Program Evaluation Report

United States Geological Survey Oceanographic Program in Glacier Bay, Alaska

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Executive Summary

USGS-Alaska Science Center has been conducting a monitoring program of oceanographic conditions of Glacier Bay, Alaska from 1993-2006. In recent years, it was recognized that there was a need to conduct an overall evaluation of the objectives, costs, and information value of the program to factor into a decision about whether and how to continue the program into the future. As a result, physical and biological oceanographers and marine ecologists were brought together for a one day workshop to evaluate the Glacier Bay oceanographic program. This report represents the compilation of discussion from this workshop as well as collective recommendations for the future operation of the oceanographic monitoring program.

Overall, there was strong support for the continuation of the Glacier Bay oceanographic monitoring program. First, this program represents one of the only long-term data sets for oceanographic conditions in southeast Alaska. An ongoing long term oceanographic data (such as that currently conducted in Glacier Bay) is important in understanding the southeast Alaska marine system, the linkage between atmospheric and oceanic systems, and the implications of climate change on high latitude systems. In addition, Glacier Bay is an intact pristine ecosystem in a National Park and marine protected area, and it represents a unique ecosystem that acts as a laboratory for climate change studies, since it is currently undergoing rapid local change. Further, high concentrations of marine organisms suggest that Glacier Bay may represent a “hotspot” in southeast Alaska biological productivity. The oceanographic dataset compliments past and ongoing research on marine mammals, seabirds, forage fish, benthic invertebrates, and intertidal and subtidal community dynamics, and therefore provides baseline information upon which to understand the marine ecosystem of Glacier Bay. Thus, there are a variety of issues that provide support for a continued oceanographic monitoring program.

The majority of this report constitutes a summary of the topics covered in the workshop. The workshop synopsis includes four sections: 1) General discussion regarding the Glacier Bay oceanographic program; 2) Potential changes to be made to the Glacier Bay oceanographic program; 3) What data are we missing to understand the Glacier Bay oceanographic system?; and 4) Technical issues with the oceanographic program that need to be resolved. The general discussion puts the current sampling in Glacier Bay into perspective in terms of our current knowledge of the southeast Alaska marine ecosystem. The section on potential changes outlines how the current sampling program could be modified to increase the value of the data set. The next section is a discussion of additional data that could be collected that would complement the current oceanographic sampling program and would fill the gaps in our current understanding of the Glacier Bay marine system. Lastly, there is a summary of technical issues that need to be addressed to ensure that the data are processed, stored, presented and distributed in the best manner.

One of the outcomes of the workshop was a list of recommended actions to improve the Glacier Bay oceanographic program. Paramount to the specific detailed recommendations is the overall need to secure sustainable funding for the program to ensure its integrity into the future. Many of the recommended steps to make the data we already have more useful or the program more successful do not necessitate large

monetary investments, but involve substantial personnel time to revise the protocol on data storage, visualization, and distribution. The original objectives of the program were reviewed and updated objectives are presented. Examples of specific research questions related to past and ongoing studies in Glacier Bay that could be addressed using the oceanographic program dataset were formulated. These research questions, in addition to the list of researchers and educators that the data have been distributed to over the years, illustrate tangible examples of the application of the Glacier Bay oceanographic dataset.

Introduction to Program Review

USGS-Alaska Science Center has been conducting a monitoring program of oceanographic conditions of Glacier Bay from 1993-2006. The overall objective of the external review was to determine if the original and/or updated objectives of the monitoring effort are being met and whether they should be modified. It was recognized that there was a need to conduct an overall evaluation of the objectives, costs, and information value to factor into a decision about whether and how to continue the program into the future.

<u>Objectives of program review:</u>

1) Evaluation of the appropriateness of the original and/or updated monitoring objectives.
2) Examination of the methodology of the sampling program (instruments, data collection, processing, interpretation) and suggestions to correct any problems or update the program to bring it in line with advancements in technology.
3) Examination of the spatial and temporal resolution of the sampling and recommendations on time periods/locations that could be added or deleted. For example: Could the program be more efficient in its data collection? Are certain sites providing repetitive data? Are we missing critical sites? Are we missing critical time periods?
4) Examination of current data presentation and dissemination, with suggestions for ways to share these data with multiple user groups (e.g., NPS managers, NPS scientists, ecologists, biological oceanographers, physical oceanographers).
5) Recommendation of other data sets that could be efficiently collected as part of the oceanographic monitoring program.
6) Evaluation of costs.

<u>Objectives of the Glacier Bay Oceanographic Monitoring Program:</u>
Original: The original objectives of this program were defined in a 1993 proposal that stated, "The major goals are to establish a sustainable method of monitoring monthly temperature and salinity characteristics and the chlorophyll a content of Glacier Bay throughout the year. This will allow us to begin to establish *a* time-series of physical oceanographic information. This information will not only provide a framework to link current multi-disciplinary research but will also make Glacier Bay more attractive to new researchers and increase the opportunities for multi-agency cooperations with NPS."

Updated: We have recently proposed the followed objectives for this monitoring effort:

1) To provide a dataset on physical oceanographic conditions in Glacier Bay (salinity, temperature, stratification, photosynthetically available radiation (PAR), optical backscatterance (OBS, turbidity)) that can be used to understand seasonal and interannual changes in the estuarine dynamics of Glacier Bay as well as the southeast Alaska oceanographic system.
2) To provide a baseline oceanographic dataset (salinity, temperature, stratification, photosynthetically available radiation (PAR), optical backscatterance (OBS, turbidity), and chlorophyll *a* fluorescence) that can be used by a variety of

biologists to understand spatial and temporal variation in the abundance patterns of a variety of organisms including zooplankton, marine invertebrates, fishes, mammals and seabirds of Glacier Bay.

3) To provide a dataset on chlorophyll *a* fluorescence that can be used to understand the spatial, seasonal, and interannual variation in phytoplankton biomass within Glacier Bay.

Workshop Synopsis

Glacier Bay Oceanographic Program Review Workshop
November 15, 2005
University of Alaska Southeast Schaible House, Juneau, AK

Participants (see complete contact information in Appendix 1):
Lisa Eisner (NOAA, Auke Bay Laboratory, Juneau, AK)
Ned Cokelet (NOAA, PMEL, Seattle, WA)
Lisa Etherington (U.S. Geological Survey, Alaska Science Center)
Jim Taggart (U.S. Geological Survey, Alaska Science Center)
Karen Oakley (U.S. Geological Survey, Alaska Science Center)
Yumi Arimitsu (U.S. Geological Survey, Alaska Science Center)
Lewis Sharman (National Park Service, Glacier Bay National Park)
Chris Gabriele (National Park Service, Glacier Bay National Park)

The workshop involved an overview presentation by Lisa Etherington and then general discussion by the group throughout the day from 9:00am to 4:30pm.
The following sections summarize the issues that came up during the workshop discussion. In addition, the ideas and suggestions provided by Jim Bodkin (USGS-Alaska Science Center), Gail Irvine (USGS-Alaska Science Center), and Bill Eichenlaub (NPS-Glacier Bay National Park) (who were not present at the workshop) were incorporated into this summary.

