IGERT: Marine Ecosystem Sustainability in the Arctic and Subarctic (MESAS)

1. List of Participants

1. William Smoker[1] (PI, Leadership Team) – salmon fishery biologist, course instructor, IGERT steering and admission committees
2. Ginny Eckert[1] (Co-PI, Leadership Team) – marine ecologist, course instructor, IGERT steering and admission committees
3. Keith Criddle[1] (Co-PI, Leadership Team) – fisheries economist, course instructor, IGERT steering committee
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9. Nicola Hillgruber[1] – fishery ecologist, course instructor, IGERT admission committee
10. Katrin Iken[2]– marine ecologist, IGERT admission committee
11. Paula Cullenberg[6]– coastal community development specialist, program advisor on AK native and rural student involvement, IGERT steering committee
12. Terry Quinn[1]– fisheries biomathematician, course instructor
13. Rolf Gradinger[2]– sea ice & polar ecologist
14. Brenda Norcross[2]– fisheries oceanographer
15. David Tallmon[1] – evolutionary and population geneticist
16. Ray Barnhardt[7] – cross-cultural anthropologist
17. Russ Hopcroft[2] – biological oceanographer
18. Brenda Konar[8] – marine ecologist
19. Matthew Wooller[2] – chemical oceanographer

Collaborators

1. Gary Kofinas[5,9] – arctic subsistence community specialist - PI/Director of UAF Resilience and Adaptation Program (RAP) IGERT -
2. Stuart C. Chapin III[9,10] – ecosystem ecologist - Co-PI RAP IGERT
3. Craig Gerlach[3] – anthropologist, chemist - Co-PI RAP IGERT
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2. Vision, Goals, and Thematic Basis

Vision and Goals

This interdisciplinary graduate training program in marine ecosystem sustainability in the Arctic and Subarctic (MESAS) will prepare professionals to solve problems arising at the interface between dynamic environmental and social systems. Students will gain a broad background in fishery science, ecology, marine science, marine policy, economics, and anthropology to complement their own specialized expertise acquired through dissertation research and study. These graduates will be well-prepared to contribute to both the understanding and management of marine ecosystems to ensure ecosystem-based strategies for the sustainable use of living marine resources in the context of competing local, national, and international interests. Across the nation, and particularly in Arctic and Subarctic ecosystems, these competing interests demand complex solutions; requiring knowledge not provided in traditional graduate programs. For example, questions demanding answers include: how can scientific information be used in combination with local and traditional knowledge; how can the effects of climate change or fishing and other anthropogenic pressures on biological communities be distinguished; and how can society prioritize natural resources for different uses? The differences between these alternatives are usually indistinct. Resolution of conflicts and approaches to achieve such complex objectives require a multidisciplinary perspective and an interest in fostering collaboration among diverse stakeholders. Alaska is an ideal location to realize this new vision for an ecosystem-based approach to the sustainable use of living marine resources. Here, as elsewhere in the circumpolar north, anthropogenic and naturally-forced changes in climate, oceanography, marine biological communities and ecosystems, fisheries and maritime human communities are already dramatic and will have broad consequences. For instance, Arctic air temperatures have increased at nearly twice the global average rate in the past 100 years (IPCC 2007). While these changes are particularly pronounced in the Arctic and Subarctic, similar forces are changing marine ecosystems throughout the world. Professional scientists educated in Alaska will have excellent preparation for a career in marine ecosystems anywhere in the world.

Our goal is to educate future leaders who will be creative agents for change to develop society's capacity to cope with, manage, and mitigate threats to our nation's oceans, including climate change, fishing pressure, habitat loss, and pollution (Pew Oceans Commission 2003, US Commission on Ocean Policy 2004). This education will necessarily transcend traditional boundaries and sub-disciplines of natural and social sciences, and will require cultural changes in graduate education. Our program ultimately will broaden the scope of marine science and challenge disciplinary gatekeepers. Nationally, a few cross- and inter-disciplinary graduate training programs in ocean research are underway (e.g., UCSD Marine Biodiversity IGERT and URI Assessing Change in Coastal Ecosystems IGERT). Our marine IGERT complements and builds upon the successes of these previous marine IGERTs, but is unique because it directly addresses how an ecosystem approach can inform management of living marine resources in the context of future anticipated changes in economics and climate in high latitude marine ecosystems.

Our proposed marine sustainability IGERT will:

- Stimulate new approaches and solutions to fisheries that simultaneously serve local/subsistence needs and large commercial interests.
- Prepare graduate students to lead future management of marine ecosystems by guiding them through policy formulation and implementation early in their academic careers.
- Foster collaborative research and training across natural and social science disciplines, thereby broadening perspectives of University of Alaska faculty and their professional colleagues.

- Foster interaction between terrestrial and marine scientists working on similar issues through interactions between the Resilience and Adaptation IGERT and this proposed IGERT.

