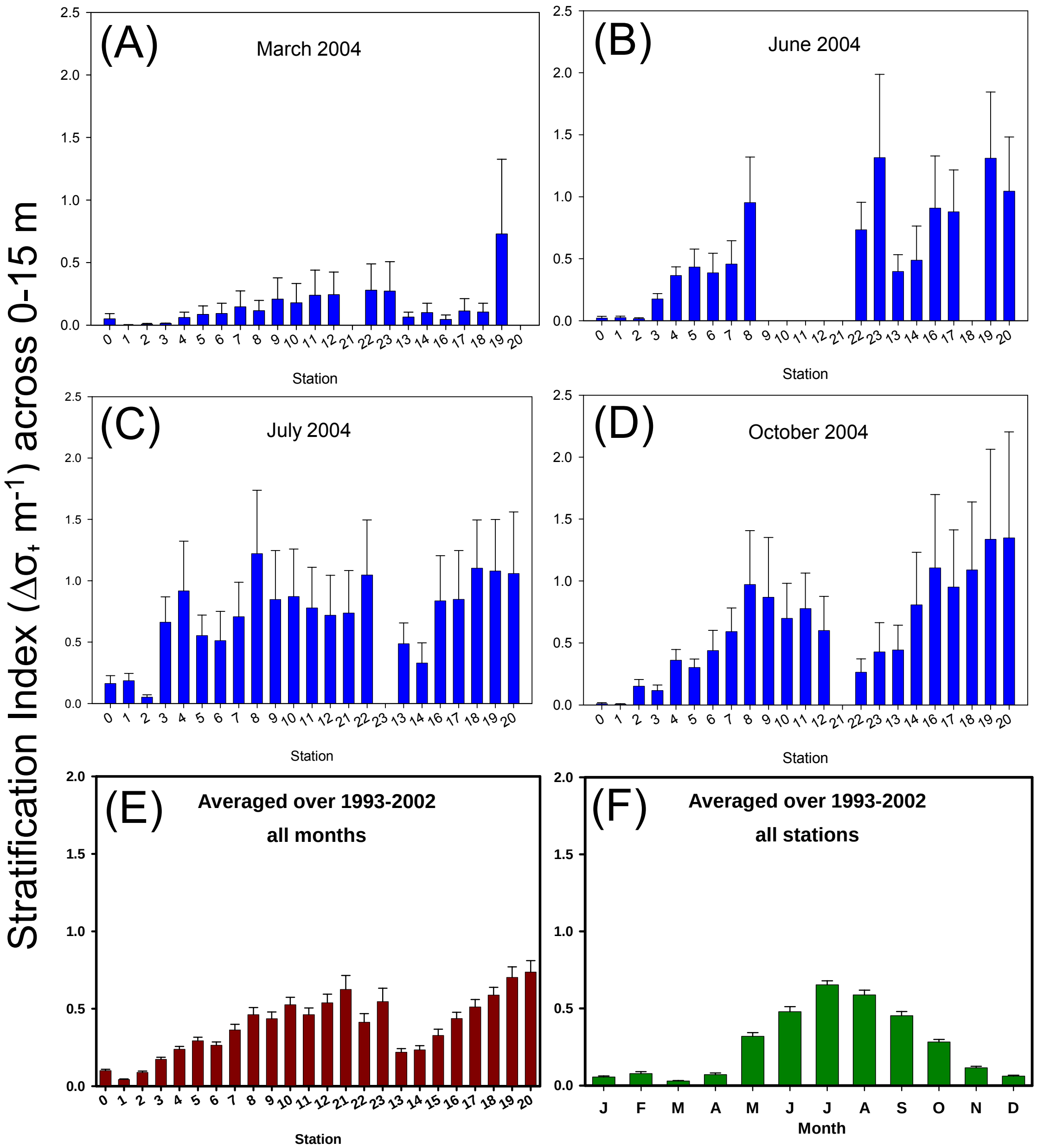

Fig. 4. Stratification patterns observed at Glacier Bay oceanographic monitoring stations. Values represent means (+ standard error) of stratification index. The stratification index for each cast represents the mean of the density differences from adjoining 1-m depth bins for the top 15 m of the water column. Panels A-D represent 2004 values by month and station with each data point representing one cast. Zero data is presented where sampling was not conducted during that month (see Table 1 for stations sampled each month during 2004). Panel E represents water temperature patterns for each station averaged over all months during the years 1993-2002. Panel F represents water temperature patterns for each month averaged over all stations during the years 1993-2002. Stations are oriented from the mouth to the head of the Bay, with stations 0-12, 21 representing the axis of the Bay from Icy Strait to the head of Tarr Inlet (West Arm), stations 22 and 23 characterizing Geikie Inlet, and stations 13-20 representing the Muir Inlet (East Arm) axis.

