# A Dendroclimatic Record of Paleoclimate of the Last 10,000 Years, Glacier Bay National Park and Preserve: Progress Understanding Climate Change In Southeast Alaska

*Coring the mixed species forest in the shadow of Excursion Ridge*

**ANNUAL REPORT 2007**

**Studies Conducted As Part of Research Project:**
**Long-term tidewater and terrestrial glacier dynamics, glacier hydrology, and Holocene and historic glacier activity and climate change in Glacier Bay National Park and Preserve**

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**2007 Annual Report**

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## Executive Summary


Our investigations in 2007 focused on continuing collection and analyses of tree rings from living trees and building a long ring-width series from interstadial wood. These interstadial forests were extensive and their preservation, although discontinuous and fragmented, is remarkable. In situ stumps, still rooted in growth position, and logs held within sediments remain from forests that existed at various times between glaciations over approximately the last 10,000 years.

We have analyzed previous and new collections of ring-width tree-ring series, including a multiple species collection from near Excursion Ridge in the southeast portion of the Park. These tree-ring series have a strong temperature signal and together with our other collections along the Gulf of Alaska are being used in three undergraduate theses. The trees show a *divergence* from expected growth within some sites and this decrease in growth is being investigated in Glacier Bay and along the Gulf of Alaska. We continue to share our tree-ring data with other researchers (Capps, Clague, Luckman) working on ice-dammed lakes of Brady Glacier who have been able to tree-ring date a significant lake damming event along the ice margin. Denny Capps, a PhD candidate from Simon Fraser University, worked at The College of Wooster Tree Ring Lab on tree cores from Brady Glacier during the fall of 2007, acquiring data that will be useful to both of our projects.

Our further sampling and tree-ring dating of logs from the southern end of Glacier Bay suggests a remarkably rapid advance of the tidewater glacier as it reached near its Holocene maximum in the early 1700s. This is an interesting find in that it meshes with the relatively well-documented oral history compiled by others for the area and the recent work of Streveler, Connor, Howell and Montieth. We built on our work in the previous year that developed calendar-dated ice advances about AD 800 and a relative tree-ring sequence spanning several hundred years tied to radiocarbon dating that suggests ice advance into forest about 3000 yr BP both from Geikie Inlet. During the summer of 2007, we targeted key stratigraphic sites within North Fingers Bay that had logs from both of these advances within glacial sediments, thus providing a context for the wood. We also

concentrated on sampling in the Charpentier Inlet to target ~4500 yr BP wood. These collections are currently being analyzed.

We seek to continue documenting wood bearing exposures across the Park to gather sufficient data and wood sections for developing the potential 10,000-year record of paleoclimate and to place present glacier and ecological changes into a long-term context of climate changes that affected Glacier Bay and the North Pacific. Because of the complex regional and sub-regional climatic regimes, and the timing and location of glacial advance and retreat across the Park, numerous sites must be examined in detail to develop a full tree-ring chronology and glacial history. Thus to reconstruct the entire 10,000 year chronology, we must sample each location where forests grew prior to ice advancing across them: for example trees killed during the ice advance of 9000 years ago occur near the heads of inlets, whereas trees overrun by the same advancing ice 7000 years ago are located in mid-bay sites near Geikie and Adams Inlet.  Each area is thus equally critical to developing a model of ice advance and retreat into lower Glacier Bay tied directly to the paleoclimate.

*Early Holocene (~7400 C14 yrs BP) age interstadial tree stump in McBride Inlet*

## Introduction

Heavy snowfall in the high mountains surrounding Glacier Bay feeds one of the larger active glacier complexes along the Gulf of Alaska, a part of the largest glaciated region in the world outside of the large ice sheets (Meier 1984; Meier et al 2007). With the exception of some lowlands at the southeastern and southwestern margins, Glacier Bay was covered by ice as recently as AD 1770 during the Little Ice Age (Motyka et al., 2003). The recent loss of ice in Glacier Bay alone has had a significant effect on global sea level rise (Arendt et al., 2002, Larson et al., 2006); it is estimated to have contributed as much as 1 cm of global sea level rise of the Little Ice Age rise of approximately 20 cm. Deglaciation in the Bay is one of the best documented in the world, with ice margins retreating distances as far as 100 km at some of the highest rates ever recorded. During this retreat, forests that were overridden previously by ice have been uncovered and radiocarbon dating of these interstadial forests reveal that in addition to the advance during the Little Ice Age, ice apparently advanced into Glacier Bay several other times beginning as early as 12,500 years ago (Lawson et al, 2007).

Global climate is changing, and humans likely have a significant role in affecting those changes. Placing these contemporary changes into a long-term context is crucial to our understanding of how the climate system works and to demonstrating the full range of natural variability of the climate system especially on annual to millennial time scales. As warming progresses, major changes in the cryosphere and biosphere are being observed especially in the higher latitudes. It is with this need in mind that we are conducting research on the paleoclimate of Glacier Bay, a climatically-sensitive region of the North Pacific where the unique 10,000+ year long tree-ring chronology can provide high-resolution information on the highly variable climate of the Holocene with respect to each successive ice advance.

The arctic and subarctic regions are particularly sensitive to current and predicted warming; however, our knowledge is hampered by the relatively short-term, climatic records. For the North Pacific region, most observational climate records are less than 100 years long, spanning only the interval of possible anthropogenic influence. The large repository of interstadial wood within Glacier Bay will provide a long-term thermal history for the North Pacific region. These paleoclimate data will allow us to reconstruct critical parameters that are now lacking but required to understand climate dynamics and to calibrate Global Climate Models (GCM's) used to better predict future changes in climate.

In this Annual Report, we describe the results of our most recent work extracting tree-ring records from the interstadial wood and living trees within the context of the overall research effort. These records are synergistic with the climate monitoring and glacial history objectives of the larger ongoing projects in Glacier Bay. The tree-ring record will directly provide calendar dates on wood that are of significance to glacial and geomorphologic events and potentially dates on wood of archaeological significance. To extract a climate signal from the series, we are using the meteorological records from along the Gulf of Alaska, but the real gain in understanding climate and contemporary tree growth will be in comparing the records from the climate monitoring efforts within Glacier Bay (Lawson and Finnegan 2008; Finnegan et al 2007). The ongoing efforts to monitor changes and place these changes into a long-term context will be a history that many other research efforts in Glacier Bay can use.

**History of the Study of Interstadial Wood**

The continuing sampling of the wood has revealed that a huge repository of information existed for perhaps the last 10,000 or more years. The incredibly well-preserved wood when first exposed by erosion of the glacial deposits suggested that it may be possible to develop a tree-ring record for each of the time periods represented by the ancient forests. However, we also realized early on that the interstadial forest was transitory – that it remained suitable for sampling for only a brief period of time, perhaps as little as two to three years after exposure, and further that because of the environment in which they are exposed, mainly eroding slopes and active flood plains and debris fans (*Figures 1a, b*), the wood was being lost to the sea within 3 or less years after being exposed. Combined, these losses put urgency into sampling the wood and thus preserving it for analysis.

***Figure 1a.*** *Log exposed by erosion of glacial deposits in steep gully in Wachusett Inlet.*

Thus, our wood sampling began in earnest in 1996, with basic laboratory processing and radiocarbon dating of the samples done as sections and cores were acquired. All wood samples were slowly dried, stabilized with glue and then rough and fine sanded for an initial appraisal of their suitability for tree-ring work. Samples of the wood were radiocarbon-dated to define the range of representative ages and later identify the groups of wood required for further sampling of sections necessary for the tree-ring analyses.

