Assessing the Sensitivity of Alaska's Coastal Rainforest Ecosystem to Changes in Glacier Runoff

Eran Hood and Sanjay Pyare

Environmental Science and Geography Program
University of Alaska Southeast, Juneau, AK, 99801

1. Background and Need

Coastal temperate rainforests watersheds along the Gulf of Alaska (GOA) are experiencing some of the highest rates of glacier volume loss on earth (Arendt et al., 2002; Berthier et al., 2010). Glaciers currently cover 18% of the land area that drains to the GOA and runoff from glaciers accounts for about half of the land-to-ocean flux of freshwater into the GOA (Neal et al., 2010). Understanding the climate-induced vulnerability of this freshwater flux is critical considering that the changes expected from glacier runoff are much larger than those projected for other components of the water cycle (IPCC, 2007). Moreover, the North Pacific Landscape Conservation Cooperative (NPLCC) has recognized the importance of understanding changes in terrestrial snow and ice cover, its effects on freshwater discharge, and ways in which this drives highly productive nearshore marine ecosystems. These research priorities are aligned with those of the North Pacific Research Board (NPRB), which has focused on improving understanding of the coupling between nearshore waters of the Alaska Coastal Current and the influx freshwater from terrestrial sources.

At a landscape level, changes in glacier runoff shift the timing and volume of freshwater and nutrients delivered from coastal temperate rainforests to the eastern North Pacific Ocean, thereby altering both aquatic and terrestrial habitats. For example, runoff from glaciers has pronounced impacts on the physical properties of aquatic habitats such as water temperature and clarity (Hood and Berner, 2008), which are both critical parameters in salmon spawning (Lorenz and Eiler, 1989; Milner and Bailey, 1989; Dorava and Milner, 2000). Runoff from glaciers is also biogeochemically distinct compared to runoff from other terrestrial ecosystems and can strongly influence fluxes of limiting nutrients (Phosphorus), micronutrients (Iron), and bioavailable organic carbon delivered to near-shore marine ecosystems (Hood and Scott, 2008; Hood et al., 2009; Crusius et al., 2011). Recent studies suggest that micro-and macro-nutrients in glacier runoff play an important role in marine productivity along the GOA (Schroth et al., 2009; Fellman et al., 2010). This project will introduce a comprehensive framework for modeling changes in glacier runoff and associated changes in biogeochemical fluxes on a regional scale.

The results of our efforts will have broad societal impacts along the Gulf of Alaska. Runoff from glaciers along the GOA, which exceeds the annual discharge of the Mississippi River, is an important control of the structure of the freshwater-driven Alaska Coastal Current (ACC). The ACC, in turn, sustains multi-million dollar commercial fisheries, subsistence fisheries, and millions of coastal marine birds and mammals. In this context, our findings will directly improve management of near-shore marine ecosystems along the GOA by providing information about future changes in glacier runoff. Glacier-related flooding and erosion also affect many Alaska Native villages, and Alaska has significant data gaps in this area making it difficult to assess the severity of the problem or make informed management decisions (GAO, 2003). Our findings will begin to fill that gap, providing information to reduce uncertainty geomorphic hazards such as glacial mudflow and outburst flood events in coastal watersheds. Changes in Alaska's glacier runoff also have the potential to significantly impact the availability of hydropower resources in southcentral and southeast Alaska (Cherry et al., 2010), particularly in light of the increased generation potential associated with glacier mass loss. Thus improving future predictions of glacier discharge will inform present and future efforts to sustain and develop hydropower resources in the North Pacific region. Finally, the changes volume of Alaska glaciers and their contribution to rising sea level is similar to losses from the great ice sheets of Antarctica and Greenland (Meier et al, 2007; Bamber et al, 2010; Wu et al., 2010). While these losses do not have a direct effect on the Gulf of Alaska region due to isostatic and tectonic adjustments, other coastal communities will be affected. Therefore a robust understanding of Alaska glacier mass budget is of paramount importance to Earth's coastal population.