General discussion regarding the Glacier Bay oceanographic program

Studying oceanographic processes in Glacier Bay is of importance for the following reasons:
- Glacier Bay is an intact pristine ecosystem in a National Park and marine protected area.
- Physical and biological oceanography are the foundation to ecological interactions in the marine ecosystem, and an understanding of these processes are necessary to preserve and protect the park's resources.
- An oceanographic dataset compliments past and ongoing research within Glacier Bay on marine mammals, seabirds, forage fish, benthic invertebrates, and intertidal and subtidal community dynamics.
- An ongoing long term oceanographic data (such as that currently conducted in Glacier Bay) is important in understanding the southeast Alaska marine system, the linkage between atmospheric and oceanic systems, and the possible implications of climate change on high latitude systems.
- Glacier Bay is a unique ecosystem that acts as a laboratory for climate change studies, since it is currently undergoing rapid local change.
- Glacier Bay is a representative system to understand what other areas went through during deglaciation.
- Glacier Bay may represent a "hotspot" in southeast Alaska biological productivity.

An initial question was raised regarding the role USGS versus NPS plays in the Glacier Bay oceanographic program. The program has always been managed by USGS scientists (however, these scientists were once a part of NPS and then NBS) and NPS has helped to maintain the project by providing funding and logistical support since 1993. It is estimated that the program currently requires approximately $70,000 per year to operate, with much of this cost going to the time contributed by a senior scientist as well as one technician. In the past, NPS has contributed approximately $20,000 of the total cost of the program per year.

The group recognized the need to consider whether the data that are currently being collected meet the needs of not only NPS and USGS, but also outside researchers, and to think more broadly about how the oceanographic program contributes to our understanding of southeast Alaska. The NPRB (North Pacific Research Board) Southeast Alaska Oceanography Synthesis workshop (Eckert and Eisner 2005) identified major gaps in our understanding of physical and biological oceanography in southeast Alaska. It is very possible that Glacier Bay's oceanographic dataset could play a significant role in filling these data gaps, because to date, it is the only dedicated long-term monitoring program that exists for the region. There are also possibilities to tie the Glacier Bay oceanographic program into the southeast AOOS (Alaska Ocean Observing System) program, which is in its infancy.

Throughout the day, there was discussion of what other long term oceanographic data sets exist in southeast as well as how the Glacier Bay program could potentially be linked to other data sets. In the Synthesis Report from the Southeast Oceanography workshop, Lisa Eisner summarizes the biological oceanographic data sets in the southeast Alaska (Eckert and Eisner 2005). The lack of extensive long term data in the region highlights the importance of the Glacier Bay data set. Many of the longer oceanographic data sets are in the northern Gulf of Alaska. One southeast program of interest is the Southeast Coastal Monitoring (SECM) program conducted by NOAA (Auke Bay Laboratory, Juneau, AK), which is a juvenile salmon survey (http://www.afsc.noaa.gov/abl/MarSalm/4secm.htm). Results from this program can be found in annual reports (e.g., Orsi et al. 2005). This program collects samples in Icy Strait out to the shelf break near Icy Point monthly from May through September. The CTD data collected by NOAA are lacking in some of the important parameters (e.g., light levels, turbidity, chlorophyll-*a*); however, efforts are being made to add these parameters to the sampling scheme. The potential of linking data from Glacier Bay with this data set was discussed. The best initial contact for the SECM program would be Phil Mundy, who is the new director of the Auke Bay Lab. Joe Orsi within SECM is responsible for the CTD data collection effort.

In addition to its application in understanding biological patterns and processes, the Glacier Bay oceanographic monitoring dataset could be useful to a physical oceanographer for studies such as 1) Examination of sill processes and the exchange of water between the estuary and outside waters; 2) Analysis of potential ENSO (El Niño Southern Oscillation) or PDO (Pacific Decadal Oscillation) signals; 3) Examination of potential climate change indicators.

The group discussed issues of climate change and how Glacier Bay could be a location to detect climate change. What will Glacier Bay look like in 50 years? Are we sampling the right locations and time periods to be able to detect these changes? What do we expect climate change to look like in Glacier Bay? In the oceanic environment we might expect warmer water temperatures; however, in Glacier Bay we might expect increased melting, which could in actuality decrease water temperatures. Similarly, other indicators of climate change could be salinity (and the resulting depth of less saline layer) and stratification levels, given increased glacial melting. These in turn could cause a shift in phytoplankton species as well as influence bloom dynamics in terms of initiation, magnitude, and extent. Another idea regarding expected changes in the oceanographic system due to climate change is that the glaciers may now be discharging freshwater all year long (as opposed to discharging primarily in warmer months). Our current sampling scheme would not detect this type of input; we would need to have continuous sampling to capture these glacial dynamics. With the data we have in hand, we really can't pick out a climate signal yet. It seems like 10 years worth of data would be the bare minimum for any type of climate study, and it is not probable that we can see ENSO or PDO signals with the data yet.

<u>Potential changes to be made to the Glacier Bay oceanographic program</u>

Given the current climate of funding reductions, we tried to find ways to trim the program to make it less expensive. This task proved to be difficult due to the main costs being personnel time and potentially ship time. Since most of the time in the field is consumed with running time between stations, compared with the 10 minutes that it takes to collect a CTD sample, it does not appear that trimming stations (e.g., dropping every other station) would help in reducing time or costs. The idea was posed that maybe we could sample the full suite of stations every other year, with the lower Bay stations sampled every time period and year. However, it is possible that we would want to know about anomalous events/years, which we would have a 50% chance of missing. One thought was to eliminate the 2 stations in Geikie Inlet, since it takes a long time to go all the way to the head of the inlet and back. Geikie stations were added in 1999. Highest chlorophyll-a levels have been noted at the Geikie Inlet stations; however, this may be because they are characteristic of more nearshore conditions compared with the other mid-channel stations. Dropping the Geikie stations would not influence our ability to assess the longitudinal gradient in oceanographic conditions along the axes of the Bay.

An alternative to trying to find ways to trim the program is to make the project more valuable by increasing the applicability of the program to more users. So, part of our discussion revolved around identifying what we are not capturing with the current sampling protocol and what we could do with only slightly more money to make the program more useful to a wider audience. Other ideas for ways to reduce the cost of the project would be to get other investigators involved and integrate several projects so that the costs of ship time would be reduced. On the other hand, it should be noted that if crew transfers are necessary in combining projects, there is the potential to waste boat and scientists' time due to the need for Park support for the transfers and the potential for logistical problems.