Although sections of interstadial wood received the initial laboratory processing annually, the detailed analysis of the tree-ring record was not begun until 2002, the primary reason for the delay being that sufficient dated samples had to be gathered to prove that enough wood existed in the park to piece together a long tree-ring record.

***Figure 1b.*** *Typical eroding slope and alluvial fan environment in which interstadial logs are commonly found. Such a dynamic, high energy environment readily transports these logs into adjacent fjords where they are no longer able to be sampled. Such activity results in a loss of the critical paleoclimate record held within them.*

It was initially difficult to believe that such a lengthy record existed, because no other such long-term wood repository was known from a heavily glaciated terrain like that of Glacier Bay. In most instances, subsequent glacial activity wipes much, if not most of the record of previous glaciations, and thus in most formerly glaciated regions of the world, a long-term record of ancient forests would be impossible to document and obtain enough samples for a tree-ring analysis. Glacier Bay goes against that principle and the more sampling we did, the clearer it became apparent that the Park had preserved within it an unprecedented record of the glacial history and the paleoclimate of the interstadial forests. Because all wood has to be first located by searching on foot, it takes a significant amount of time to obtain samples necessary for the analysis and hence the initial delay in conducting the tree-ring analyses. In addition many samples are split, have some rot and contain sand within the cracks and wood itself, causing some samples to be incomplete.

Thus since 1996, we have sampled interstadial wood at numerous sites across the Glacier Bay watershed. We have located wood in the West and East Arms, as well as the lower bay. Traverses in search of interstadial stumps and logs have often located wood in many valleys feeding the primary inlets and bays, as well as within the intertidal zone as tectonic and isostatic uplift exposes it. Logs and stumps we sampled prior to 2005 no longer exist in the field due to erosion and transport into the sea, or burial within fluvial deposits. Decay of wood has also taken its toll and only fragments often remain.

Extensive sample processing and tree-ring analysis has provided the first calendar-dated tree-ring record for Glacier Bay and several groups of interstadial wood have been counted and ring-widths analyzed. These chronologies will be linked with other groups to provide a continuous record; the current focus is on the last 3000 years because we can tie it directly to calendar-dated chronologies within the Gulf of Alaska of the last 1500 years and provide the first tree-ring record in the Gulf that extends an additional 1500 years using the Glacier Bay samples. As we develop the chronologies, additional analyses, including ring density and the stable isotopic composition and radiocarbon content of each ring, will be undertaken to provide high resolution information on seasonal and annual paleotemperature and other paleoclimatic information.

**Overall Objectives**

The overall objective of this research is to develop a high-resolution record of climate for North Pacific over the past ten thousand years in Glacier Bay using exactly-dated tree-ring records and reconstructed glacial histories. Our paleoclimatic studies in 2007 specifically focused on sampling and developing tree-ring chronologies and analyzing these records for their climatic significance. Specific tasks included:

1) Coring living trees and developing ring-width series for the past several hundred years.
2) Identifying the climate signal in these series,
3) Preliminary use of the tree-ring series in modeling climate in the North Pacific,
4) Obtaining sections of interstadial wood that grew for various intervals through the past 8000 years to supplement existing radiocarbon-dated sections for which ring-width chronologies could be developed.

**Background on Dendrochronology and Methods**

In this section, we outline some basic principles of dendrochronology and standard methods employed in our research. For those readers familiar with this, please skip to the next section on our 2007 work. Dendroclimatic studies involve the statistical comparison of tree growth (such as measured ring widths) to important climatic factors such as regional temperatures from instrumented climate records (Fritts 1976). We must show that modern trees have tree-ring widths that vary with climate, thus providing the basis for future analyses of paleoclimate in the 10,000-year chronology. Climate data now being collected at sites across Glacier Bay (Lawson et al 2006 b, Lawson and Finnegan, 2008) will provide data on how climate varies regionally across the Park, and will allow us to determine whether historical records from climate stations outside Glacier Bay reflect the climate within the bay.

Radiocarbon dates from the exhumed interstadial wood are at their youngest 250 to 500 years old, In order to know the exact year of growth on each of these older specimens, we need to connect them to the present day calendar-dated tree-ring record, which can be done with the oldest still-living trees (*Figure 2*). We have sampled five locations within the Park including Excursion Ridge, Beartrack Cove, Dundas Bay, Icy Strait and the ridge above Tlingit Point. These older living trees grew through most of the Little Ice Age, some exceeding a 650 year life span

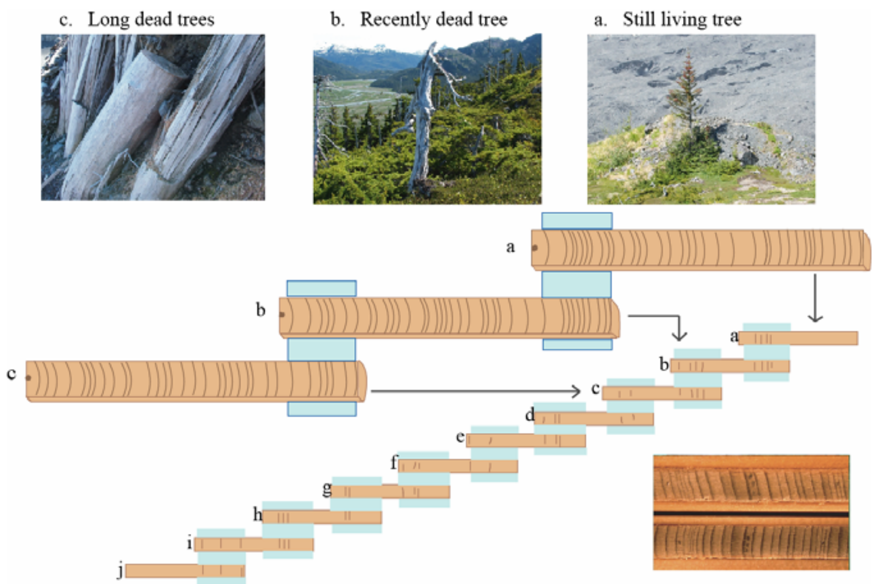


***Figure 2.*** *Diagram showing the tree-ring crossdating technique. The age of the wood increases to the left. We are now establishing calendar-dated tree-ring records from living trees in Glacier Bay and matching them with floating ring-width series from interstadial wood, extending the calendar-dated series back several millennia.*

Once we have fully established that tree ring properties reflect climate in response to changes in air temperature, and have linked the interstadial wood to the exactly-dated tree ring series (Figure 2), we can build on this series using the radiocarbon-dated sections of interstadial wood. These ancient trees have dates spanning the last 10,000 years, but each section may span only a few hundred years necessitating a large sample size.

Thus we must acquire multiple groups of wood sections to cover the entire ten thousand year period, and we must also collect a sufficient number of wood sections of a particular age range to produce a continuous and reproducible tree–ring record. We estimate that based on measuring 2 to 3 radii from each cross section and needing approximately 20 radii for a reliable, well-replicated dendroclimatic signal that we will need approximately 7 – 10 samples cross-sections throughout the tree-ring series.