2. Objectives

The overall objective of our work is to quantify the regional effects of climate changes on the timing, quantity and distribution of glacier runoff to the Gulf of Alaska. Our study will provide a framework for mapping present and projecting future effects of changes in glacier runoff on Gulf of Alaska ecosystems. The project will be structured around a detailed conceptual system model that will provide managers with a wide range of decision support tools to inform resource conservation efforts. In particular, we will identify key areas that are particularly sensitive to future changes in glacier volume loss and increased freshwater discharge.
Within this framework we will address the following science objectives from the call:

1. *Identify and quantify the major sources of freshwater runoff to the GOA;*
2. *Develop methods to upscale point measurements to be regionally representative;*
3. *Determine what proportion of glacier runoff is derived from a loss of glacier volume versus a melting of the seasonal snowpack;*
4. *Determine what proportion of glacier changes are driven by climatic versus dynamic physical processes;*
5. *Identify key sensitivities in physical and biogeochemical processes to the stability of the freshwater cycle;*
6. *Assess what parameters are likely to control the future evolution of glacier discharge to the GOA.*

This science framework will fill important information gaps about the links between climate change and hydrology along the North Pacific coast and will ultimately provide valuable information for subsistence and commercial fisheries management, hydropower development, and glacier hazard mitigation.

3. Methods

Our proposed work will be divided into two Phases. During Phase I we will build a conceptual framework that will provide a basis for quantifying changes in glacier runoff within watersheds along the GOA. Our first step will be to assemble any and all available direct field observations, remote sensing datasets, stream gauging and meteorological data, and glacier inventory data to determine the appropriate spatial and temporal scales over which to conduct a detailed regional analysis during phase II (Fig. 1). Detailed methodologies will be developed to allow partitioning between glacier runoff components derived from changes in glacier storage (volume change) versus seasonal runoff, as well as climate and internal dynamics as modulating forces of glacier mass balance. Understanding the sensitivity of these processes to small changes is extremely important, and we will delineate methods to evaluate sensitivities and effects of runoff changes on aquatic habitat and riverine biogeochemical fluxes in the North Pacific coastal rainforest ecoregion. During Phase I we will also work to stabilize and maintain glacier freshwater discharge monitoring networks in the Gulf of Alaska that are key resources for our ongoing research activities and identify the largest gaps in process constraints to address in Phase II.

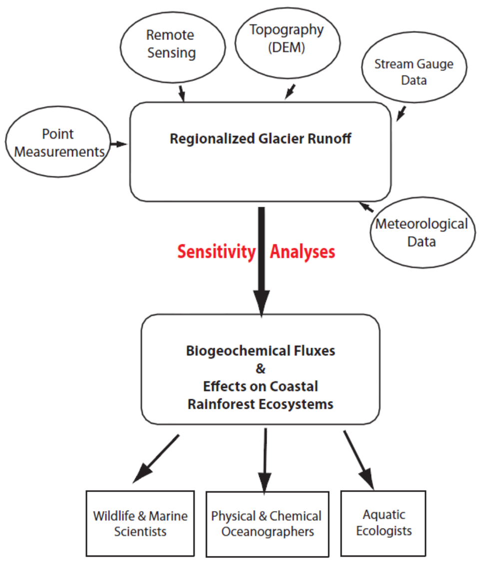

Figure 1: Flowchart of conceptual system model to assess effects of changes in glacier-derived runoff on coastal and rainforest ecosystems of the Gulf of Alaska.

Several processes and systems are known to present large-scale knowledge and data gaps. Our conceptual model will combine data across disciplines, giving us greater opportunities to assess factors including but not limited to: 1) methods for upscaling point measurements to regional estimates; 2) uncertainty in runoff from ungauged streams; 3) oceanic controls on glacier health; 4) strong feedbacks between physical, geochemical and biological systems; 5) the sensitivity of glacier surface mass balance to radiative and thermal forcings; and 6) the routing of glacial meltwater and the lag time for its delivery to river systems.