One project that came to mind for integrating with the oceanographic monitoring is the marine predator surveys that are conducted by USGS-Alaska Science Center (Jim Bodkin, John Piatt, and Gary Drew; Anchorage, AK). Combining these two projects could have two advantages: 1) more directly integrate the oceanographic data set and predator abundance and distribution data, 2) provide the Park with a tangible package, which would be slightly reduced from the sum of the two and might survive better as a unit.

To determine the source waters for Glacier Bay, it would be useful to have two additional stations outside of Glacier Bay that are in deeper water in Icy Strait. The most important one would be west of the Bay mouth in deeper water NW of Lemesuier Island. Another helpful addition would be east of the Bay mouth in deeper water south of Pleasant Island. These stations would allow a more thorough understanding of the linkage of Glacier Bay with the Gulf of Alaska and inside waters of southeast Alaska. A Cross Sound mooring was deployed July 2005. Phyllis Stabeno at PMEL in Seattle could be contacted to see how it is doing and to investigate potential ways to link the Glacier Bay data with Cross Sound data. Perhaps a station could be added near the mooring so that there is temporal coverage at specific depths (from the mooring) to go with the vertical profile CTD data (although travel distance to Cross Sound would add substantial time to the sampling trip). Also, it may be useful to integrate the Auke Bay SECM CTD and nutrient data in Icy Strait with the USGS data – perhaps use similar locations for sampling.

One of the criticisms of the oceanographic sampling program is that it concentrates all of the effort on the center channel regions and it is unknown whether these data are representative of nearshore dynamics. Jim Taggart has done an analysis of nearshore and center channel oceanographic data for one of his Dungeness papers (Taggart et al. 2003). The correlation between the nearshore and center channel stations was good for some parameters (e.g., temperature, salinity), and poor for others (e.g., turbidity). John Piatt, Yumi Arimitsu, and Lisa Eisner collected CTD samples in June-July 2004 across 87 stations in Glacier Bay. John Piatt also has nearshore data from fish inventory work in 2001-2002. The nearshore stations associated with these sampling efforts could also be compared with center channel stations to examine the correlation. The correlation between center channel and nearshore stations would be expected to be poorest near the glaciers. It might also be expected that the correlation would be low in more enclosed bays.

If we did do some nearshore sampling, where would it be? There was some discussion of overlaying different data sets to come up with potential regions of interest to add nearshore stations. Data sets could include: Gary Drew's (USGS-Alaska Science Center, Anchorage, AK) analysis of the predator survey data (marine birds, marine mammals), Chris Gabriele's whale distribution data, Yumi Arimitsu's fish distribution data, Jim Bodkin's sea otter distribution data, Jim Taggart's crab distribution data, location of Gail Irvine's coastal monitoring stations, and Beth Matthews (University of Alaska Southeast, Juneau, AK), Gail Blundell (Alaska Department of Fish and Game, Juneau, AK) and Jamie Womble's (NPS-Glacier Bay National Park, Juneau, AK) harbor seal distribution and foraging data. Other potential locations include harbor seal and sea lion haulout areas as well as known fish spawning sites and female crab aggregation areas. It might be a good idea to find where some of these taxa "hotspots" overlap as well as find locations of little biological activity ("coldspots") and to identify several nearshore stations to sample along with the mid-channel stations.

Another option for getting better spatial and temporal coverage of water temperature data would be to use moored Tidbit temperature loggers (http://www.onsetcomp.com/index.html). These data might also be good to determine the amount of variability in the oceanographic parameters and how well the seasonal patterns represent the conditions in the Bay. These instruments would also be useful in measuring events (e.g., warm water intrusion events) as well as understanding freshwater input and tidal fluctuations. Currently, there are a number of NPS and USGS water temperature Tidbits available for use. Before deciding to deploy Tidbits, it would useful to examine the existing data from subtidal monitoring stations established by NPS Sea Otter Effects project (Glacier Bay National Park) as well as Jim Taggart's data associated with crab studies. Star-Oddi data storage tags (http://www.star-oddi.com) are also able to continuously measure salinity, but their accuracy (0.75 psu) may not be adequate to address some questions, and biological fouling is a potential problem. It is possible to create moorings with a 30 pound anchor and float, with data loggers attached at multiple depths (e.g., 5 and 10 m). Continuous nearshore water sampling equipment could be linked to Dan Lawson's existing weather stations and the data relayed remotely.

Temporal coverage of oceanographic data is fairly patchy from 1993-2005 (Table 1). Much of the sampling schedule was driven by boat availability rather than directed sampling during certain time periods. Therefore, there is a problem in trying to assess interannual variation in oceanographic patterns. It may be possible to look at a few months that were more consistently sampled (e.g., March, July, October) and assess variation among several years. Two years ago (2003) a sampling protocol was put into place, whereby standardized sampling was recommended in March, July, October, and once in December or January. March represents an initial bloom period, July represents the mid-point of summer conditions and the highest levels of stratification and turbidity, October represents fall conditions with increased precipitation, December and January are fairly homogenous and represent winter conditions. If additional money and time are available, a June sampling is recommended, since this is the month with highest chlorophyll-*a* levels. The reviewers agreed that this sampling plan looked like it was appropriate to obtain seasonal signals in oceanographic properties. The objectives of the oceanographic monitoring program were not well-defined from the beginning. It appears that this is one of the reasons for the patchy temporal coverage in the data. Nevertheless, the data are still useful to many people for a variety of purposes (see Appendix 3).

The participants felt that the updated objectives look good in terms of describing the general goals of the program. Objective #3 could probably be folded into objective #2. In addition to general objectives, it might be helpful to put in more detailed objectives that are tied to specific questions and demonstrate the application of the data. These questions might help to focus the program, provide specific application of the data, as well as generate support for the program by demonstrate the potential uses of the data set.

One of the aspects of the Glacier Bay system that has not been examined closely is how tides are influencing the oceanographic patterns of the Bay. For example, should we standardize the sampling based on tidal parameters? The timing of sampling of the lower 4 stations (0,1,2,3; Fig. 1) that are most influenced by tidal velocity is standardized so that data are collected during mid-flood tide. That is, stations are sampled in sequential order and the goal is to sample station 2 as close to 180 minutes after slack low tide, such that the maximum rising tide is followed into the Bay. The sampling isn't standardized for tides for the Arms or other areas of Glacier Bay. Currently, there is no standardization regarding what part of the lunar cycle to sample, and therefore we are missing information on the influence of tidal range (spring versus neap) on oceanographic conditions.