The resulting living ring-width series are correlated (calibrated; Fritts, 1976) with the instrumental data from meteorological records from nearby sites, which include Juneau, Sitka, Haines and Yakutat. We also compared the series to an existing network of tree-ring series available from the Gulf of Alaska (Figures 2; Wilson et al., 2007) (Barclay et al 1999; Wiles et al 1999,).

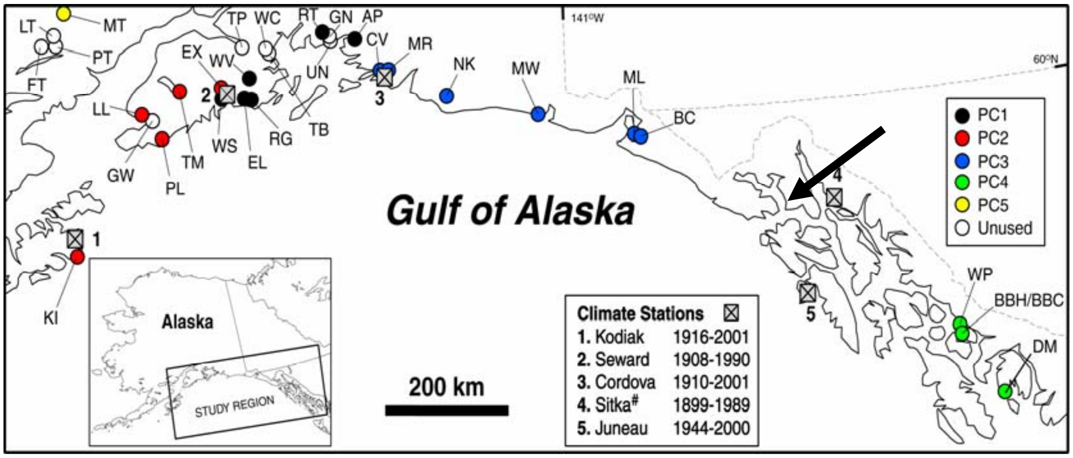


***Figure 3.*** *Location map of tree-ring sites and climate stations in the Gulf of Alaska Region (from Wilson et al., 2007). Large arrow shows approximate location of the Beartrack ring-width chronology developed in 2006. The locations of the five climate stations that are used to identify the regional climate response are also shown.*

Ring-width chronologies from the interstadial sites are crossdated with chronologies from the living sites when they overlap in age, or used as *floating* tree-ring series when they lie outside the range of the calendar-dated series (*Figure 2*). As we continue to obtain and to analyze tree ring records from new interstadial wood sections, we will link these floating series to develop a continuous tree-ring record. Thus, a current focus is to obtain the necessary sections for filling in the entire series beyond the calendar-aged wood. We are especially encouraged because the extensive set of living tree-ring records and interstadial records from other regions along the Gulf of Alaska match well with the tree –ring records from Glacier Bay (*Figure 3*). For example, a 1500 year long tree-ring record from Columbia Bay in Prince William Sound correlates well with tree-ring series from Geikie Inlet and other sites that have known caches of logs in the age range of 1200 yr. BP.

Tree-ring records from the interstadial trees are developed from sections cut from in situ stumps and logs in glacial sediments. We use standard geological methods to determine the nature of the deposits associated with the wood and to interpret their origins, particularly whether the death of the wood resulted from a glacial advance and thus aid in producing information on the glacial history of the bay. These methods include defining the glacial stratigraphy by sedimentological analysis of deposits (e.g. Benn and Evans 1998), and by dating organic material in soils, peat horizons and small pieces of wood within these sediments using radiocarbon methods (e.g. Bowman 1990). Each core and section sample site is located precisely by GPS, photographed and various parameters, such as dimensions, position of each sample section relative to the roots, tree species and overall condition, are recorded.

***Figure 4.*** *Cross section cut from unusually well preserved interstadial log exposed in 2006 by flooding and slope erosion in the upper reaches of the Geikie River valley. Approximate age is 3000 C14 yrs BP. A return visit to this site in 2007 revealed that it had been lost to additional erosion and apparent transport down the Geikie River. Note that most sections are split, with sand and silt filling cracks and impregnating partly rotten wood.*

In the lab, the core and wood sections (*Figure 4*) are slowly dried and then glued and sanded for counting and measuring the rings. We must carefully scrutinize multiple wood sections to account for missing rings, as rings may be locally absent on a cross section due to various stresses in the environment. In addition, small samples (several grams) of the outermost five rings of interstadial wood sections are radiocarbon-dated using the high-resolution Accelerator Mass Spectrometry (AMS) technique (e.g. Gove 1999).

**Continued Tree-Ring Chronology Development**

Significant progress was made in sampling and analyzing the living tree-ring width chronologies in the Park, building on the work done in the previous year at Beartrack Cove. We collected multiple species from near tree line on Excursion Ridge (see cover photo). The data from this group of living trees show a strong regional summer temperature signal when compared with a regional record of monthly climate records over a 100 year period. One mountain hemlock tree-ring series collected in July 2007 has the strongest temperature signal (highest correlation with historical temperature records) that we have analyzed in the over 40 ring-width coastal series from elsewhere across the Gulf of Alaska region (Trutko et al., 2007). It clearly illustrates how strong the climate signal from Glacier Bay is likely to be and the potential for such records to provide a highly detailed chronology applicable to other disciplines. For example the Excursion Ridge ring-width series as a surrogate for temperature changes may record events corresponding to Tlingit legends that talk about intervals without summer (Figure 5).

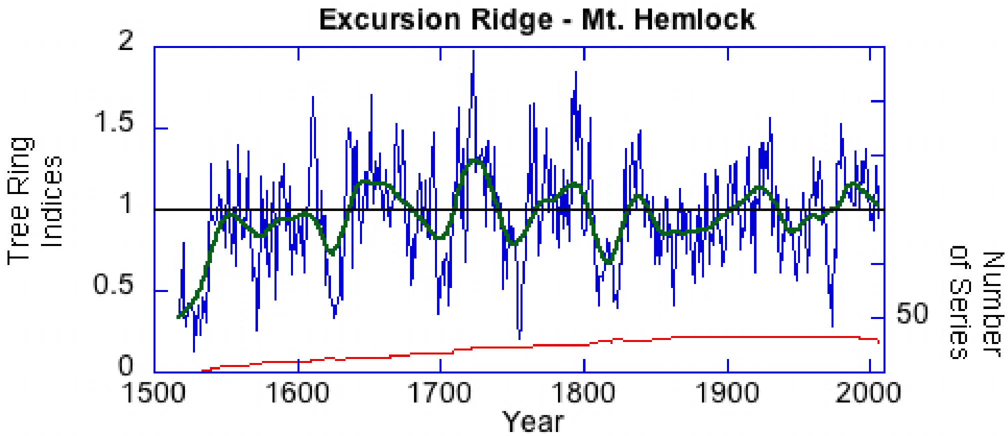


***Figure 5.*** *Excursion Ridge ring-width series. This chronology can be considered a record of temperature change. Note the intervals of suppressed tree growth about AD 1750 and the early 1800s. Tlingit legends report intervals without summer; these intervals could potentially correspond with the legends.*

The relationship of air temperature and ring-width in living trees also supports our previous work on interstadial tree-ring samples (Lawson et al 2006d) that showed strong crossdating with other tree-ring records from Prince William Sound. This important finding is crucial to interpreting the paleotemperature record from interstadial tree ring width series.