Phase II activities will involve expansion of research activities, model development and monitoring networks. Although Phase II goals will not be supported under the current proposal, they will guide Phase I activities so that at the end of the project, a foundation will be in place upon which broader resource management and research activities can be supported.

4. Leveraging

An extensive leveraging network will be utilized to complete the proposed work. Our group and collaborators have access to rich datasets that can be used to support the model development and extrapolation efforts, including satellite gravimetry data (Arendt, UAF), altimetry data collected as part of NASA's Operation Ice Bridge Alaska (PI Larsen, UAF), glacier surface velocity maps determined from SAR interferometry (PI Braun, UAF), regional glacier mass balance simulations using degree-day modeling (PI Hock, UAF), detailed information about glacial biogeochemical (Carbon, Nitrogen, and Phosphorus) fluxes (Hood), estimates of GOA watershed discharge using statistical extrapolation tools (PI Hill, OSU), a quantified evolution of Columbia Glacier's Retreat (Pfeffer, O'Neel), 4 high altitude weather stations in the coastal mountains (CRREL), the USGS benchmark glacier data set and mass balance data collected at Mendenhall Glacier (Hood) since the mid- 1990s. UAF is also developing strong ties to Alaska state hazard assessment programs and will be co-sponsoring a graduate student thesis project aimed at modeling glacier runoff for a specific GOA watershed.

5. Geographic Extent

The spatial extent of our proposed research covers the northern portion of the NPLCC, however our findings will provide a framework for evaluating future changes in the hydrology and biogeochemistry of glacier-dominated ecosystems throughout the full range of the NPLCC. Development of our conceptual model will specifically target the coastal mountain ranges extending from southeast Alaska to Anchorage. This includes the Kenai Mountains, Chugach Range, St. Elias Mountains, and the Coast ranges, which include the Stikine and Juneau Icefields. Our data integration and modeling framework will incorporate field measurements from Columbia, Wolverine and Mendenhall Glaciers, including accumulation and melt rates as well as meteorological parameters.

6. Timeline

Start date: July 1, 2011

Duration: 1 year

July-Sept., 2011	Data stabilization efforts (Mendenhall, Columbia Glaciers, weather stations)
Summer, Fall 2011	Data assembly, student training
Oct. - Nov. 2011	PI meeting in Juneau (1 week), Development of modeling framework
Winter 2011-12	Begin report preparation.
Spring 2012	Finalize report, Prepare phase 2 proposal.

7. Outreach and Education

Each of us has extensive outreach experience, having appeared in television documentaries, designed visitor center interpretive displays and dealt with popular media. Model products and project findings will be made available to agencies and the public through the southeast Alaska GIS library (http://seakgis.alaska.edu/), which is run by Pyare, and the Geographic Information Network of Alaska (http://www.gina.alaska.edu/). The project will include training and education opportunities for undergraduate research assistants working with Hood and Pyare at UAS. We will also conduct outreach about our project through the newly formed Alaska Coastal Rainforest Center, which is housed at UAS and was co-founded by Pyare. Finally, we will design an interpretive display highlighting key project findings for the Mendenhall Glacier Visitor Center in Juneau, which is visited by more than 300,000 people each year.

8. Qualifications and Scope of Work

Dr. Eran Hood is an Associate Professor in the Environmental Science Program at the University of Alaska Southeast and a member of the Pacific Northwest and North & West Alaska CESUs. Dr. Hood has extensive experience in the use of field measurements and models to quantify hydrological and biogeochemical fluxes in glacial watersheds along the Gulf of Alaska. He has worked collaboratively on interdisciplinary research teams involving academic institutions and federal research agencies and has previously received funding from the US Geological Survey and the National Science Foundation for his research in Alaska. Sanjay Pyare is an Associate Professor in Environmental Science & Geography at the University of Alaska Southeast. His focus is geospatial analysis and modeling across a wide variety of systems and disciplines, with specialties in ecosystem change, biogeography, and increasingly, climate science. He also coordinates the UAS Spatial Ecosystem Analysis Lab (SEALAB), a node of the UA-GINA program, facilitates a multiagency partnership to steward regional geospatial data through the Southeast Alaska Geospatial Library, and provides instructional and research-mentoring support to undergraduates in the geospatial sciences at UAS.