Thematic Basis

Marine ecosystem sustainability is an emerging theme in marine and fishery science, politics, policy, economics, and socio-economics (Browman and Stergiou 2004, Criddle 2004, Pikitch et al. 2004, Browman and Stergiou 2005, Beddington and Kirkwood 2005, Daan et al. 2005, Hughes et al. 2005, Schumacher and Kruse 2005, Marasco et al. 2007). In the northeast Pacific Ocean, as elsewhere, the challenge of implementing an ecosystem-based approach is to move beyond vacuous platitudes and to identify meaningful objectives, concrete management strategies, and explicit performance measures (Francis et al. 2007, Leslie and McLeod 2007, Murawski 2007, Arkema et al. 2006). Historically, fisheries management has compared the status of an exploited fish stock to the well-being of users of that resource but, since the 1990s, new requirements demand a broader scope (FAO 2003) because: (1) the generally poor performance of single-species fishery management worldwide; (2) the heightened awareness of interactions among fisheries and ecosystems; (3) a better understanding of the functional value of ecosystems to humans; and (4) a recognition of the wide range of societal objectives associated with marine fishery resources and ecosystems. The well-being of the users needs to be considered in the context of sustainability, and here traditional and local knowledge can play an important role. There is a growing awareness that commercial fish catches are just one of a broad suite of ecosystem services (Schumacher and Kruse 2005). Fisheries management has been moving slowly toward multispecies and ecosystem approaches, now termed ecosystem-based fisheries management (EBFM). An appreciation of diverse societal objectives recognizes that benefits arising from fish harvests form just one of the services that humans derive from marine ecosystems. "*Ecosystem-based fishery management recognizes the physical, biological, economic, and social interactions among the affected components of the ecosystem and attempts to manage fisheries to achieve a stipulated spectrum of societal goals, some of which may be in competition*" Marasco et al (2007).

In addition to providing criteria and reference points needed for the management of fisheries, ecosystem management will require new research and new frameworks for evaluating the likely effects of alternative management actions and policies as diverse as the approval and location of mariculture and ocean ranching facilities, monitoring and controlling invasive species, preserving heritage sites, planning coastal development, and coping with the effects of climate change. This new approach to the sustainable management of living marine resources will be required to provide a framework for evaluating alternative management actions and risks associated with other threats, including exploration and development of minerals and petroleum, leaking radiation and toxic wastes from defunct military facilities and shipwrecks, and the impacts of transboundary pollutants. Among these, management plans have been most fully developed for fisheries

Broader Impacts

The goal of this IGERT program is to promote teaching, research training and learning for PhD students in integrative and innovative approaches to marine ecosystem management and research. It is our goal to recruit and retain 20 PhD trainees over the course of the grant and to broaden participation of underrepresented groups by actively recruiting women and minorities, especially Alaskan Natives. Although Alaska has one of the highest percentages of Native Americans, the University of Alaska and state and federal management agencies have a very low percentage of Alaska Natives in professional positions. The percent of faculty or resource management professionals at UAF or state and management marine resource agencies (Alaska

Department of Fish and Game, Alaska Region of NOAA) ranges from 0 to 4%, while percentage of Alaska Natives in the state of Alaska is 16%. One of our goals is to double the historic number of Alaska Native PhD graduates (4) from UAF. We plan to build on previous successes at UAF at the Bachelors and Masters levels in attracting and graduating Alaskan Natives in science and social science fields. We will continue UAF's cross-cultural approach to education in which students exchange scientific and social perspectives with students from throughout the world. To that end,IGERT students will mentor rural and Alaska Native undergraduates. This IGERT will enhance infrastructure for research and education through curriculum development, through creating infrastructure for interdisciplinary marine graduate education, and through partnerships with governmental agencies and non-governmental organizations. Results of research projects undertaken by IGERT students and faculty will be disseminated broadly through presentations at local, regional, national and international forums and during an annual retreat. It is the primary objective of this IGERT to train future leaders who will be creative agents for change with the capacity to manage and mitigate threats to our nation's living marine resources, including climate change, fishing pressure, habitat loss, and pollution. This IGERT, focused on marine science and ecosystem-based management of living marine resources in Alaskan waters, will commence during a pivotal time for the development of a new understanding of, and approach to, ocean research in a region where future changes will have global effects.

An ecosystem-based interdisciplinary graduate training program in Alaska will have greater impacts to society than one developed elsewhere because of the following.

- Alaska comprises more than half of the US coastline, continental shelf, and exclusive economic zone (EEZ) (Figure 1).

Figure 1. The US EEZ extends 200 nautical miles offshore and is the largest in the world. Alaska comprises more than half of the US EEZ. Modified from US Commission on Ocean Policy (2004).