We have also made significant progress assembling tree-ring records from the interstadial wood during the last two years. These records are synergistic with the climate monitoring and glacial history objectives of the larger ongoing projects in Glacier Bay (Lawson et al 2006 a, b). The tree-ring record will provide calendar dates on wood that are of significance to the timing of glacial and geomorphologic events, and potentially calendar dates on the death dates of wood with archaeological significance, bearing directly on Tlingit legends.

Our objectives this year built on previous studies outlined in our reports (Lawson et al 2004, 2006 a, b, c, d). Below we summarize the preliminary findings of a three-student project funded by the Keck Geology Consortium (Keck), and supplemented by a National Geographic Society (NGS) grant, with logistics provided by the Glacier Bay National Park. We are continuing the analyses reported in a mid-year progress report ( Wiles et al 2007); additional results discussed in this report were presented at national meetings of the Geological Society of America and American Geophysical Union and for which abstracts were published (Trutko et al., 2007, Wiles et al., 2007, Laxton et al., 2007) have resulted. In addition, our 2006 tree-ring series (Bear Track) has been used in a glacier-climate related study that we will publish in the journal *The Holocene* (Malcomb and Wiles, submitted 2007).

***The Keck/NGS Project:***
The undergraduate student participants working with Wiles and Lawson were Adam Plourde (Colorado College), Erica Erlanger (Union College), and Alex Trutko (The College of Wooster). In addition, Sarah Laxton (PhD candidate, University of Cincinnati) initiated field work for her doctoral degree, having received her Masters degree from the University of Victoria, B.C.

***Project Objectives:***
Our primary goal for the student projects was to sample living trees and recover subfossil wood from Glacier Bay National Park and Preserve. Following field work, students worked processing the cores and cross sections in the Wooster Tree Ring lab in order to develop the ring-width chronologies, date subfossil wood, and identify the climate signal in the tree rings. This work contributes directly to the overall ongoing research on paleoclimate of Glacier Bay in building the multi-millennial tree-ring chronology. Due to logistics and interests of the participants, we focused on the lower portion of the bay for subfossil wood and for the living tree-ring record on Excursion Ridge. We collected four living tree-ring sites (*Table 1*, *Figure 6*) and have processed two of these for ring-widths.

| *Living Tree Ring Sites* | *#Cores /Trees* | *Location Lat/ Long* | *Start year AD* | *Status* |
|---|---|---|---|---|
| Crang's Ridge - Western Hemlock (CR) | 51/30 | 58 27.409/135 33.788 | 1116 | prelim. |
| Crang's Mire – Lodgepole pine (CM) | 50/25 | 58 26.671/135 35.650 | 1660 | in proc. |
| Crang's Lair - Yellow Cedar (CL) | 59/26 | 58 26.680/135.35.688 | 1534 | in proc. |
| Excursion Ridge – Mt. Hemlock (EX) | 80/44 | 58 26.931/135 33.360 | 1517 | prelim. |
| *Beartrack Mountain – Mt. Hemlock | 27/20 | 58 36'34.94/13551'39.37 | 1569 | final |

*sampled in 2006

***TABLE 1** – Living tree-ring sites collected from Glacier Bay in 2006-2007.*

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*Preliminary Results of Individual Student Projects:*
Alex Trutko (College of Wooster) – is investigating the phenomenon known as *divergence* in tree growth. Divergence is the recognition that some tree-ring sites in northern forests are not keeping pace with warming – this was first recognized in Glacier Bay by Alex who noted that individual trees at the Beartrack and Excursion Ridge mountain hemlock sites over the last few decades were decreasing their ring-widths. He is focusing his analyses on the Glacier Bay collections. His work and the recognition of the divergence in tree growth have implications with respect to forest health in the Park and to the broader issue of forest growth in northern latitudes and the global carbon budget.

Erica Erlanger (Union College) was largely responsible for processing the CR (Crang's Ridge) mountain hemlock site (Table 1) and analyzing its climate signal. This site has some of the oldest trees cored in Alaska, with one 891 years old. Because of the poor

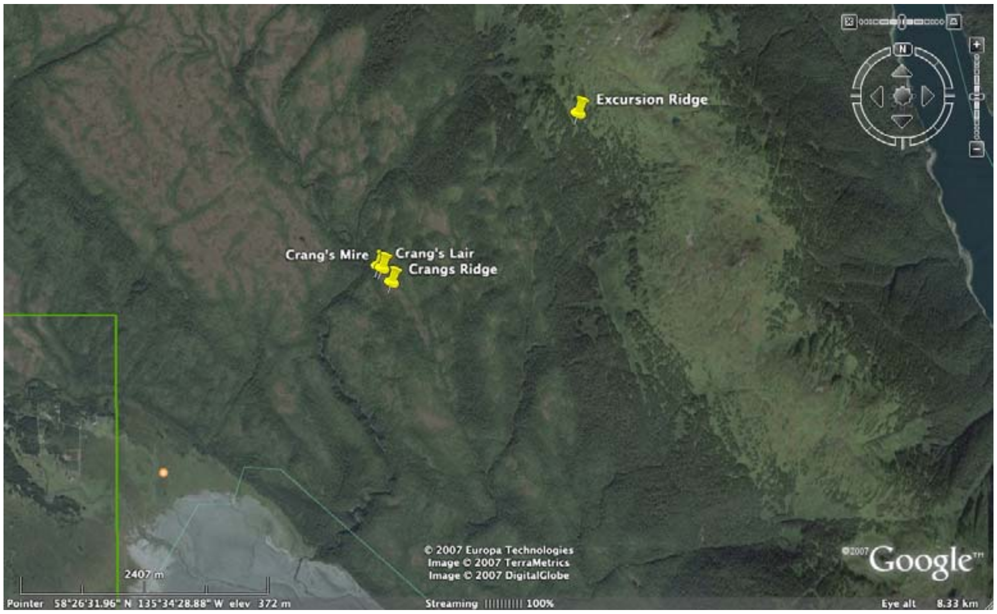


***Figure 6*** *– Locations of living tree-ring sites collected in June 2007 (see Table 1).*

climate signal in the CR site, possibly due to senescence (senility) in the trees, Erica will be working to reconstruct and extend the long Sitka Alaska temperature series using the Excursion Ridge (EX) site together with other tree-ring series from along the Gulf of Alaska (Figure 3). The Sitka meteorological record is of wide interest to oceanographers and climatologists as it was begun in 1828 and is the longest temperature and precipitation series in Alaska. Erica is using principal component modeling regression