Hood and Pyare will both contribute to the design of a regional modeling framework for estimating current and future glacier discharge along the Gulf of Alaska. Hood will be responsible for integrating glaciological and hydrological data and for designing an approach to use existing hydrologic datasets to validate estimates of glacier runoff. In addition, he will be responsible for developing a framework for modeling riverine biogeochemical (C, N, and P) fluxes associated with estimates of glacial runoff. Pyare will be responsible geospatial aspects of the project and model development including: a) Working with the group to identify the geospatial data requirements for quantifying and modeling glacier runoff contributions, b) Investigating, collating, standardizing, and addressing uncertainties in physiographical, hydrographical, and climatological geospatial-data sources, c) Developing an analytical geospatial template for regional up-scaling and quantification of potential future investigations of glacier runoff contributions, streamflow, and hydrological parameters, and d) Developing preliminary spatial data infrastructure to steward, disseminate and exchange geospatial data and related modeling products.

9. Deliverables

The primary product of Phase I of this project is to take inventory of available data relevant to the GOA freshwater budget and prepare a detailed conceptual framework for quantifying glacier-related processes and terms in this budget. Our efforts will not only assess the available inputs to a large scale modeling effort, but will also delineate in detail the appropriate methods for performing such a task. The results of this interdisciplinary effort will be disseminated in three primary fashions including: 1) a co-written USGS report and/or academic publication by all four PIs; 2) presentations at USGS and academic meetings; and 3) outreach activities including but not limited to the Mendenhall Glacier Visitor Center.

10. References

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Berthier, E., E. Schiefer, G. K. C. Clarke, B. Menounos, F. Rémy, (2010) Contribution of Alaskan glaciers to sea-level rise derived from satellite imagery, *Nature Geosci.* 3, 92-95.

Fellman, J.**,** R.G.M. Spencer, R.Edwards, D. D'Amore, P.J. Hernes, and E. Hood (2010) The impact of glacier runoff on the biodegradability and biochemical composition of terrigenous dissolved organic matter in near-shore marine ecosystems, *Marine Chemistry* 121: 112-122, doi:10.1016/j.marchem.2010.03.009.

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Hood, E., and L. Berner (2009) Effects of changing glacial coverage on the physical and biogeochemical properties of coastal streams in southeastern Alaska, *J. Geophys. Res.,* 114, G03001, doi:10.1029/2009JG000971.

Hood, E. and D. T. Scott (2008) Riverine organic matter and nutrients in southeast Alaska affected by glacial coverage, *Nature Geoscience* 1: 583-587, doi:10.1038/ngeo280.

Crusius,J., A.W. Schroth, S. Gassó, C.M. Moy, R.C. Levy, M. Gatica (2011), Glacial flour dust storms in the Gulf of Alaska: Hydrologic and meteorological controls and their importance as a source of bioavailable iron, *Geophys. Res. Lttrs.,* 38, L06602, doi:10.1029/2010GL046573.

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Meier, M. F. and nine others (2007). Glaciers dominate eustatic sea-level rise in the 21st century. Science 17, 1064-1067.

Milner, A.M. and R.G. Bailey (1989) Salmonid colonization of new streams in Glacier Bay National Park, Alaska. Aquaculture Research 20, 179-192.

Neal, E.G., E. Hood, and K.Smikrud (2010) Contribution of glacier runoff to freshwater discharge into the Gulf of Alaska. *Geophys. Res. Let.*, 37: L06404, doi:10.1029/2010GL042385.