The need to examine oceanographic conditions during different parts of the tidal cycle depends upon what one is interested in studying. If we are particularly interested in sill processes (both physically, e.g., deep water renewal, mixing dynamics of estuarine/outside waters; as well as biologically, e.g., larval transport), we would want to do more work in the area of the entrance sill and sample at spring and neap cycles. It possible that we may already have the data in hand to examine such processes, since data were most likely collected during a variety of conditions. For example, if we were interested in the frequency of deep water renewal, we could go back and analyze the influence of tidal range on salinity/density at bottom depths at stations 2 and 4. After analyzing the data with respect to tides, we could change the sampling protocol if large differences were apparent. One 24-hour sampling effort has been conducted at a single station (stn. 4; Fig. 1), therefore, we could look at how time in the tidal cycle influences oceanographic parameters in this section of the Bay.

In addition, there is interest in how variation in the tidal range influences density fronts in the entrance region of Glacier Bay as well as current patterns in the central and upper portions of the Bay. One solution for understanding tidal influences on water currents would be the examination of the results of a 3-D hydrodynamic model of Glacier Bay, which is currently in development by Dr. David Hill (Penn State University). Dave plans to have a functioning model by late spring 2006.

<u>What data are we missing to understand the Glacier Bay oceanographic system?</u>

There are several pieces of weather data that are not available for Glacier Bay that would substantially help in our understanding of atmospheric-oceanographic linkages. For example, wind data is lacking for Glacier Bay. The Juneau and Yakutat wind data are not good enough to describe Glacier Bay. It is possible that wind data could be collected as part of the current Bartlett Cove weather station that the rangers maintain. There is the possibility that NPS will be funding an upgrade to the current weather station. In addition, it is thought that Dan Lawson has some wind data at multiple locations within the Park that would be useful in understanding variability within the Bay. Ideally, it would be great to have wind data for the East Arm, West Arm, and lower Bay.

Another piece of data that we are missing in Glacier Bay is the amount of available light. It is possible to put a radiometer – PAR (photosynthetically available light) sensor on a building in Bartlett Cove and have the meter collect continuous data. This light sensor could be integrated into the current Bartlett Cove weather station that the rangers maintain. Options would include a more expensive Eppley radiometer or a simpler, cheaper LiCor instrument. It would be best to have an instrument that takes continuous measurements and integrations over the day can be made; however, if funds were not available, then an observer could take daily measurements using a hand-held meter and note weather conditions and cloud cover.

There is extremely little information on nutrients within Glacier Bay. It is possible to take water bottle samples and have nutrient analyses conducted on samples. In addition, you can now get optical sensors that measure nitrate (Satlantic ISUS nitrate sensor, $25,000, http://www.satlantic.com); however, the technology is very new. It is likely that wind patterns will have a strong influence on nutrient levels. Preliminary analyses of nutrients collected July-August 2002 (Taggart cruise) indicated that near surface (10 m) nutrients were in fairly high concentrations (> 5 µM nitrate) at most locations. This could be due to injection of nutrients into the upper mixed layer due to localized upwelling and wind mixing during summer storm events. In addition, John Piatt's group took ~290 nutrient samples from 87 stations throughout Glacier Bay in 2004. They are currently trying to obtain funds (~$3500) to analyze these samples.

In terms of phytoplankton ecology of southeast Alaska, one issue of importance is the timing and mechanisms responsible for the initiation of the spring phytoplankton bloom. Lisa Eisner is interested in the regional differences in timing. In Auke Bay, the bloom occurs in April, after several days of sunshine. It is possible that stratification in Glacier Bay is high enough throughout much of the year, and therefore, the initiation of the spring bloom is caused by the increase in day length coupled with decreased cloud cover, rather than an increase in stratification in the spring. The current sampling program is deficient in looking at spring bloom dynamics, since it possible that some years the March data are collected before the bloom, while in other years the data are collected after the bloom. Sampling must be conducted on a finer temporal scale to capture the bloom dynamics. Lewis Sharman has been very interested in starting up a program to look at the timing, magnitude and extent of the spring bloom in Glacier Bay, and has proposed to take daily measurements off the dock in Bartlett Cove. Lisa Eisner suggested that a simple solution would be to take Secchi disk depth measurements off of the Bartlett Cove dock (this is similar to method that Bruce Wing uses in Auke Bay). A thermometer could also be added to the Secchi disk to get a temperature reading. Daily sampling in Bartlett Cove seems more efficient to get an idea of bloom characteristics rather than surveying the whole Bay multiple times in the spring. As a response to this workshop, Lewis Sharman began sampling in March 2006 using a Secchi disk off the Bartlett Cove dock to measure spring bloom patterns. Ned Cokelet suggested that the spring bloom might be initiated by ice melt; however, the timing of the increase in chlorophyll-*a* does not coincide with the spring decrease in salinity that is associated with an increase in melting. Besides initial bloom characteristics, other items of importance would be to determine the total production over the growing season and to understand what sustains the bloom during the summer (e.g., intermittent nutrient injection).

A question was raised as to the contribution of macroalgal primary production in nearshore environments compared with contributions of phytoplankton primary production. For the whole system, it can be expected that the contribution of macroalgae in fjords would generally be low, due to steep sloping subtidal regions and low light penetration. Nevertheless, in shallower bays macroalgal production could play a larger role. There was discussion of whether kelp beds have been mapped (e.g., data from Mike Donnellan (NPS-Glacier Bay) flying the shoreline of Glacier Bay) and what these distribution patterns could tell us. Bill Eichenlaub (NPS-Glacier Bay) would be the best contact for information regarding this data set.

Zooplankton dynamics are a missing piece in understanding the Glacier Bay marine system. However, an intensive zooplankton study would be a huge effort, mostly in sorting time. It might be possible to link up with the Southeast Coastal Monitoring program and do some joint zooplankton sampling. NOAA used to send most of their data to Poland to be sorted, but may now do all of their zooplankton enumeration “In House.” A contact for this aspect of the program is Molly Sturdevant. An intensive zooplankton study might be a good dissertation topic. Another option to net sampling for zooplankton would be hydroacoustics and optical profilers. However, many of the methods end up taking a lot of processing time and require ground truthing with net samples. Other alternatives to zooplankton net sampling would be analyses of forage fish, including diet analyses, isotope analyses and fatty acid analyses.

Associated with understanding zooplankton dynamics is the degree of benthic-pelagic coupling in different regions of the Bay. For example, does the timing of the phytoplankton bloom influence the response of zooplankton and therefore the amount of carbon maintained in the pelagic system versus delivery to the benthos? The spatial distribution of larger phytoplankton cells would influence benthic-pelagic coupling, since larger cells would sink faster than small cells. For example, Lisa Eisner detected a higher percentage of large cells near the East Arm sill compared with other areas in Glacier Bay during June-July 2004.