- Substantial segments of five large marine ecosystems (LMEs) border Alaska: the Gulf of Alaska, Bering Sea, Chukchi Sea, Beaufort Sea, and Arctic Ocean. Consequently, ecosystem-level approaches to management of living marine resources are politically feasible. In fact, the North Pacific Fishery Management Council (NPFMC) is currently finalizing a Fishery Ecosystem Plan for the Aleutian Islands and is beginning to develop an ecosystem-based Fishery Management Plan (FMP) for the Arctic Ocean. Moreover, the overall harvest caps adopted in the late 1970s for the Bering Sea and Gulf of Alaska FMPs represent an early effort to manage fisheries as components of an overall ecosystem.

- Although more than half of US commercial fish and shellfish landings are harvested from Alaskan waters, Alaska's fish stocks remain healthy (Witherell et al. 2000). Nevertheless, Alaska also presents examples of fishery and marine mammal stocks that have been driven to extinction (e.g., the Steller sea cow), been identified as endangered (e.g., the

western DPS of the Steller sea lion and the Bowhead whale), remain far below historic levels (e.g., GOA shrimp and Prince William Sound herring), have been adversely impacted by environmental disasters (e.g., the Exxon Valdez oil spill) or recovered from depleted levels (e.g., Pacific ocean perch in the 1950s, Pacific halibut in the 1930s and 1970's, and Pacific salmon in the 1970s).

- While Alaskan fish, shellfish, and other living marine resources are harvested by some of the largest and most technologically advanced fishing vessels, they are also harvested in small-scale fisheries including artisanal fisheries that rely on gear and harvest strategies that have scarcely changed in the past century. Harvests taken from Alaskan waters are valued at local, state, national and global levels and are inextricably linked to regional economic prosperity, individual and cultural identity, and ecosystem and human health. Thus, Alaska's fisheries provide an appropriate model for study of world-class industrial fisheries and for the study of artisanal fisheries that are still prominent in many less-developed regions around the world.

- Alaskan fisheries are managed under a wide array of alternative governance and regulatory structures, including cooperative management, limited entry, individual fishing quotas, AFA cooperatives, individual fishing quotas that are linked to processing quotas, community development quotas, super-exclusive registration areas, areas closed to particular gear types, seasonal apportionments, bycatch caps, sector allocations, community quotas, pot limits, marine protected areas, hot-spot closures, local-area management plans, subtidal leases, etc. Nearly every form of fisheries management in use around the world exists or has existed in Alaska.

- University of Alaska faculty members (Criddle, Eckert, Greenberg, Hills, Kruse, Norcross, Quinn) are directly involved the management of Alaska's living marine resources through their membership in science advisory committees to the NPFMC. This ensures that students in this program will benefit from information on current and pending efforts by NPFMC to implement an ecosystem-based approach to fisheries management and provides a conduit for outcomes of student and faculty research to enter into consideration in the management process.

- Climate change is magnified in northern latitudes of Alaska (ACIA 2004, Grebmeier et al. 2006). Past changes in the marine ecosystem have led to substantial changes in the absolute and relative abundance of commercially and culturally important living marine resources, changes that have reverberated through the social and economic fabric of resource-dependent communities. Deepening climate change can be expected to have ongoing impact on the socio-economic fabric of the commercial and subsistence fisheries associated with these ecosystems.

3. Major Research Efforts

An ecosystem-based approach to management and sustainability of living marine resources in the Arctic and Subarctic requires integrated studies of the "*physical, biological, economic, and social interactions among the affected components of the ecosystem*" (Marasco et al. 2007) and is the thrust of research associated with this IGERT. Such an approach is not simple; it requires transcending disciplinary boundaries and developing an interdisciplinary approach to research. Student research projects, which will be required to be interdisciplinary, will bring together students and faculty from diverse disciplines. UAF is unique in that faculty across these diverse disciplines share a common interest understanding the processes that drive and link physical,

biological and social systems that comprise marine ecosystems and a shared desire to design management measures that will sustain those systems. These faculty are currently engaged in interdisciplinary research (Box 1), and this IGERT will allow for more and continued research collaboration across disciplines. Although most student research projects will focus on Alaska, UAF faculty have ongoing research projects in other marine regions, and the skills that students will acquire are readily transferable to other regions. The following research themes and questions are the cutting-edge problems and topics that our faculty are distinctively poised to address.

Interrelationships between Marine Management and Science

R. Barnhardt, K. Criddle, P. Cullenberg, G. Eckert, R. Gradinger, J. Greenberg, M. Herrmann, N. Hillgruber, R. Hopcroft, K. Iken, B. Konar, G. Kruse, B. Norcross, T. Quinn, W. Smoker, T. Weingartner, M. Wooller