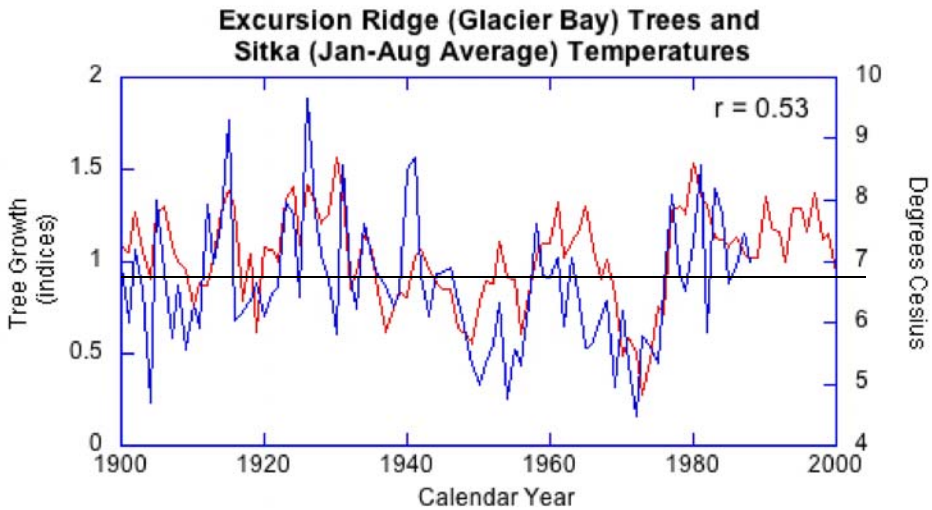


***Figure 7****. Excursion Ridge ring-width series (red) compared with January through August average monthly temperatures from Sitka, Alaska (blue).*

analysis to incorporate the tree-ring width data and extend the temperature record. The Glacier Bay EX site is well-suited for this task as it correlates strongly with the temperature record at Sitka (Figure 7).

Adam Plourde (Colorado College) worked to date Little Ice Age (last several hundred years) logs by matching ring-width patterns from logs in the intertidal areas of the lower bay with living tree-ring chronologies (Figures 8, 9). He was able to crossdate logs sampled during the summers of 2005 and 2007 and determined that the trees were killed near the mouth of Bartlett Cove between 1704 and 1724 and 5.25 km further south toward the mouth of Glacier Bay by 1735. Each of the logs he crossdated had their outer rings intact. The significance of these dates with regard to the glacier history is under discussion. Such an advance is consistent with some of the Tlingit legends, although we have not yet consulted those researchers who know the legends well (e.g. Monteith et al., 2007).

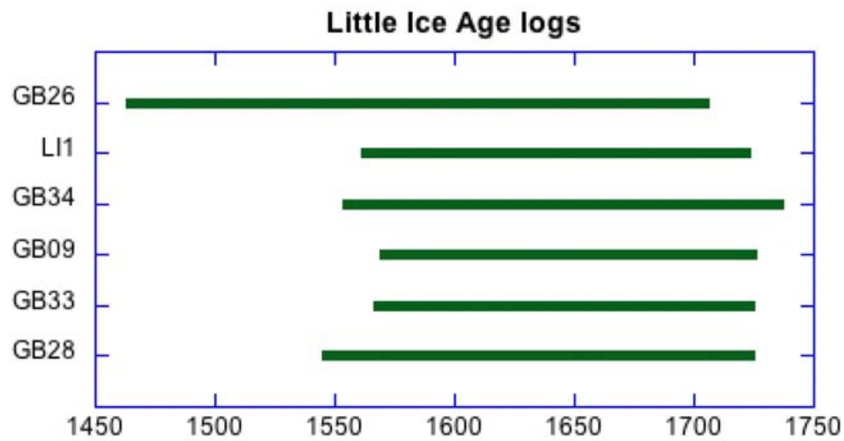


***Figure 8.*** *Crossdated positions of 6 logs sampled from the lower portion of Glacier Bay. The green bars represent the life span of the individual trees; they are calendar-dated with the living trees from the region (see Figure 6).*

Adam is now doing his thesis using tree-rings in the North Pacific (including the Glacier Bay series) to model lake levels in the Laurentian Great Lakes. This exercise exploits the Pacific North American teleconnection pattern (PNA) that links North Pacific climate with evaporation and precipitation in the Midwest of North America. Adam compared the monthly record of lake levels for Lakes Huron, Michigan and Ontario with the tree-rings and the correlations of the two data sets prompted him to continue the modeling using principal component analyses to reconstruct the lake levels back several hundred years.

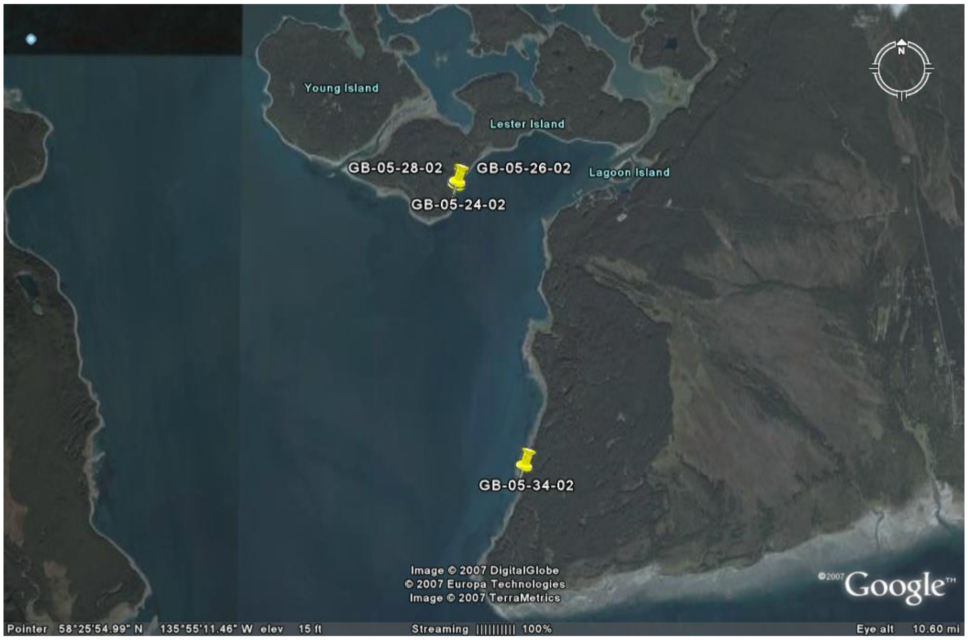


***Figure 9.*** *Location map of interstadial logs which we have crossdated using ring-width series from Glacier Bay and others and subsequently calendar-dated (see Figure 8).*

Sarah Laxton (University of Cincinnati) is working on several related aspects of the Glacier Bay paleoclimate and glacial history investigations, including an analysis of the divergence issue comparing the data from Glacier Bay with that of other coastal sites in the Gulf of Alaska region, and on the mid-Holocene glacial history of the bay. She gave a presentation at the meeting of the American Geophysical Union in San Francisco in December 2007 (Laxton et al., 2007) which featured the work done in 2007 on divergence records in Glacier Bay. The mid-Holocene, from about six to three thousand years ago, is a period of near millennial scale rapid climate change events, which have been recognized globally. Subfossil samples analyzed by Lawson et al. (2006 c, d) indicate that there is strong evidence of mid-Holocene glacier activity in the upper bay areas. Sarah plans to conduct a detailed study of glacial sedimentary exposures in the Mt. Wordie area of Wachusset Inlet, where this summer we discovered new exposures eroded by river activity that contain multiple layers of subfossil wood and other organic debris. These analyses will help to unravel the complex timing and extent of glacier advance in the upper reaches of the bay.

*Ongoing Work and Presentations:*

The undergraduate students will complete their theses in the fall of 2008 and individually present their results at the annual Keck Consortium Meeting at Smith College in the spring. Additionally, Wiles and Plourde (2008) will present the result of the Great Lakes modeling, building on Plourde's work with the Glacier Bay data on Lakes Huron, Michigan and Ontario.