Schroth, A.W, J. Crusius, E.R. Sholkovitz, and B.C. Bostick (2009) Iron solubility driven by speciation in dust sources to the ocean. Nature Geoscience 2, 337 – 340.

11. Biographical Sketches

Eran Hood
Associate Professor of Environmental Science
Phone: (907) 796-6244
Fax: (907) 796-6406

University of Alaska Southeast
Natural Science Department
Juneau, AK, 99801
Email: eran.hood@uas.alaska.edu

Education:

Ph.D.	2001	University of Colorado, Boulder	Geography (Hydrology and Biogeochemistry)
M.A.	1997	University of Colorado, Boulder	Geography (Snow Hydrology and Climatology)
B.A.	1991	Harvard University (Biology)	

Professional Background:

2010-present	**Department Chair** University of Alaska Southeast, Natural Science Department
2008-present	**Associate Professor of Environmental Science** University of Alaska Southeast, Natural Science Department
2004-present	**Affiliate Professor of Environmental Science** University of Alaska Fairbanks, Civil and Environ. Engineering Dept.
2002-2008	**Assistant Professor of Environmental Science** University of Alaska Southeast, Natural Science Department
2002	**Postdoctoral Researcher**, LTER DON inter-site comparison project, University of Colorado

Publications (five most relevant):

Petrone, K.C., J.B. Fellman, **E. Hood**, M.J. Donn, and P. Grierson (2011) The origin and function of dissolved organic matter in agro-urban coastal streams, *J. Geophys. Res.*, doi:10.1029/2010JG001537, in press.

Neal, E.G., **E. Hood**, and K.Smikrud (2010) Contribution of glacier runoff to freshwater discharge into the Gulf of Alaska. *Geophys. Res. Let.*, 37, L06404, doi:10.1029/2010GL042385.

Hood, E., J. Fellman, R.G.M. Spencer, R.Edwards, D. D'Amore, P.J. Hernes, and D. Scott (2009) Glaciers as a source of ancient and labile organic matter to the marine environment. *Nature* 462: 1044-1048, doi:10.1038/nature08580.

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Hood, E. and D. T. Scott (2008) Riverine organic matter and nutrients in southeast Alaska affected by glacial coverage. *Nature Geoscience* 1: 583-587, doi:10.1038/ngeo280.

Five Other Relevant Publications

Fellman, J., **E. Hood**, and R.G.M. Spencer (2010) Fluorescence spectroscopy opens new windows into dissolved organic matter dynamics in freshwater ecosystems: A review. *Limnology and Oceanography*, 55: 2452-2462, doi:10.4319/lo.2010.55.6.2452

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organic matter in near-shore marine ecosystems, *Marine Chemistry*, doi:10.1016/j.marchem.2010.03.009.

Fellman, J., **E. Hood**, R. Edwards, and J.B. Jones (2009) Uptake of allochthonous dissolved organic matter from soil and salmon in coastal temperate rainforest streams. *Ecosystems*, doi:10:1007/s10021-009-9254-4.

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Hood, E., J. Fellman, and R.T. Edwards (2007) Salmon influences on dissolved organic matter in a coastal temperate brownwater stream: An application of fluorescence spectroscopy. *Limnol. Oceanogr.* 52: 1580-1587.

Synergistic Activities

Associate Editor, *Biogeochemistry,* 2007-present

Hydrology/Glaciology Instructor for *Alaska Marine Highway* and *US Forest Service Mendenhall Glacier Visitor Center* Naturalists, Juneau, Alaska 2005-present.

Science Fair Mentor/Judge, *Juneau/Douglas High School* 2004-present

Undergraduate Student Mentor: *National Science Foundation* Research Experience for Undergraduates (REU) Program and *University of Alaska EPSCoR* Undergraduate Research Program (9 Students total, summers 2005-2009).