The relevance of marine research conducted by UAF faculty and students is amplified by the relatively strong role of UAF faculty in fishery management. Four of the current 15 North Pacific Fisheries Management Council (NPFMC) Scientific and Statistical Committee (SSC) members, including three former committee chairs and the current vice-chair, are UAF faculty; a fifth is a UAF graduate and adjunct faculty member, and a sixth is a former member of the NPFMC SSC. Three UAF faculty currently serve on the NPFMC's groundfish and crab plan teams. In addition, UAF faculty routinely undertake contracts from state and federal agencies to conduct research into pressing fishery management and ecosystem issues. Most of these faculty have current graduate students involved in fishery management-related research; many of these projects are interdisciplinary projects that combine fisheries oceanography, population dynamics, and bioeconomics. Graduate thesis committees often include researchers employed by federal and state fishery management agencies and many of the students are part- or full-time employees of these agencies. UAF-based research has stimulated changes in fishery management in Alaska, e.g., the establishment of fishery thresholds (levels below which commercial fisheries are closed); harvest rate strategies for groundfish, salmon, and invertebrates; Steller sea lion protection measures; management of impacts of fisheries on benthic habitats; hatchery operations; mechanisms for maximizing the value of catches; incentive structures to minimize bycatch; criteria for allocating catches among competing user groups; product development for new fisheries; and other fishery management measures. The intimate involvement of UAF faculty in fishery management assists UAF scientists to design research that answers fundamental questions and provides information that is directly relevant to priority fishery management issues, which fosters the development of collaborative relationships with agency scientists, and leads to ongoing service of UAF faculty as science advisors to state and federal mangers.

Major research questions that MESAS IGERT students might address include the following.

- ***How can existing fisheries legislation incorporate an ecosystem based approach?***

  National law and policy requires ecosystem-based fisheries management (EBFM) to be operational (MSFCMA 1996, U.S. Commission on Ocean Policy 2004). To date, most progress in this area has been conceptual, focusing on definitions, broad statements of goals and objectives, and compilations of lists of ecosystem indicators (Pew Commission 2003, NMFS 2004). New policies and institutional frameworks are needed to put ecosystem-based management into practice (Pikitch et al. 2004, Arkema et al. 2006, Marasco et al. 2007). Moreover, scientific research is required to develop useful performance measures for specific ecological indicators, so that they can be implemented directly into decision rules for fisheries management (Leslie and McLeod 2007). Despite broad acceptance of the requirement to incorporate an ecosystem perspective in the management of fisheries, the

current management paradigm remains largely grounded in a single-species model that, for the most part, emphasizes target species biomass (Pew Commission 2003, U.S. Commission on Ocean Policy 2004) and the single greatest flaw with this approach is a failure to set and adhere to conservative overall catch limits. Some ecosystem considerations are incorporated into fishery management in Alaska (Witherell et al. 2000, Witherell 2004). Examples include limits on bycatch and discards in groundfish fisheries. Prohibited species catch (PSC) limits are established as a small fraction of crab and herring biomass and chinook and chum salmon abundance; when PSC limits are attained, areas are closed to fishing (Witherell and Pautzke 1997). Other ecosystem considerations led to large area closures to bottom trawling and dredging to protect corals and sponges, crabs, and other bottom habitats. Ninety-five percent of the Aleutian Islands management area (~277,100 nm^2) has been closed to bottom trawling since 2005 (Witherell 2005). The State of Alaska has closed some state waters to trawling since the late 1960s in efforts to protect crab habitats. Presently, nearly all state waters in the GOA and southeastern Bering Sea are closed to trawling, and only fixed gears (e.g., pots, longlines, jigs) are allowed for groundfish. Other ecosystem considerations in fishery management in Alaska include numerous measures to protect Steller sea lions and reduce seabird bycatch and a prohibition on fisheries directed at forage fish species throughout the GOA, Aleutian Islands, and Bering Sea. Finally, the NPFMC has recognized that the Aleutian Islands are a region containing unique ecological values that the Council wishes to preserve. As a result, the NPFMC is in the process of developing a Fishery Ecosystem Plan for the Aleutian Islands.

❖ ***What are the new paradigms for fisheries management?*** Fisheries management requires decisions about allowable harvests based on available information, and understanding of populations gained through research. Decisions may be made in the absence of good information, but sound management must be informed by science including that embedded in the knowledge of those who participate directly in the fisheries. State and federal fisheries management in Alaska have a well-deserved reputation of rendering science-based management decisions. In federally managed fisheries, the abundances of fish and invertebrate stocks are assessed by scientists who combine fishery-dependent data with routine fishery-independent resource surveys and state-of-the-art statistical estimation models. Nevertheless, aside from a few commercially important fish and invertebrates, information about the structure and functioning of pelagic and benthic communities off Alaska is sparse. Research of benthic habitats has been generally small scale, which limits information available to management of fisheries. A more comprehensive understanding of the functioning of benthic habitats and how they are affected by fishing or other stressors is needed. As climate changes, fisheries and other human activities are likely to shift into the northern Bering, Chukchi and Beaufort Seas – areas where knowledge about biological communities and habitats is even more limited.