Many other fjord systems show hypoxic/anoxic conditions in the deep basins in the absence of deep water renewal. These conditions would greatly alter the benthic community structure. So, the question remains whether dissolved oxygen is a problem in Glacier Bay. Matthews and Quinlan 1975 and Matthews 1981 examined DO levels in Muir Inlet and suggested that deep water renewal occurred over much of the year, peaking in winter, and ceasing during peak summer runoff. John Piatt’s crew also took some dissolved oxygen measurements down to 248 m in 2004. It is possible to measure DO with a meter on the CTD, or alternatively, you can take water bottle samples and do Winkler titrations. University of Washington Marine Chemistry Lab could analyze Winkler samples. The 2 CTDs that are currently used for Glacier Bay monitoring are pressure rated to only 300 m, which would prevent reaching the deepest basins that would be expected to be most susceptible to low DO. A DO meter costs around $5000. It might be possible to borrow a CTD from NOAA that has a DO meter and also has the capability of reaching the deepest parts of Glacier Bay.

Other types of data that could improve the coverage of the present sampling schedule could include satellite data for the surface waters. Nevertheless, there are drawbacks in using this technology in our system due to high turbidity and cloud cover. Dave Douglas (USGS-Alaska Science Center) archived and analyzed AVHRR and Landsat images for sea surface temperature. This dataset could be useful for other analyses such as identifying oceanographic features, such as persistent frontal regions. These images can be good at looking at surface water features; however, they are not representative of total water column properties. Philip Hooge looked at Landsat images of Glacier Bay and interpreted them as indicating high sediment loads in the lower Bay; however, the oceanographic monitoring data do not appear to support such a conclusion. Could the lower Bay Landsat values be a result of dissolved organic matter?

Adding a thermosalinograph (TSG) to one of the research boats in Glacier Bay would allow for continuous data collection and provide finer temporal resolution of surface temperature and salinity to the monitoring data and would allow us to examine some small scale features. This type of instrument (e.g., SBE45 TSG with interface box and 100 ft. cable) costs approximately $3,000 (plus the cost of a pump) and could be mounted to research boats such as the Capelin or Gyre or alternatively, on the passenger day-boat (e.g., Baranof Wind) or on a cruise ship. One complication is that the vessel may have to go into dry dock to put such an instrument on. The data generated by a TSG are easier to process than CTD data. A nutrient sensor could be added onto a TSG as well, but may require a more expensive TSG (SBE21) or modifications to interface the data. There are outreach opportunities available with such data and a website or kiosk could be developed. According to Glacier Bay National Park interpretive rangers, Park visitors often want to know the temperature and salinity of the water. It might be worth checking out the Alaska Ocean Science Learning Center opportunities for funding. If data are transmitted real-time, this might also attract data users.

It would be very useful to do high temporal resolution studies by putting out some moorings for a few years. It might be possible to coordinate with AOOS, which has put a mooring in Cross Sound. Phyllis Stabano (NOAA/PMEL) began a two-year oceanographic mooring deployment in Cross Sound in August 2005 measuring temperature, salinity, and current at multiple depths. One of the biggest program concerns is the cost of deploying, maintaining, and retrieving the moorings, with each action costing approximately $50,000. Pairing with other programs might reduce these costs. Another concern would be the extreme currents in the shallow entrance region of Glacier Bay.

The point was brought up that Glacier Bay National Park owns an ADCP (acoustic Doppler current profiler) and that current measurements could be taken with this instrument. The research vessels Gyre, Sigma-t, and Capelin all have mounts for the

ADCP. One caveat in using the ADCP is the need for an accurate GPS/Inertial Navigation system to measure the ship's heading (this could cost as much as $60,000). One alternative to this is to use measurements from only when the vessel is stopped. It may be that the instrument's bottom tracking capability will give an adequate velocity reference frame. Another issue is the skill needed in processing the data.

Technical issues with the current oceanographic program that need to be resolved

Our fluorometry measurements are not absolute, but only relative. They are adequate for measuring changes within a cruise, perhaps within a year, but perhaps not between years. They require calibration against chlorophyll samples taken from water sampling bottles. Also, the relationship between fluorescence and chlorophyll-*a* concentration depends upon species composition, health of the cells, light levels, etc. Lisa Eisner collected water bottle sample data and compared these with fluorometry data during July-August 2002 and June-July 2004. Comparisons between fluorometer voltage and extracted chlorophyll-*a* concentration indicated $R^2 \sim 0.8$ for both time periods. Instead of looking at concentration (as now computed from the manufacturer's suggested scaling) we might as well look at straight voltage from the fluorometer. Nevertheless, there is still the question of how to compare values across years when different fluorometers were used under different conditions. We might be able to make comparisons among sampling times/years with more confidence when the same fluorometers were used (i.e., post-1999).

The optical backscatter sensors have been calibrated with benthic grab samples. We assumed that the benthic substrate is representative of what is in the water column. We have used one equation for all stations to convert from volts to mg m^{-3}, since there was little variation among the station-specific equations.

Currently, the DOS version of SeaBird's data processing modules is being used to process raw datafiles. SeaBird recommends using the newer windows version. Salinity spiking is often found in oceanographic data and has been noticed in contour plots in the Hooge and Hooge (2002) report. Switching to the Windows version of the Seabird software would provide a better tool for spotting and removing spurious salinity spikes, especially if the operator was shown what to look for.

There was a discussion about the utility of using ArcView 3.2 and the Oceanographic Analyst extension (created by Philip Hooge) to manipulate, summarize, and visualize the data and whether this should be continued. There was a general agreement that we should not bring the data into ArcView anymore. Oceanographers do not use ArcView for creating contour sections and ArcView is usually not that good for 3-D or time series data. It is not a universal program that many people have, so we should find something that is simple and easily accessible. Also, the functions that were used to fit the contours to the data were incorrect. Philip used a 5^{th} order polynomial for creating the gridded surface upon which the contours were based upon. This higher order polynomial creates some spurious results such as density overturns. It was strongly suggested that we should not be using this extension to view the data, or if we did, to use a linear equation for interpreting the data.

Instead of using ArcView for processing and summarizing CTD data, many oceanographers use Ferret, Matlab, Surfer, Ocean Data View (http://odv.awi-bremerhaven.de), or Ocean Atlas (http://odf.ucsd.edu/joa/jsindex.html). The suggestion was that we need to use a data display program that is specific to oceanography. It is also possible to link Access with Surfer or Matlab. It is likely that it will take a fair amount of work to set it up, but then the processing should be pretty easy.

The question came up as to what is the best way to manipulate, store, and query the data. This aspect of the program is increasingly important as the dataset gets bigger. In the past few years, JMP software (SAS) has been used for this purpose. Files were then exported as Excel and .txt files for distribution to users. Many of the workshop participants recommended using Access to manipulate, store, and query the data, since it is a widely used and accessible program, and is able to handle very large quantities of data. Nevertheless, Access only holds about 2 gigabytes, so maybe other options should be considered. Consultation with a database manager is recommended.