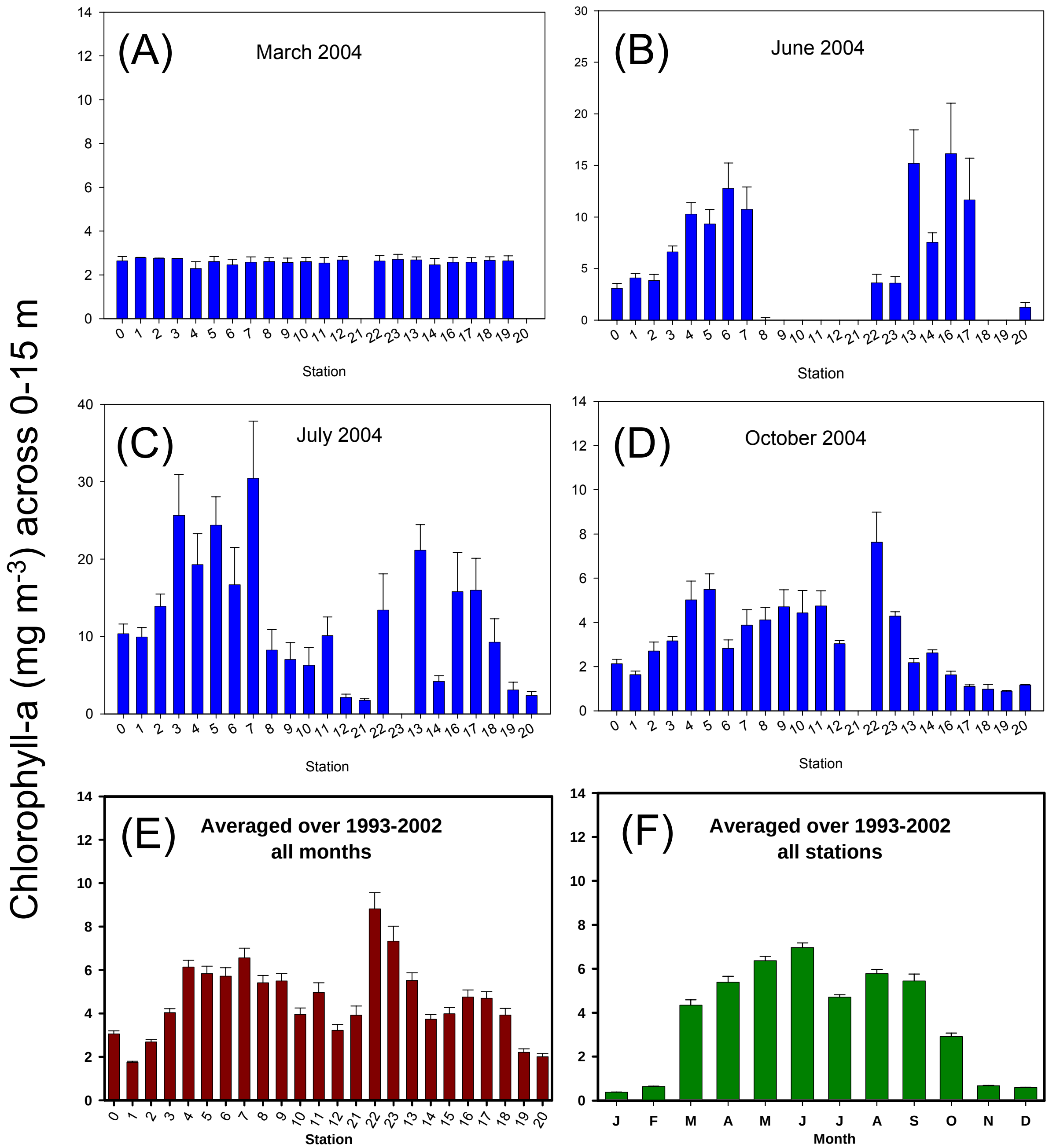

Fig. 5. Chlorophyll-a patterns observed at Glacier Bay oceanographic monitoring stations. Values represent means (+ standard error) of chlorophyll-a averaged over the top 15 m of the water column. Panels A-D represent 2004 values by month and station with each data point representing one cast. Zero data is presented where sampling was not conducted during that month (see Table 1 for stations sampled each month during 2004). Panel E represents chlorophyll-a patterns for each station averaged over all months during the years 1993-2002. Panel F represents chlorophyll-a patterns for each month averaged over all stations during the years 1993-2002. Note the change in y-axis scale for June and July when chlorophyll-a levels are much higher. Stations are oriented from the mouth to the head of the Bay, with stations 0-12, 21 representing the axis of the Bay from Icy Strait to the head of Tarr Inlet (West Arm), stations 22 and 23 characterizing Geikie Inlet, and stations 13-20 representing the Muir Inlet (East Arm) axis.