**Continued Dating of Interstadial Wood and Glacial Chronology**
Additional progress has been made in assembling a *floating* ring-width series that spans portions of the past three millennia. We have added to the calendar-dated series over the past two millennia and have obtained additional radiocarbon ages on wood that will span portions of this series in our efforts to increase the sample size and provide a more robust dendroclimatic and dating series. This ongoing tree-ring work derived from subfossil exhumed wood continues to show that crossdating is viable for intervals over the last 3000 years, building on the tree-ring work of Lyon (2007) at Geikie Inlet. The dendrochronological analysis of new wood sections and crossdating of samples date to the first millennium AD based on crossdating the living tree-ring records with subfossil tree-ring samples from Glacier Bay with other records from the Gulf of Alaska. This combination of Glacier Bay tree-ring series with a regional tree-ring master chronology for the Gulf of Alaska extends the record back tentatively into the second century AD (Figure 10)

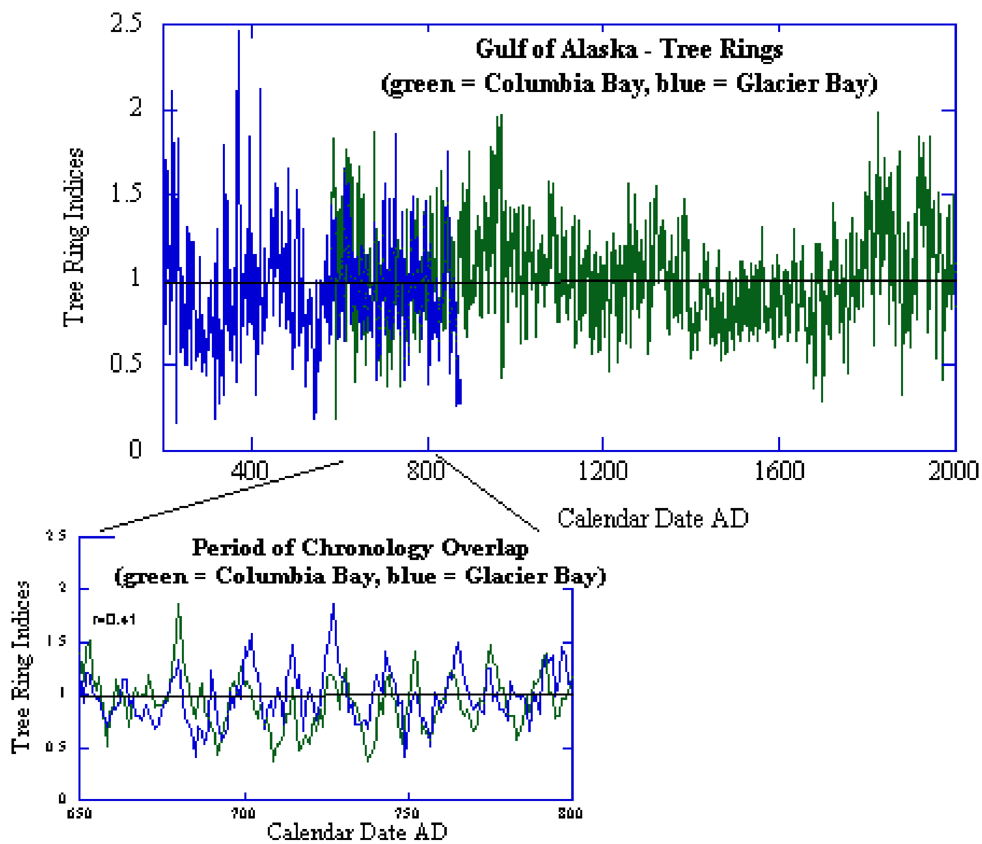


***Figure 10.*** *Tree-ring dating of the Glacier Bay samples. The green curve is a ring-width record composite from logs in Columbia Bay, Prince William Sound. The inset shows graphically the matching ring-width variations from the Glacier Bay chronology and the Prince William Sound record.*

Samples to further replicate this interval are in-hand, sampled from Geikie Inlet during the 2007 field season as well as Adams Inlet based on previous radiocarbon dating results. Additionally radiocarbon ages obtained on logs with two floating ring-width series suggest that the two series are equivalent in age to the 3000 yr. BP series and their integration into this series is underway.

In addition to building on the work cited above, we worked on the geological analysis and sampling of glacial stratigraphic sections, as well as collecting subfossil wood at known sites in order to calendar date ice advances during the past 3000 years (Figure 11). Wood samples from Berg Bay, Ripple Cove, North Lester Island, Kidney Island and Bartlett Cove were sampled from new sites to gain data on ice advance during the First Millennium AD. Several new exposures of stumps and partly buried logs were discovered, including those in Berg Bay, the Beardslee Islands and Ripple Cove, which appear to be of LIA or First Millennium AD age. They are important finds for precisely defining the calendar dates of glacial advance into the lower bay. They are currently in the CRREL laboratory being prepared for ring-width analyses.


*Figure 11. Sites examined for interstadial wood in summer 2007.*

At North Fingers, Reid Glacier, south Charpentier valley and Wachusett Inlet, emphasis was placed on obtaining samples from within glacial sedimentary deposits and from in situ stumps in growth position beneath the glacial sediments. These sequences are important to understanding the history of ice advance and retreat. In particular the sedimentary sequence in the Upper Wachusett Inlet area was not exposed until recently, and appears to have a long record with multiple glacial deposits recording several ice advance and retreat cycles. A peat horizon lying directly on bedrock and overlain by a till may correlate with a similar sequence at Reid Glacier where it was previously dated at over 12,000 years BP. This may be one of the sites that will provide data critical to unraveling the glacial history in the East Arm. Additional radiocarbon age dates on two stumps in lower Muir Inlet and will provide an estimate of the death date when tree was killed by the glacier overrunning the North Fingers and Wachusett site and thus constrain the glacial history. These sites will be examined in more detail in 2008 based on the several dates to be obtained in the off-season.

| Sample ID | Map location (Figure 8) | Site name | Lat/Long | Description |
|---|---|---|---|---|
| GB07-163-16, 221-222 | 1 | North Fingers | 58’56.969/ 136’23.911 | Sections, 14C |
| GB07-168-174 | 2 | Charpentier Fan | 58’42.196/ 136’31.774 | Sections, 14C |
| GB07-176 | 3 | Geikie Inlet | 58’60.600/ 136’54.883 | Section, 14C |
| GB07-178-182 | 4 | Stump Point | 58’52.140/ 136’06.674 | Sections, 14C, peat |
| GB07-183-198 | 5 | Wachusett Inlet | 58’95.263/ 136’42.724 | Sections, 14C, peat |
| GB07-199-200 | 6 | White Thunder Ridge | 59’01.760/ 136’10.730 | Sections, 14C |
| GB07-201-202 | 7 | Wolf Cove, south | 58’59.041/ 136’01.074 | Sections, 14C |
| GB07-203, 232-233 | 8 | S. Lester Island | 58’46.576/ 135’89.584 | Sections, 14C, peat |
| GB07-204-206 | 9 | E. Bartlett Cove | 58’44.796/ 135’89.825 | Sections, 14C |
| GB07-207-211 | 10 | Beardslee Islands | 58’50.991/ 135’90.234 | Sections, 14C, peat |
| GB07-212 | 11 | Ripple Cove | 58’44.703/ 136’08.679 | Section, 14C |
| GB07-213-217 | 12 | Adams Inlet-Granite Valley Fan | 58’91.073/ 135’81.422 | Sections, 14C |
| GB07-218-220 | 13 | Adams Inlet – Fan WNW of Mt. Case | 58’86.096/ 135’93.361 | Sections, 14C |
| GB07-225-227 | 14 | Reid Glacier, east lateral moraine | 58’84.611/ 136’80.018 | Peat, wood fragments, 14C |
| GB07230-231 | 15 | Intertidal south of Ripple Cove | 58’42.484/ 136’06.111 | Sections, 14C |