Board of Directors, *American Water Resources Association*, Alaska Chapter, 2008-2010.

Member, *City and Borough of Juneau Mayor's Panel on Climate Change*, 2006.

Advisor, *City and Borough of Juneau (CBJ) Avalanche Control Program*. Maintain and operate a remote, real-time snow/climate monitoring station at the CBJ Eaglecrest Ski Area.

Ad-hoc NSF proposal reviewer: Hydrologic Sciences, Ecosystem Science, and Arctic Biology.

Scientific Collaborators:

Anthony Arendt (UAF Geophysical Institute)
David D'Amore (PNW Forestry Science Lab)
Cory Cleveland (Univ. Montana)
Richard Edwards (PNW Forestry Science Lab)
Scott Gende (NPS Juneau)
Mike Gooseff (Penn State)
Matthew Heavner (Los Alamos National Lab)
Peter Hernes (UC Davis)
Regine Hock (Univ. of Alaska Fairbanks)
Diane McKnight (Univ. Colorado Boulder)
Amy Miller (NPS Anchorage)
Sonia Nagorski (Univ. Alaska Southeast)
Diana Nemergut (Univ. Colorado Boulder)
Shad O'Neel (USGS Alaska Science Center)
Peter Raymond (Yale)
Durelle Scott (Virginia Tech)
Robert Spencer (Woods Hold Research Center)
Aron Stubbins (Skidaway Institute of Ocean.)
Mark Williams (Univ. Colorado Boulder)
Kevin White (AK Dept of Fish and Game)

Graduate Advisees:

Jason Fellman (Univ. of Alaska Fairbanks)	PhD	2005-2009
Jonathan O'Donnell (Univ. of Alaska Fairbanks)	PhD	2007-2010
Mike Nassry (Virginia Tech)	PhD	2009-present

Postdocs:

Andrew Vermilyea (University of Alaska Southeast) 2009-present

Graduate and Postdoctoral Advisor:

Mark Williams University of Colorado Boulder

Sanjay Pyare
11120 Glacier Hwy
University of Alaska Southeast
Juneau AK 99801
907.796.6007
sanjay.pyare@uas.alaska.edu

Professional Preparation:

Hartwick College	Biology B.A., 1992
University of Nevada Reno	Conservation Biology and Ecology Ph.D., 2000
University of Nevada Reno	Endangered Species Recovery Post-Doc., 2001-2004

Appointments:

2005-present	Assistant Professor of Environmental Science and Geography University of Alaska Southeast
2006-present	Affiliate Professor Institute of Arctic Biology & School of Fisheries and Ocean Sciences University of Alaska Fairbanks

Recent and Relevant Publication Activity

Shanley, C.S., **S. Pyare** & G.P. Kofinas. Balancing the conservation of wildlife habitat with subsistence hunting access: a geospatial scenario approach. In review in *Ecology and Society*.

Shanley, C.S., **S. Pyare** & W.P. Smith. Forest-matrix condition shapes habitat selection in a fragmented landscape. In review in *Ecography*.

Moore, J.A., D.A. Tallmon, J. Nielsen& **S. Pyare**. Effects of the landscape on gene flow: does the pattern-process relationship hold true across variable landscape conditions? In review in *Molecular Ecology.*

Breck, S.W., M.I. Goldstein, **S. Pyare** & D. Kellet. 2010. Use of occupancy modeling to monitor occurrence of beavers in the Colorado River Ecosystem. In review in *Ecological Indicators*.