We discussed ways to distribute the data to users. In the past few years, this has been done on a case-by-case basis along with metadata (Word document describing parameters). This process emphasizes the need to have someone who really understands the data fill the requests. It was suggested that we produce section plots and make these available with the data. Maybe we could give an example of what the sections would look like so that people knew what they could get. It would be great to have this information on the web so that people were aware of the data. However, this is going to take a fair amount of work and will likely increase the work load for data distribution. A suggestion was made that NODC (National Ocean Data Center) may not be the best place to put the data since the organization is often hard to deal with. It might be easier to have your own website and distribute the data through ftp files. There would have to be some work done with the metadata before these data could be passed along in this manner. Another idea is to have AOOS be the clearinghouse for the data. One thought is to consider who the audience is – this could be wide-ranging from scientists to interpreters and cruise ship passengers. Is there a way to meet the needs of all these users on a website?

Regarding thoughts on how to structure annual reports, suggestions were to keep them to a minimum. The report should be sure to describe equipment quirks and anomalies in sampling. The format in which they are currently done looks ok. However, suggestions were made to make section plots: one focusing on 0-15 m and then one of the whole water column, so that the variability in the surface can be detected. The problem would be the large number off plots that would need to be generated in one year (2 transects * 6 parameters * 2 depth sections * 4 trips = 96 plots); however, once a program is set up, it should be easy to generate plots for year, season, or month.

Program Review Recommendations

The following are consolidated recommendations for steps that should be taken to improve the Glacier Bay oceanographic program. The suggestions represent priority items that do not require a large monetary investment. Nevertheless, many of the items could involve a substantial investment in personnel time. We have tried to order them by what we would consider priority.

One of the most important recommendations is to develop a means to secure sustainable funding for the program to ensure its integrity into the future.

<u>Steps that can be taken to make the data we already have more useful or the program more successful:</u>

1) Modify the program objectives to provide examples of specific issues that are being addressed.
2) Document protocol changes that have occurred through time and set up a process for creating more thorough metadata.
3) Collect water bottle samples for calibration of fluorescence and salinity sensors. (see Appendix 4 for details).
4) Revise the protocol for processing raw data files (move from DOS to Windows version of SeaBird data processing software) with some guidance from a physical oceanographer.
5) Find a new way to store and distribute data (Access?).
6) Revise the protocol for summarizing data (Surfer, Ferret, Matlab, Ocean Data view, Java Ocean Atlas?).
7) Revise the protocol for visualizing data and plotting sections using a low-order polynomial (e.g., linear) interpolation to create contours that do not have possibly spurious density overturns.
8) Consider adding stations that might contribute to the value of the dataset. For example, source sites (Icy Strait) or nearshore sites.
9) Consider removing 2 Geikie Inlet stations to reduce sampling time.
10) Integrate oceanography sampling with other vessel-based research.
11) Examine interannual variability (for several years) in oceanographic conditions by targeting months that have substantial amounts of data (e.g., March, July, October).

<u>Additions to the program that would address more focused questions/objectives</u>

12) Observe spring phytoplankton bloom dynamics at Bartlett Cove using a Secchi disk.
13) Add LiCor or Eppley PAR sensor to weather monitoring station at Bartlett Cove.
14) Collect nutrient samples on a regular basis. (see Appendix 4 for details).
15) Deploy Tidbits in multiple locations (if existing temperature logger data is found to be useful).
16) Examine dissolved oxygen levels (particularly at deepest depths of Bay) potentially using a NOAA CTD rated to 600 m with a DO meter attached.

Revised Objectives and Specific Questions

Revised general objectives for the Glacier Bay oceanographic program:

1) To provide a dataset on physical oceanographic conditions in Glacier Bay (salinity, temperature, stratification, photosynthetically available radiation (PAR), optical backscatterance (OBS, turbidity)) that can be used to understand seasonal and interannual changes in the estuarine dynamics of Glacier Bay as well as the southeast Alaska oceanographic system.
2) To provide a baseline oceanographic dataset (salinity, temperature, stratification, photosynthetically available radiation (PAR), optical backscatterance (OBS, turbidity), and chlorophyll *a* fluorescence) that can be used by a variety of biologists to understand spatial and temporal variation in the abundance patterns of a variety of organisms including zooplankton, marine invertebrates, fishes, mammals and seabirds of Glacier Bay.

Potential specific questions that could be addressed using the Glacier Bay oceanographic data set: (These topics provide examples of past or ongoing studies conducted in Glacier Bay)

1) *Whales*. Why do whales frequent Glacier Bay in such high numbers compared with other southeast Alaska areas? How do oceanographic conditions aggregate whale prey in Glacier Bay and how does this influence the distribution patterns of whales, which change from month to month and year to year?
2) *Marine birds.* How do oceanographic conditions aggregate pelagic bird prey in Glacier Bay and how does this influence the distribution patterns of seabirds? How does circulation within Glacier Bay influence spatial recruitment of nearshore benthic invertebrates that provide food for seaducks and shorebirds?
3) *Crabs.* How do oceanographic conditions (degree of turbulent mixing vs. stratification) influence sedimentation and benthic substrate type (e.g., cobble versus mud) and the resulting prey communities? How are levels of phytoplankton biomass related to the degree of benthic-pelagic coupling and the supply of organic material to benthic habitats?
4) *Larval transport.* How do oceanographic conditions within the entrance region of Glacier Bay influence export and import of crustacean and fish larvae between a marine protected area and outside waters? How do frontal features influence the larval dispersal and subsequent recruitment of organisms within Glacier Bay?
5) *Phytoplankton.* How do the oceanographic conditions of the lower Bay influence nutrient regeneration to Glacier Bay and the resulting high and sustained levels of phytoplankton biomass from spring through fall? What causes seasonal changes in spatial patterns of phytoplankton abundance within Glacier Bay?
6) *Forage fish.* How do oceanographic conditions influence distribution and abundance patterns of forage fish? How does spatial differentiation in oceanographic conditions influence habitat type and spawning locations of forage fish?
7) *Intertidal communities*. How do circulation patterns and rates of sedimentation influence recruitment and development of intertidal communities? How do

shallow water temperature and salinity fluctuations resulting from freshwater discharge influence growth rates and tolerance levels of intertidal bivalves?

8) *Otters***.** How do current and sedimentation rates influence benthic habitats and prey communities? How do current and sedimentation patterns influence kelp distribution, which provide rafting habitat for otters?
9) *Climate.* How does climate change influence oceanographic properties and circulation patterns of a glacial fjord? What are the implications of these estuarine changes on the exchange of materials between the fjord and coastal ocean?
10) *Fjord sill processes.* What is the frequency of deep water renewal to the Glacier Bay central basin and Muir Inlet basin and how does this influence dissolved oxygen levels in these areas? What are the patterns of exchange in water masses between Glacier Bay and outside waters, and how do these change with tidal range and rates of freshwater input?