❖ ***How can multiple trophic levels be included in fisheries management?*** While commercially exploited fish stocks in the Alaskan LMEs are well-managed, declining populations of some marine mammals (e.g., Steller sea lion, northern fur seal) and some seabirds (e.g., short-tailed albatross, Steller's eiders) have raised concerns about the adequacy of current management processes for addressing ecosystem-scale issues. Although the MSFCMA requires consideration of ecosystem effects, and although annual catch quotas for commercially exploited fish stocks are often reduced below the single-species acceptable biological catches (ABCs) to reflect concerns about trophic relationships, progress towards adopting ecosystem-based management regimes has been halting. While the models of population dynamics used to determine ABC and overfishing levels (OFLs) increasingly include trophic relationships, and while a new generation of ecosystem models

is being developed for the GOA and Bering Sea/Aleutian Islands (BSAI) regions, lingering doubts about the structure of the ecosystem models and their associated trade-offs between sampling and specification errors have limited the direct use of ecosystem models in establishing ABCs and OFLs (e.g., Quinn 2003, Longhurst 2006). Moreover, regulation, sampling, and enforcement institutions – and the fishing industry and fishery-dependent communities – have been structured around a single-species or a species-suite; little is known about how these institutions, industries, and communities would change under an ecosystem-based management regime.

❖ ***How can stakeholders be included in an ecosystem-based approach to management?*** In addition to ethnic, cultural and environmental drivers, the social and economic structure of Alaska's fisheries and fishery dependent communities have evolved to their present form, partly in response to the various single species management regimes that have governed access to fishery resources. While the social and economic attributes of open access, limited entry, spatial use rights, and IFQ and pooled quota share managed fisheries have been studied extensively (e.g., Criddle and Macinko 2000), the design of regulatory structures to support EBFM and the likely social and economic impacts of EBFM and the transition to EBFM have not been well-explored. There is a need for research to examine the magnitude and distribution of costs and benefits under alternative EBFM management structures; to anticipate how EBFM might affect net benefits to fishermen, crew, processors, wholesalers, etc.; to anticipate how EBFM might impact direct, indirect, and induced benefits (costs) to communities and industry sectors; and to anticipate how EBFM might alter external benefits and costs to real and vicarious resource users (recreation, personal use, subsistence, non-consumptive). Integrated management approaches encourage coordination of local and national strategies to guide resource allocation among competing interests. As a research activity and outcome, identification and inclusion of all stakeholders is critical if integrated ecosystem-based management is to succeed in defining solutions to conditions in Alaskan waters and beyond. In addition to federal, state, and local government entities, stakeholders might include non-governmental organizations (NGOs), universities and research institutes, fishermen, processors, the general local population, developers, coastal industries (including tourism, processing, mining), and others at national and international levels of interest and organization.

❖ ***How robust and resilient are alternative management strategies under varying environmental and ecological conditions?*** This is an avenue of research that has not yet been well-examined in the context of current regulatory structures, let alone in the context of EBFM. Research topics that could be explored include questions about whether entitlement- and tenure-based management regimes increase or decrease the resilience of social and economic institutions when the relative abundance, relative value, and relative distribution of target and non-target species varies in response to variations in the biophysical system. Included within this general avenue of research are questions about: how spatial and temporal dimensions of fishing effort respond to changes in relative abundance or relative value of target species, incidental catches of bycatch species, and changes in the relative abundance of species that might compete for target or incidental catches of overlapping or non-overlapping size-classes of the same species (e.g., sea birds, marine mammals, sharks, etc.).

❖ ***How do historical indigenous systems of marine management differ from those in use today?*** The first human occupations of the coastal regions of Alaska date to ca. 7500 B.P. (Moss and Earlandson 1995; Schaaf 2002) in the GOA and Aleutian region. More northerly coastal settlement occurred during the mid-Holocene ca. 4500 B.P. (Dumond

1987). In all areas, archaeological, historical and ethnographic data indicate that once settlement occurred it was continuously occupied to the present, albeit with shifts in settlements, populations, and marine exploitation patterns corresponding to episodes of climate change and variations in regional and local marine productivity. Evidence for marine resource use is apparent from the onset of coastal settlement with exploitation of a vast array of shellfish, marine and anadromous fish, marine mammals, and seabirds. Ethnographic and historic data demonstrate that the indigenous peoples of Alaska had complex and well-defined systems of sea tenure that regulated access to and distribution of marine resources (e.g., DeLaguna 1972). Resources were treated as commodities, staples or supplements, while others were viewed as prestige items imbued with great symbolic value and occupied what might be considered important cultural 'keystone positions' (c.f., Garibaldi and Turner 2004). These methods of valuation were not necessarily independent of one another, nor were they fixed over time.

Box 1. UAF faculty are currently engaged in interdisciplinary research. MESAS provides the opportunity to expand and build on this capability. The following are a few recent (in chronological order) examples of interdisciplinary products by UAF MESAS faculty.

Robards, M, (***biologist***) and J.A. Greenberg (***economist***). 2007 Global constraints on rural fishing communities: Whose resilience is it anyway? *Fish and Fisheries*. Vol. 8.