Pyare, S. & W.P. Smith. 2010. Functional connectivity of conservation reserves in temperate rainforest landscapes. In review in *Conservation Biology.*

Gende, S.M., A.N. Hendrix, K.R. Harris, B. Eichenlaub & **S. Pyare.** Identifying the role of ship speed and other factors influencing encounters between humpback whales and cruise ships in Alaska. In press in *Ecological Applications.*

Shanley, C.S. & **S. Pyare**. 2010. Evaluating the road-effect zone on wildlife distribution in a rural landscape. In press in *EcoSphere.*

Smith, W.P., D.K. Person & **S. Pyare**. 2010. Source-sinks, metapopulations, and forest reserves in the temperate rainforests of Southeast Alaska. In: *Sources, Sinks, and Sustainability across Landscapes*, Cambridge University Press, Cambridge, U.K.

Pyare, S., W.P. Smith & C. Shanley. 2010. Den use and selection by northern flying squirrels in fragmented landscapes. *Journal of Mammalogy*. 91:886-896.

Olson, D. & 16 other contributors. 2009. Herpetological conservation in the Pacific Northwest. *Northwestern Naturalist* 90:61-96.

Adams, M.J., S. Galvin, D. Reinitz, R. Cole, **S. Pyare**, M. Hahr & P. Govindarajalu. 2008. Incidence of the fungus, *Batrachochytrium dendrobatidis,* in amphibian populations along the northwest coast North America. *Herpetological Review* 38:430-431.

S.Nagorski, G. Eckert, E. Hood & **S. Pyare**. 2008. Assessment of Coastal Water Resources and Watershed Conditions at Lake Clark National Park and Preserve, Alaska. Natural Resource Technical Report NPS/NRWRD/NRTR- 2008/373.

Pyare, S., S. Cain. D. Moody, C. Schwartz & J. Berger. 2004. Carnivore recolonisation: reality, possibility, and a non-equilibrium century for grizzly bears in the southern Yellowstone ecosystem. *Animal Conservation* 7:1-7.

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Recent and Relevant Funding

- Ecological and Sociocultural Implications of Changes in the Distribution and Abundance of Sockeye Salmon. Alaska EPSCoR. $28,878. 2010-2011.
- Spatial Ecosystem Analysis Lab at UAS. Geographic Information Network of Alaska (GINA). $300,000. 2005-2010.
- Interdisciplinary lab for analysis of ecosystem change. Alaska EPSCoR Integrative Faculty-Development Award. $18,000. 2009-2010.
- Landscape genetics of Glacier Bay brown bears. National Park Service. $40,918. 2010-2012.
- Interactions between cruise ships and humpback whales in Glacier Bay National Park. National Park Foundation.$199,423. 2010-2013.
- Development of a GIS National Hydrography Dataset (NHD) in Alaska. U.S. Geological Survey. $63,572. 2010-2011.
- Southeast Alaska GIS Library, user training module development, and pilot demonstration project. U.S. Fish and Wildlife Service. $79,000. 2008-2011.
- Southeast Alaska GIS Library. U.S. Forest Service Alaska Region. $45,000. 2009-2010.
- The Alaska Gap Analysis Program. U.S. Geological Survey. $1,340,790. 2009-2011.
- Assessment of coastal water resources and watershed conditions in and adjacent to SW Alaska National Parks. National Park Service. $127,920. 2005-2008.
- Monitoring of boreal toads in Southeast Alaska. Alaska Department of Fish and Game Non-Game Program. $70,000. 2005-2006.
- Landscape connectivity of the Tongass old-growth reserve system. Earthwatch Foundation. $29,180. 2005-2006.
- Landscape connectivity of the Tongass old-growth reserve system. U.S. Fish and Wildlife Service. $174,000. 2005- 2008.
- Species-distribution modeling in relation to climate change. Alaska EPSCoR Young Investigator First Award. $48,660. 2006-2007.

Synergistic Activities

- Alaska Coastal Rainforest Center, Affiliate Scientist and Co-founder, 2009-present
- Southeast Alaska Geospatial Library, Chair of Steering Committee, 2007-present
- Spatial Ecosystem Analysis Lab, Coordinator, University of Alaska Southeast, 2005-present
- Southeast Regional Program Leader, Alaska Gap Analysis Project, 2008-present