Literature Cited

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Matthews, J.B. 1981. The seasonal circulation of the Glacier Bay, Alaska fjord system. Estuarine, Coastal and Shelf Science 12:679-700.

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Taggart, S.J., P.N. Hooge, J. Mondragon, E.R. Hooge, A.G. Andrews. 2003. Living on the edge: distribution of Dungeness crab Cancer magister in a recently deglaciated fjord. Marine Ecology Progress Series 246: 241-252.

Figure 1. (A) Glacier Bay, Alaska, USA and the oceanographic sampling stations. Stations were grouped into four zones based on physical properties such as similarities in bathymetry, relative position to glaciers and source of oceanic waters, and general examination of oceanographic patterns. Zones were defined as lower Bay (stations 0, 1, 2, 3), central Bay (stations 4, 5, 6, 13, 14, 15), West Arm (stations 7, 8, 9, 10, 11, 12, 21, 22, 23) and East Arm (stations 16, 17, 18, 19, 20). (B) Plan view of Glacier Bay bathymetry and location of present glacial extent. Gray/black shading represents deeper portions of the Bay, while light gray shading represents shallower depths.

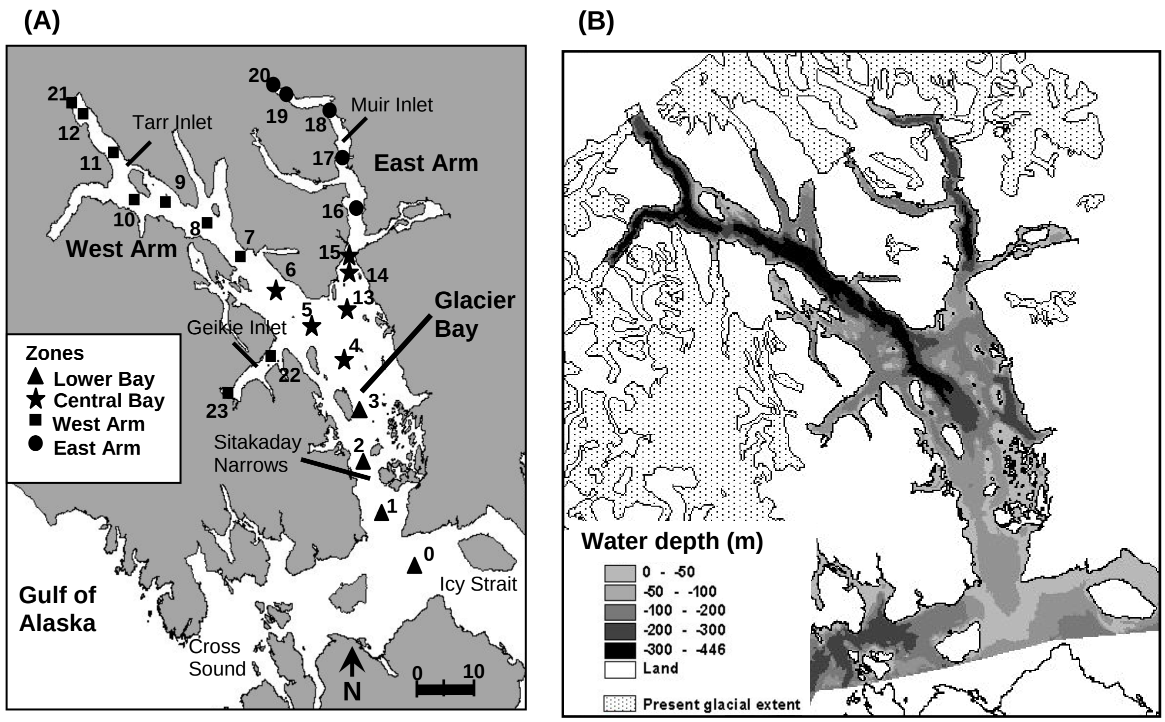

Table 1. Table of oceanographic data collected at 24 stations within Glacier Bay, AK. Letters indicate which months of each year were sampled. (a) designates surveys with good coverage of the available sites (≥ 12 sites sampled), while (b) designates low to moderate coverage over all sites (<12 sites sampled); (c) denotes periods when salinity and density data are not available, and (d) indicates times when PAR data are not available (otherwise, PAR available from November 1993-present). OBS turbidity data are available for August 1999 - present. Fluorescence data (chlorophyll-a) are available from May 1994 - present.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1993							a	a	a	a	a	a
1994	b			b	a		a	a				
1995										b,c	b,c	
1996			b			b			d	d		
1997					d		d				d	
1998		d				a				a		a
1999			a			a	a	a		a		
2000	a		a		a	a	a	a	a			b
2001		b	b	a			a			a		
2002	a		a	a			a	b		a		
2003		b		a		b	a	a, d		a, d		a, d
2004			a			a	a			a		
2005	a		a			a	a			a		a
2006			a									

Appendix 1. List of Workshop Participants

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Appendix 2. List of oceanographic data distribution

In addition to our own analyses of the data, we continue to provide oceanographic data from the Glacier Bay oceanographic monitoring program to fellow researchers who use these data in interpreting their own data and formulating new research questions and projects. In addition we provide these data to the National Park Service and educators for interpretation purposes. The below list documents the variety of uses of the oceanographic data from 2003-2006.

<u>Glacier Bay oceanographic data were delivered to the following colleagues during 2003:</u>
1) Dr. Lisa Eisner (NOAA-Auke Bay) - used to understand phytoplankton abundance and distribution patterns in Glacier and to provide supporting material for justification in writing NSF proposal.
2) Chris Gabriele (NPS-Glacier Bay) - used to correlate oceanographic data with Glacier Bay whale distribution and abundance patterns
3) Jennifer Fisher (Moss Landing Marine Laboratory) - correlated oceanographic data with crustacean larval abundance patterns within Glacier Bay
4) NPS staff and Gustavus community members - oceanographic data used to present a talk on Glacier Bay oceanographic system

<u>Glacier Bay oceanographic data were delivered to the following colleagues during 2004:</u>
1) Dr. Ned Cokelet (NOAA/PMEL, Seattle, WA) - oceanographic data used to interpret thermosalinograph, acoustic doppler current profiler (ADCP), fluorescence (chlorophyll-a) and nutrient data collected in Glacier Bay.
2) Won Park (University of Alaska Fairbanks, Juneau, AK) - used in correlating oceanographic conditions with zooplankton abundance and distribution within Glacier Bay.
3) Martin Robards (University of Alaska Fairbanks, Fairbanks, AK; U.S. Geological Survey) - used to understand the relationship between physical oceanography and the spatial distribution of nearshore and pelagic fish in Glacier Bay.
5) Chris Gabriele (NPS-Glacier Bay) - used to understand sound velocity and the acoustic environment of Glacier Bay (related to humpback whale behavior)
6) Leesa Wingo (South Anchorage High School, Anchorage, AK) - used in high school marine science curriculum - activities to understand estuarine oceanographic dynamics.
7) Glacier Bay National Park interpretation staff - used in a lecture to provide basic information on the Glacier Bay oceanographic system to be translated to Park visitors.