Schumacher, J.D. (***oceanographer***), and G.H. Kruse (***fishery management biologist***). 2005. Toward sustainable ecosystem services from the Aleutian Archipelago. *Fisheries Oceanography* 14(Suppl. 1): 277-291.

Criddle KR (***economist***) and S Macinko (***anthropologist***). 2001. Political economy and profit maximization in the Eastern Bering Sea fishery for walleye pollock. In A Shriver and R Johnson (Editors). *Proceedings of the International Institute for Fisheries Economics and Trade*, Oregon State University, Corvallis, OR.

Criddle KR (***economist***), HJ Niebauer (***oceanographer***), TJ Quinn II (***fisheries biology/population dynamics***), E Shea (**environmental science**) and AV Tyler (***fisheries biology***). 1998. Marine biological resources. Pages 75-94 *in* P Anderson and G Weller, editors, *Implications of Global Change in Alaska and the Bering Sea Region.* Center for Global Change and Arctic System Research, University of Alaska Fairbanks, AK.

Callaway D (***anthropology***), KR Criddle (***economics***) and E Shea (***environmental science***). 1998. Subsistence fisheries. Pages 95-104 *in* P Anderson and G Weller, editors, *Implications of Global Change in Alaska and the Bering Sea Region.* Center for Global Change and Arctic System Research, University of Alaska Fairbanks, AK.

Responses of Marine Ecosystems to Human-Induced Climate Changes

P. Cullenberg, R. Gradinger, N. Hillgruber, R. Hopcroft, K. Iken, B. Konar, G. Kruse, M. Murray, B. Norcross, T. Quinn, D. Tallmon, T. Weingartner, M. Wooller

National law and policy require the protection of essential habitat (MSFCMA 1996). In a far-reaching action in February 2005, the NPFMC banned the use of trawl gear throughout 95% of the vast Aleutian Islands management area and 10 additional smaller areas in the GOA thought to contain deep-water corals. Yet, the necessary process-oriented research in support of this and similar actions to define marine protected areas is lacking. There is a need for research to understand the linkages between marine biological communities and habitats and (1) climate and climate change, (2) trophic interactions among species and connections to managed species, and (3) human impacts. These linkages need to be understood in light of large-scale drivers, which in Alaskan waters include changes in temperature, magnitude and timing of precipitation and river runoff, seasonal ice cover, and large-scale nutrient regimes. Predictive models are needed in each Alaskan LME to forecast how these large-scale drivers affect marine community composition, primary production, secondary "invertebrate" production, fish

production, marine mammals, and ultimately the human communities and economies that are dependent on marine resource extraction. Archaeological and paleoecological data indicate that species composition and abundances have changed in the past in concert with major paleoenvironmental shifts (see Davis 2001, Finney et al. 2002); such data can provide useful information for building predictive models of future changes.

Major research questions that MESAS IGERT students might address include the following.

- ***What will be the effect of climate-induced changes in the Gulf of Alaska (GOA)?***
  The GOA shelf extends nearly 2000 km from Ketchikan in Southeast Alaska to Unimak Pass in the southwestern Gulf. The shelf is deep (150-200 m), bathymetrically complex, and varies in width from 5 km in the southeast to nearly 200 km in the northwest. The shelf is fed by amounts of coastal freshwater runoff greater than that of the Mississippi River and is low in macronutrients (Childers et al. 2005) but high in glacial sediments (Hampton et al. 1986) and dissolved iron (Wu pers. comm.). Two swift current systems drive along-shore advection. The Alaskan Stream flows westward along the Aleutian Islands as well as into the Bering Sea basin. The Alaska Coastal Current (ACC) originates on the British Columbian shelf and enters the Bering Sea shelf in the western GOA. These current systems are an excellent conduit of climate signals (heat, nutrients, disease, and introduced species) that originate outside the GOA. Freshwater plays a crucial role in structuring the GOA ecosystems. The dispersal of freshwater influences the formation of both horizontal (fronts) and vertical (stratification) density gradients. For example, the ACC front provides an important foraging habitat for juvenile salmon as these fish emerge onto the shelf and the ACC provides a migratory corridor for these fish as they make their way to the open ocean. Similarly, winter mixing and nutrient replenishment in the basin is a function of the vertical salinity gradient (Freeland and Whitney 1999). It also appears that changes in freshwater content affect the zooplankton composition in both the basin (Whitney et al. 1998, Freeland and Whitney 2000) and the shelf (Coyle and Pinchuk 2005), and this freshwater content may affect the condition of juvenile salmon on the shelf (Haldorson pers. comm.). Consequently changes in freshwater delivery rates and/or timing may influence these marine ecosystems by altering the upper ocean stratification and/or iron supply, and ultimately affecting higher trophic systems. For example, an emerging hypothesis from the Northeast Pacific Global Ocean Ecosystem Dynamics Program (GLOBEC) is that copepod and juvenile salmon success is linked, via diatom production, to the dispersal of freshwater and its enriched iron content (Weingartner et al. 2005, Coyle pers. comm.). IPCC (2007) projections indicate that climate change in the GOA will result in warmer and wetter winters, which may lead to an earlier onset of spring runoff, initiating earlier spring blooms and/or leading to alterations in iron transport pathways. Research is needed to address these predictions. Increased freshwater forcing also will be accompanied by decreased winter cooling and therefore warmer ocean temperatures, which will influence metabolic rates and perhaps establish thermal conditions conducive to introduced species. In addition freshening of the shelf will enhance ACC transport (Weingartner et al. 2005) and the along-shore advection of heat over the shelf. Pressing questions include how these current systems will change in a changing climate and will changes outside the system result in greater changes at these high latitudes. Such changes will have major impacts on fisheries, human communities and socio-economic systems.