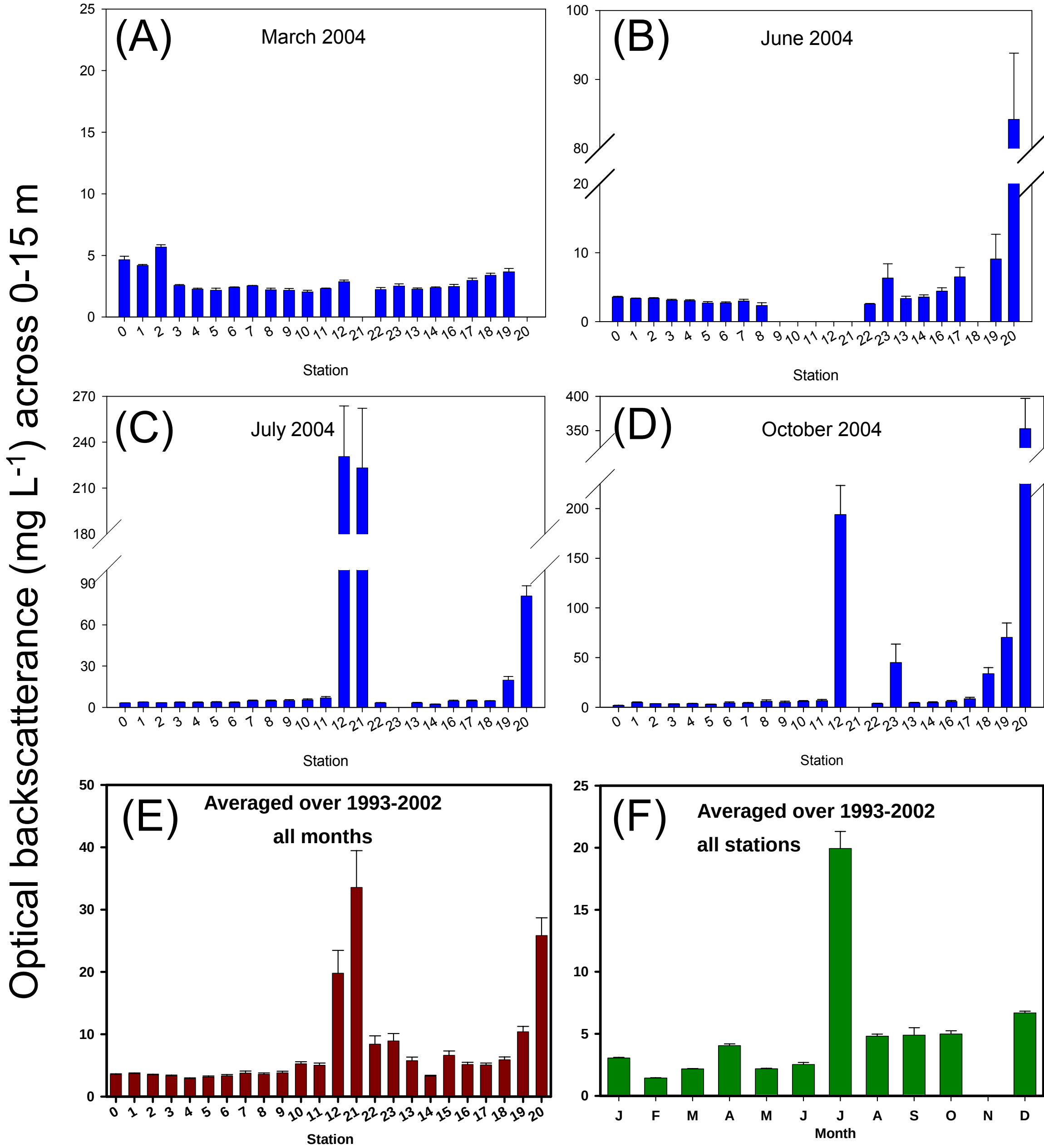

Fig. 6. Optical backscatterance patterns observed at Glacier Bay oceanographic monitoring stations. Values represent means (+ standard error) of optical backscatterance averaged over the top 15 m of the water column. Panels A-D represent 2004 values by month and station with each data point representing one cast. Zero data is presented where sampling was not conducted during that month (see Table 1 for stations sampled each month during 2004). Panel E represents optical backscatterance patterns for each station averaged over all months during the years 1993-2002. Panel F represents optical backscatterance patterns for each month averaged over all stations during the years 1993-2002. Note the change in y-axis scale for June, July and October, and the averages by station (E) when OBS levels are higher. Stations are oriented from the mouth to the head of the Bay, with stations 0-12, 21 representing the axis of the Bay from Icy Strait to the head of Tarr Inlet (West Arm), stations 22 and 23 characterizing Geikie Inlet, and stations 13-20 representing the Muir Inlet (East Arm) axis.