***Table 2.*** *Sample identification, location, and type. Samples are drying in the CRREL laboratory and processing of select groups of samples from the lower bay area has begun.*

**Future Work**

To accomplish the long-term goal of assembling a multi-millennial tree-ring series for Glacier Bay, we need to continue to collect interstadial wood from in situ stumps and logs. We have made significant progress toward this continuing primary objective to collect these sections of ancient trees overridden by the glaciers during the Holocene excursions across Glacier Bay before they are lost to erosion and decay. Yet gaps and limited numbers of samples of certain age ranges remain. With the extensive radiocarbon data set that has been assembled across the Park, we can target wood of the correct age to fill most of those gaps in the tree-ring record and to increase the sample size. We will also need to search new areas but this existing data does allow us to continue working in the laboratory simultaneously with field work and advance toward ultimately meeting our research objectives. The glacial cycles of the Park since the Late Glacial Maximum (LGM) that ended here about 14,000 years ago requires further delineation through analysis of glacial deposits in concert with radiocarbon and tree-ring dating in order to establish how glaciers responded to changes in the temperature and related climatic forcings. This correlation will be another major outcome of our research, one to our knowledge that has not been possible elsewhere for the Holocene period within the Northern Hemisphere.

Based on the existing collections, the distribution of AMS ages and number of rings in the logs, we anticipate that four years of additional collecting will be needed to assemble a long record. We anticipate three years of intensive sampling to cut sections of logs and stumps and the remainder to focus on filling difficult time periods with less than optimum sample quality or number.

We will target time intervals in our quest to assemble the long tree-ring series for the Holocene. Our work will attempt to complete the Little Ice Age interval and its intriguing link to the Tlingit legend. Secondly, we continue to strive to date well the glacial changes that took place within the last three millennia where there are limited stratigraphic sections, and interstadial wood for tree-ring analyses has been difficult to locate. Our initial data from the first millennium AD requires some replicating to be certain of the climate signal through this interval. Mapping the extent of glacial cycles during this time has been equally challenging. Based on this year’s sampling, we now have a significant number of sections for logs dating to the 4$^{th}$ millennium BP which we will combine with ongoing analyses of the third millennium analyses and extend the tree-ring width chronology through this time interval. Our quest in the field is targeting sample sites for interstadial trees in the 5000 to 6000 BP period is a new addition to this work. Other intervals of interest in the early to mid-Holocene will be targeted as caches of logs are discovered and processed. The extensive radiocarbon-database (>350 ages) will allow us to target logs from times of known abrupt climate changes (ACC), for example during 8,200 yr. BP or 5,200 yr. BP. Such periods of abrupt changes in climate are extremely important to understanding current and possible future climatic changes. Depending on logistics, and lab work done before the 2008 field season, we may choose to investigate one of these time intervals.

**Significance and Products**

Global climate is changing, and humans may have a significant role in affecting those changes. Our knowledge of how the climate system works is hampered by a lack of long-term records, which are needed to demonstrate the full range of natural variability of the climate system, especially on annual to century time scales. As contemporary warming progresses, major changes in the cryosphere and biosphere are being observed especially in the higher latitudes. It is with this need in mind that we are conducting research on the paleoclimate of Glacier Bay, a climatically-sensitive region of the North Pacific. Our research involves analysis of the climatically-driven glacial fluctuations during the Holocene, and linking this record to a unique, potentially -10,000-year long tree-ring chronology of high-latitude climatic information derived from ancient wood of trees overridden by successive ice advances. The record of glacial activity in the Park is also unique; other parts of the Gulf of Alaska as well as neighboring British Columbia have few well-defined records of glacial activity beyond 3000 years ago. Yet here, our initial data suggest that at least 6 cycles of glacial advance and recession have occurred within the last 9000 years. We have made significant progress toward our continuing primary objective to collect sections of ancient trees overridden by the glaciers during the Holocene excursions across Glacier Bay before they are lost to erosion and decay.
Our work on the tree ring series to date has produced a significantly longer record than that available elsewhere in the Gulf of Alaska region, extending the paleo-record back more than a 1000 years so far. Once completed the 10000 year record will be the longest, high latitude calendar-dated record of past climate from North America.

The primary significance of this research is thus the development and analysis of a millennia-scale tree-ring record for Glacier Bay National Park and Preserve and defining its relationship to global and regional changes in climate and the resulting periods of glacial advance and retreat. The combined records of climate change are a unique and important contribution to understanding the past and current changes in climate of Glacier Bay and thereby providing a basis for managing and adapting the Park to future climatic change.

Based on our initial and ongoing analyses, this chronology of paleoclimate has the potential of being one of the longest tree-ring records in the world. The temperature proxy record already suggests that an interval during the First Millennium AD may have been as cold as the better studied Little Ice Age, a significantly new finding. Knowledge of the paleotemperature trends during the advance and retreat cycles of the glacial systems will allow us to examine how they relate to the decadal and millennial scale variability in climate and the factors causing those changes. Ultimately it will/ be a major contribution to .larger – scale efforts to reconstruct climate variability for the Northern Hemisphere (D'Arrigo et al., 2005; Mann and Jones, 2003; Moberg, et al., 2005). The paleo records of climate and glacier response will be the only paleoclimatic data spanning the periods of abrupt (decadal) climatic changes of the Holocene, a scenario that recent research indicates could cause extreme societal and environmental disruptions were such events to happen today.

We will continue to present the preliminary and ultimately final results of our research at national and international meetings on climate change, past and present. We will also publish our research results within prestigious professional journals as they are obtained, and provide the Park with Annual Summaries of our research activities and results. In addition, our data will continue to be archived on the Glacier Bay network server and be contributed to the International Tree-Ring Data Bank, maintained by NOAA in Boulder.

**Collaborators and synergistic activities**

Over the past year we have collaborated with other researchers working in Glacier Bay. Using our Beartrack and Excursion Ridge ring-width chronologies, Brian Luckman (University of Western Ontario), Danny Capps and John Clague (both at Simon Fraser University) were successful in tree-ring dating the killing of a forest at Brady Glacier. Rosanne D'Arrigo (Lamont-Doherty Earth Observatory, Tree Ring Lab) and Rob Wilson (University of Edinburgh) are serving as advisors on the project and will be involved with us in modeling the dendroclimatic record.

We also provided wood sampled from the lower bay area for dating and inclusion in the LIA glacial and Tlingit history analyses of Streveler, Connor, Howell and Montieth. Chris Fastie (Middlebury) and Roman Motyka (UAF) have generously shared their ring-width data from sites within Glacier Bay and Icy Strait which we will compare with our results. We are currently writing a NSF proposal with R. D'Arrigo (Lamont) to fund the continuing field and laboratory work.