- ***What will be the effect of climate-induced changes in the eastern Bering Sea?***
  The eastern Bering Sea shelf is a broad (~500 km), shallow (~70 m), relatively smooth-bottomed, seasonally ice-covered shelf. The mean flow is very weak, and generally northward, thereby carrying waters from the GOA and Bering Sea basin into the Arctic

Ocean via Bering Strait. Sea ice extends southward through the winter, although the southern limit varies widely from year-to-year depending upon the strength and frequency of cold air outbreaks from the north. In spring the sea ice melts and retreats northward leaving behind a surface layer of dilute meltwater and a “cold pool” of near-freezing bottom waters. The cold pool appears to effectively constrain zooplankton development and the movement of some commercially important fish, e.g., walleye pollock (Wyllie-Echeverria 1996). Hunt et al. (2002) hypothesize that the structure of the southeast Bering Sea shelf pelagic ecosystem is controlled by the extent of the ice cover and the timing of ice retreat. Late ice retreat leads to an early (late March-April) ice-associated spring bloom in cold water whereas years of no ice or an early ice retreat lead to an open-water bloom in warm water in May-June. Zooplankton populations are not closely coupled to the spring bloom but are sensitive to water temperature. Hence in cold years, zooplankton production and fish recruitment (walleye pollock, flounder, and Pacific cod) is reduced. In warm years zooplankton are abundant and recruitment enhanced. While there appears to be little difference in primary production between warm and cold years, the fate of this production varies; in cold years more of it settles to the seabed to sustain the benthos, whereas in warm years it is available to pelagic foragers. Over the last thirty years the Bering Sea has experienced a decreased ice cover and relatively warm winters, a trend that appears to have accelerated over the past decade. On a broader scale the Bering Sea ecosystem grades from being pelagic-dominated on the southern shelf and to being benthic-dominated on the northern shelf; a biological gradient consistent with the seasonal duration of the ice cover over both regions. Under a climate warming scenario, the pelagic community of the northern shelf is expected to expand at the expense of the benthos, and the benthic community is expected to more northward into the Chukchi Sea (Grebmeier et al. 2006). Such a change might be accompanied by northward extensions in some species ranges, shifting predator-prey interactions, with concomitant alterations in trophic structure. Once again, the human impacts of these changes are vast as this region provides some of the most productive fisheries in the world.

Figure 2. Alaska offers a diversity of opportunities and experiences for IGERT students.

Responses of Marine Ecosystems to Human-Induced Changes in Community Structure

R. Barnhardt, K. Criddle, P. Cullenberg, G. Eckert, R. Gradinger, J. Greenberg, M. Herrmann, N. Hillgruber, R. Hopcroft, K. Iken, B. Konar, G. Kruse, M. Murray, B. Norcross, T. Quinn, W. Smoker, D. Tallmon, T. Weingartner, M. Wooller

Humans are part of ecosystems, and our actions shape ecosystem structure and function. For millennia, humans have significantly and substantially altered and even degraded their environments, including marine and coastal systems (Jackson et al. 2001, Springer et al. 2003, Briggs et al. 2006). Anthropological research, particularly in historical and human ecology, is an important venue for understanding the dynamic relationships among key elements of the human/marine ecosystem. It provides a variety of approaches for investigating the interaction of human and natural phenomena to drive change and shape responses to change. Ecohistories (Hardesty and Fowler 2001) can provide baseline description of the marine ecosystems that preceded industrial fishing, global trade, and large-scale industrial development (e.g., Etnier 2004). Archaeological and historical human ecological research generates a long-term perspective on the nature and intensity of human (and non-human) impacts and human/marine ecosystem vulnerability and resilience that is necessary for the development of "best-informed" conservation and management policies (Lyman and Cannon 2004). Such research can separate cumulative human impacts from those that are a consequence of short-term natural system shifts.

Major research questions that MESAS IGERT students might address include the following.