<u>Glacier Bay oceanographic data were delivered to the following colleagues during 2005:</u>
1) Dr. Lisa Eisner (NOAA-Auke Bay) - used to produce a synthesis of southeast Alaska marine biology and oceanography
2) Chris Gabriele (NPS-Glacier Bay) - used to understand sound velocity and the acoustic environment of Glacier Bay (related to humpback whale behavior)
3) Jennifer Mondragon (NOAA-Juneau) - used to understand distribution patterns of soft corals in Glacier Bay

4) Dr. Jim Taggart (USGS-Alaska Science Center) - used to determine salinity patterns of surface waters in October to decide where water can be collected for holding crabs in optimal conditions.
5) Jamie Womble (NMFS-Juneau**)** – used to understand habitat use by foraging/diving harbor seals in Glacier Bay. Used to understand seasonal abundance patterns of sea lions hauled out on S. Marble Island.
6) Glacier Bay National Park Interpretation staff - used in development of a packet of oceanographic information and figures for NPS Interpretation staff.

<u>Glacier Bay oceanographic data were delivered to the following colleagues during 2006:</u>
1) Dr. Gail Irvine (USGS-Alaska Science Center) – used to correlate with spatially explicit mussel growth rates in Glacier Bay
2) Heidi Herter (University of Alaska Southeast) – used to understand the relationship between oceanographic conditions and Dungeness crab larval supply

<u>Other known published uses of Glacier Bay oceanographic data:</u>

1) Taggart et al. 2003. Living on the edge: distribution of Dungeness crab *Cancer magister* in a recently deglaciated fjord. Marine Ecology Progress Series 246:241-252. - oceanographic data used to relate physical attributes of environment to crab abundance and distribution.
2) Fisher, J. In Press. Seasonal timing and duration of brachyuran larvae in a high-latitude fjord. Marine Ecology Progress Series.
3) Etherington, L.L., P.N. Hooge, E.R. Hooge. In Press. Physical and biological oceanographic patterns in Glacier Bay. Pages XX-XX in J.F. Piatt and S.M. Gende, editors. Proceedings of the Fourth Glacier Bay Science Symposium, 2004. U.S. Geological Survey, Information and Technology Report USGS/BRD/ITR-2006-00XX, Washington, D.C.
4) Etherington, L.L., P.N. Hooge, E.R. Hooge. In Review. Oceanography of Glacier Bay, Alaska: Implications for biological patterns and productivity in a glacial fjord estuary. Estuaries and Coasts.

Appendix 3. Documents/materials that were used in program assessment

1) *Monitoring Handbook:*
   Hooge, P.N., E.R. Hooge, E.K. Solomon, C.L. Dezan, C.A. Dick, J. Mondragon, H. Rieden, L. Etherington. 2003 version. Fjord oceanography monitoring handbook: Glacier Bay, AK. U.S. Geological Survey, Alaska Science Center, Anchorage, AK, 21pp.

2) *Reports:*
   Madison, E. and L.L. Etherington. 2005. Monitoring of oceanographic properties of Glacier Bay, Alaska. 2004 Annual Report. U.S. Geological Survey, Alaska Science Center, Anchorage, AK, 21pp.
   Etherington, L.L. 2004. Monitoring of oceanographic properties of Glacier Bay, Alaska. 2003 Annual Report. U.S. Geological Survey, Alaska Science Center, Anchorage, AK, 37pp.
   Etherington, L.L., P.N. Hooge, E.R. Hooge. 2004. Factors affecting seasonal and regional patterns of surface water oceanographic properties within a fjord estuarine system: Glacier Bay, AK. U.S. Geological Survey, Alaska Science Center, Anchorage, AK, 79pp.
   Hooge, P.N. and E.R. Hooge. 2002. Fjord oceanographic processes in Glacier Bay, Alaska. U.S. Geological Survey, Alaska Science Center, Anchorage, AK, 142pp.

3) *CD with data files representative of one sampling trip.* This included raw and processed data, an ArcView project (used for data visualization and presentation to wide audience) and .JMP statistical file (used for data manipulation, analysis, and dissemination). Also included was a listing of all available data from the monitoring project (1993-2005).

4) *Previous External Reviews*

   E. Knudsen. USGS, Alaska Science Center. Review of oceanographic monitoring study plan. 4/2001.
   T. Weingartner. University of Alaska, Fairbanks. Review of Hooge and Hooge (2002) report. 8/2002
   G. Drew. USGS, Alaska Science Center. Review of Hooge and Hooge (2002) report. 3/2002
   E. Knudsen. USGS, Alaska Science Center. Review of Hooge and Hooge (2002) report. 9/2001
   L. Sharman. NPS, Glacier Bay National Park. Review of Etherington et al. (2004) report. 6/2003
   J. Mondragon. USGS, Alaska Science Center. Review of Etherington et al. (2004) report. 6/2003

Appendix 4. Expanded details from review recommendations (numbers refer to those recommendations on p. 18)

#2. *Collect water bottle samples for calibration of fluorescence and salinity sensors.* Salinity can be calibrated using one sample per station and alternating between surface and deep samples to span the salinity range. Salinity analyses=$23 per sample, which could be done at the University of Washington Marine Chemistry Lab. Fluorescence can be converted to chlorophyll-a by regressing against chlorophyll from water samples taken at discrete depths. The simplest strategy would be to take one chlorophyll sample from the depth of the fluorescence maximum at selected stations. Another would be to take two samples, one above and one below the pycnocline (e.g., 8 m and 20 m) at each station during each cruise. Filter water onto GF/F filters and store filters at -20 or colder (supercold (-70) or liquid N are best, since storage at very cold temperatures reduces pigment degradation). Chlorophyll-*a* analyses can be run using equipment at NOAA Auke Bay lab or analyzed by U. Washington marine chemistry lab. An integrated minimal approach would be to take one water sample at each station, alternating between a near-surface sample, a fluorescence-maximum sample, and a deep sample. The near-surface and deep samples would be analyzed for salinity. The near-surface and fluorescence-maximum samples would be analyzed for chlorophyll-a.

#13 *Collect nutrient samples on a regular basis.* For additional nutrient sampling, a water bottle sample could be taken above and below the pycnocline (e.g., 8 m and 20 m) for each station. These samples would need to be frozen on the boat (or if absolutely necessary, the samples could be frozen the same day after returning to shore). Samples collected for nutrients must remain frozen until analyses. Nutrient analyses=$11 per sample, plus some overhead at the U. Washington marine chemistry lab (contact Kathy Krogslund).