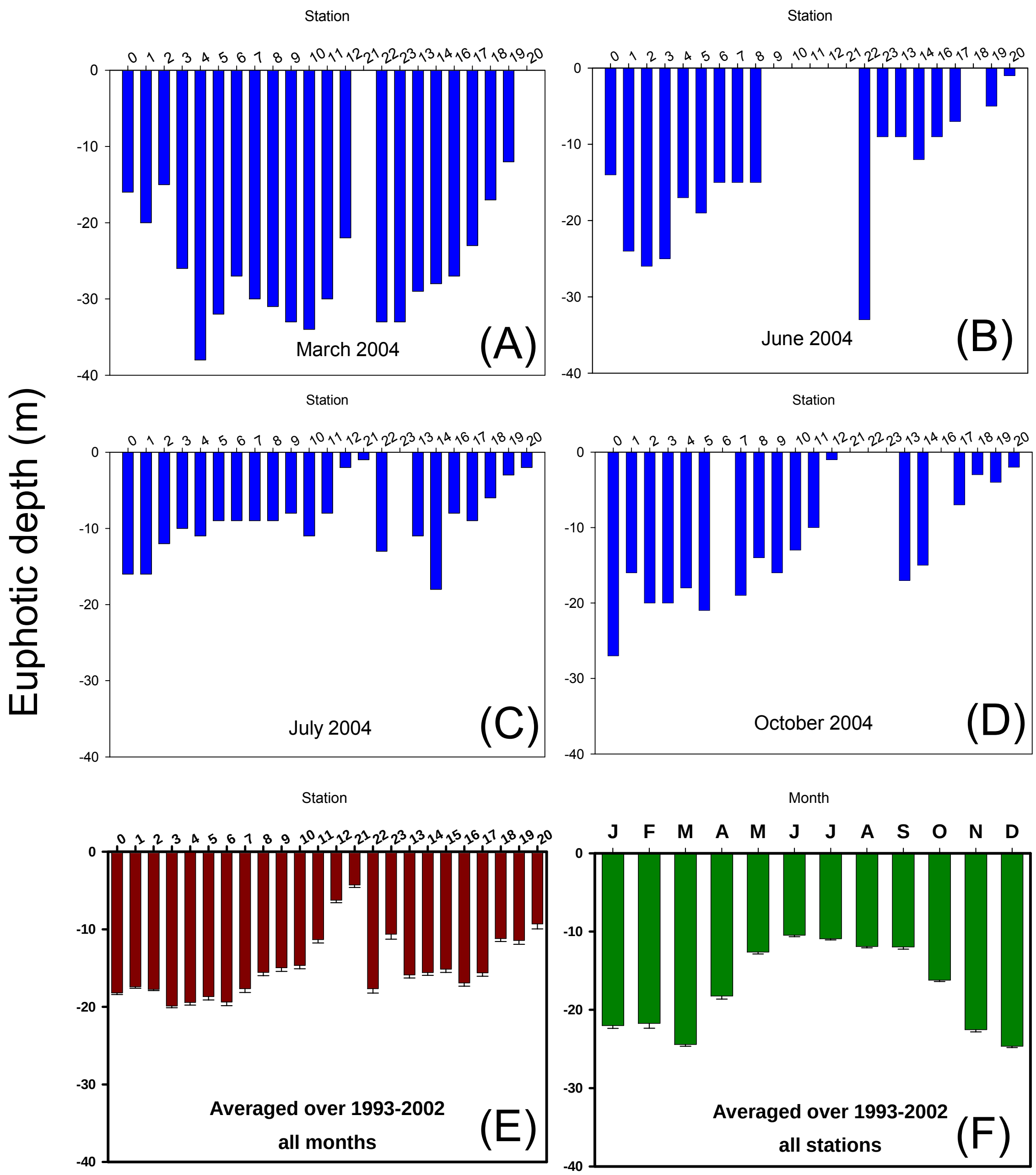

Fig. 7. Euphotic depth patterns observed at Glacier Bay oceanographic monitoring stations. Zero data is presented where sampling was not conducted during that month (see Table 1 for stations sampled each month during 2004). Panels A-D represent 2004 values by month and station with values representing the euphotic depth for one cast. Panel E represents PAR patterns (means plus standard error) for each station averaged over all months during the years 1993-2002. Panel F represents euphotic depth patterns (means plus standard error) for each month averaged over all stations during the years 1993-2002. Stations are oriented from the mouth to the head of the Bay, with stations 0-12, 21 representing the axis of the Bay from Icy Strait to the head of Tarr Inlet (West Arm), stations 22 and 23 characterizing Geikie Inlet, and stations 13-20 representing the Muir Inlet (East Arm) axis.

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