We presented two talks in 2007 at the Park visitor center auditorium, and held multiple discussions about our research and its implications with the seasonal and permanent interpreters and naturalists. We made ourselves available whenever possible to answer staff questions and those of Park visitors.

We also worked with many volunteers from the seasonal and permanent staff of the park, each traveling into the field with us to engage them in our field work, providing a better understanding of our research and its significance and hopefully providing a background useful to their work. We are extremely grateful of course for the assistance they provided!

In addition to the undergraduate students doing their theses, several high school and college undergraduate students assisted us in the field this past summer. We hope to engage a high school science teacher next season through the PolarTrec program.

**Completed and Current Theses**

Lyon, E., 2007, "Progress towards the development of a multi-millennial tree-ring chronology, Glacier Bay National Park and Preserve, Alaska", unpublished thesis, Department of Geology, The College of Wooster.

Malcomb, N., 2007, "Using tree-ring time series from the Gulf of Alaska to model mass balance from the Northeast Pacific Rim", unpublished thesis, Department of Geology, The College of Wooster (manuscript submitted to *The Holocene*)

Trutko, A., in progress, “Development and climatic analysis of the Bear Track and Excursion Ridge Ring Width Series, Glacier Bay National Park and Preserve, Alaska”, unpublished thesis, Department of Geology, The College of Wooster.

Erlanger, E., in progress, “Reconstructing Sitka, Alaska temperature change for the last 450 years using tree rings, unpublished thesis, Department of Geology, Union College.

Plourde, A., in progress, “Using North Pacific tree ring chronologies to reconstruct Laurentian Great Lakes levels over the past several hundred years”, unpublished thesis, Department of Geology, Colorado College.

Laxton, S., in progress, "Manifestation of the ~5 ka rapid climate change event in Glacier Bay, Alaska: interpreting a dendro-glaciologic record", Department of Geology, University of Cincinnati, Ohio.

**Acknowledgements**

This project has been funded in part by the Keck Geology Consortium, The National Geographic Society, US Army Cold Regions Research and Engineering Lab, National Science Foundation, Rockefeller Center for Public Policy and the Social Sciences, Institute of Arctic Studies at Dartmouth College, College of Wooster and various grants to students for laboratory and field assistance. We are extremely grateful to the current and past staff and management of Glacier Bay National Park and Preserve for their logistical support, assistance and encouragement, and importantly a vessel and crew for field work, office space, housing and other logistical support. We particularly would like to thank Tomie Lee, Former Superintendent, Susan Boudreau, Former Chief Resource Management, and Lewis Sharman, Ecologist, for their permission and encouragement to conduct the research, and in providing the continuing support of their staff and vessels, housing, office space and other facilities, and to Justin Smith, Captain of the RV Capelin and Deb Johnson, Captain of the RV Sigma T, for the safe transport in the field and their assistance and many stimulating discussions of our research.

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# Appendix A
# Sample Status

The following list includes the sections now being processed at the Wooster and Cincinnati Tree-Ring Labs. Results from the cores of living trees are included in the text. Samples at CRREL have been listed previously on a DVD sent to Bill Eichenlaub; an updated spreadsheet will be provided separately.

| Log Inventory (Wooster) | | Radiocarbon Dates | | Status (dendrochronology.) | AD range |
|---|---|---|---|---|---|
| *GB97/98 sections* | | | | | |
| | | | | | |
| GB97 301-02 | | | | | |
| GB97 448-03 | | 1270 +/- 40 | | cal | 486-708 |
| GB97 621-02(x2) | | 1330 +/- 30 | | | |
| GB97-627-02 | | 1300+/- 50 | | cal | 580-847 |
| GB97-628-02 | | 1260 +/- 40 | | cal | 592-843 |
| GB97-640-03 | | 1270 +/- 40 | | | |
| GB98-170-03 | | 1280 +/- 50 | | cal | 559-724 |
| | | | | | |
| | | | | | |
| *GB05 Sections* | | | | | |
| GB05-45-02 | | | | cal | 618-862 |
| GB05-47-02 | | | | | |
| GB05-48-02 | | | | cal | 558-848 |
| GB05-49-02 | | | | | |
| GB05-50-02 | | | | | |
| GB05-54-02 | | | | cal | 571-874 |
| GB05-56-02 | | | | | |
| GB05-57-02 | | 1490+/-50 | | fl(a) | 193 |
| GB05-58-02 | | 3060+/-50 | | | |
| GB05-59-02 | | | | fl(a) | 287 |
| GB05-60-02 | | | | fl(a) | 102 |
| GB05-61-02 | | | | | |
| | | | | | |
| *GB06 Sections* | | | | | |
| GB06-37-02 | | | | | |
| GB06-38-02 | | | | | |
| GB06-40-02 | | | | | |
| GB06-41-02 | | | | | |
| GB06-42-02 | | | | | |
| GB06-43-02 | | | | fl(x) | 125 |
| GB06-44-02 | | | | | |
| GB06-53-02(A*) | | | | fl(x) | 261 |
| GB06-53-02(B*) | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| GB06-55-02 | | | | cal | 484-863 |
| GB06-97-02 | | | | | |
| GB06-100-02 | | Beta-218881<br>2930+/-50 | | fl(b) | 231 |
| GB06-101-02 | | pending | | fl(b) | 244 |
| GB06-102-02 | | | | | |
| | | | | | |
| *Geikie Cores* | | | | | |
| (sampled in 06) | | | | | |
| GB0645-B | | | | fl(b) | 286 |
| GB0645-C | | | | fl(b) | 198 |
| GB0645-D | | | | fl(b) | 231 |
| GB0645-E | | | | fl(b) | 252 |
| GB0645-F | | | | fl(b) | |
| GB0645-G | | | | fl(b) | 133 |
| GB0645-H | | | | | 271 |
| | | | | | |
| *Logs to Cincinnati* | - | - | - | - | - |
| Sampled in 07 | | | | | |
| GB07-41 | | | | | |
| GB07-42 | | | | | |
| GB07-43 | | | | | |
| GB07-44 | | | | | |
| GB07-45 | | | | | |
| GB07-46 | | | | | |
| GB07-47 | | | | | |
| GB07-49 | | | | | |
| GB07-50 | | | | | |
| GB07-51 | | | | | |
| GB07-53 | | | | | |
| | | | | | |
| *Logs from North Fingers* | | - | - | - | - |
| Sampled in 07 | | | | | |
| GB07-163 | | | | | |
| GB07-165 | | | | | |
| GB07-166 | | | | | |
| GB07-167 | | | | | |
| | | | | | |
| *Logs of LIA Advance* | | - | - | - | - |
| Sampled in 05 | | | | | |
| GB05-09 | | | | cal | 1570-1724 |
| GB05-24 | | | | | |
| GB05-26 | | | | cal | 1465-1704 |
| GB05-28 | | | | cal | 1601-1723 |
| GB05-30 | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| GB05-33 | | | | cal | 1568-1723 |
| GB05-34 | | | | cal | 1555-1735 |
| GB05-37 | | | | | |
| Sampled in 07 | | | | | |
| GB07-203 | | | | | |
| GB07-204 | | | | cal | 1636-1707 |
| GB07-206 | | | | cal | 1631-1708 |
| GB07-212 | | | | | |