- ***What can history teach us about marine and human community structure?*** Archaeological data indicate that historic-era fishing in the North Atlantic changed the population structure of Atlantic cod stocks. Fisheries management strategies were based on the perception that this 'anthropogenic population structure' was the natural population structure and, in combination with over-fishing during the late 20th century and a shift in the Arctic/North Atlantic climate system in the mid 1970s, led stocks to collapse in the early 1990s (Amorosi et al. 1994, Hamilton and Haedrich 1999, Hamilton et al. 2003). Many human communities in the North Atlantic were forced to reorganize socially, economically, and technologically, with some experiencing dramatic loss of population, and increasingly skewed population structures (Hamilton and Haedrich 1993, Hamilton et al. 2003). Applied historical and human ecology research is well developed in the North Atlantic but lags behind in Alaska and the North Pacific with only a few efforts to ingrate into larger efforts of marine conservation and fisheries management (cf., Etnier 2004).

- ***Are regime shifts the result of fishing?*** In the last decades, research efforts in Alaskan waters have clearly demonstrated the need for a better understanding of trophic connections between lower and upper trophic level marine populations. While some observed transitions in marine community structures appeared to be connected to climate regime shifts (Anderson et al. 1997, Anderson and Piatt 1999), the processes leading to the restructuring of marine ecosystems remain less transparent. Ecological regime shifts have had far-reaching consequences for the marine ecosystems of the GOA and the eastern Bering Sea. Some of the observed species responses included increases in gelatinous zooplankton in the Bering Sea (Brodeur et al. 1999, 2002), the occurrence of coccolithophore blooms in the southeastern Bering Sea (Iida et al. 2002), shifts in the species composition to large piscivorous groundfish in the GOA (Mueter and Norcross 2000), and the collapse of marine mammal and bird populations in the waters surrounding the Aleutian islands (Estes et al. 1998, Estes et al. 2005, Byrd et al. 2005). However, responses of apex predators to climatologic regime shifts are particularly difficult to establish, primarily due to their longer response time (Francis et al. 1998). To date, causal

relationships for ecological regime shifts have been suggested to be either bottom-up initiated by climate change, top-down, or a combination of both (Francis et al. 1998, Mueter and Norcross 2000, Hunt et al. 2002, Lees et al. 2006, Litzow et al. 2006, Mueter et al 2006).

❖ ***Are declines in higher trophic levels the result of fishing?*** The decline in Steller sea lion abundance, particularly in the waters of the eastern Aleutian Islands and the western GOA, dramatically demonstrated the need for a better understanding of causal relationships between the dynamics of upper trophic level organism and changes in the abundance and species composition of lower trophic level taxa. By 1990, the population of Steller sea lions had declined by about 80%, prompting the NMFS to list them as threatened under the Endangered Species Act (ESA). As required under this listing, research was initiated with the aim of investigating the functional linkages in the Bering Sea ecosystems and of identifying factors responsible for their reorganization. Mechanisms hypothesized to explain the decline of Steller sea lions can be broadly divided into bottom-up and top-down; bottom-up hypotheses included nutritional limitation caused by declines in prey taxa abundance resulting from an ecological regime shift or increased commercial fishing pressure of preferred prey (Anonymous 1993, Merrick et al. 1997). Top-down hypotheses encompass mechanisms such as intentional takes, incidental mortality due to commercial fishing pressure or increased predation pressure on Steller sea lions as a result of prey switching of transient killer whales. Thus, while there is little doubt about the patterns of Steller sea lion population change, factors responsible for these patterns remain unknown, and proposed regulative mechanisms severely disputed. A better understanding of ecosystem components and mechanisms responsible for changes in abundance is necessary to formulate and evaluate hypotheses of marine population regulation in Alaskan waters.

❖ ***What is the effect of fishing on habitat?*** Bottom trawling is relatively non-selective and can significantly impact the physical and structural properties of a habitat, which can translate into changes in the biological or functional composition of benthic communities (Brown et al. 2005). Mortality of bottom fauna caused by bottom trawling is particularly high for large-sized infauna, while smaller organisms are usually less affected (Bergman and Hup 1992, Gilkinson et al. 1998). Hence, diversity, abundance, size structure and the production of benthic communities can be greatly affected, and with that productivity of the system and food sources of the targeted fish resources (Jennings et al. 2002). In addition, structural disturbance of the habitat can be significant, especially in vulnerable habitat types such as seamount coral systems (Johnston and Santillo 2004). Benthic invertebrate bycatch can account for up to 90% of commercial catches, including undersized target species and non-targeted species (Andrew and Pepperell 1992, Broadhurst et al. 2006). Bottom trawling can therefore lead to changes in community composition and size structure (Kaiser and Spencer 1996, Collie et al. 2000). However, the impacts of bottom trawling depend on the character of the gear being used, how that gear is deployed, the nature of the habitat through which it is towed, and the density and frequency of tows. With the increasing recognition of the value of ecosystem-based fisheries management, where management starts with the ecosystem rather than a target species, the impact of bottom trawling on benthic communities has to be carefully evaluated. Comparisons between fished and protected areas often are flawed by inherent (and possibly unknown) differences in the system that are independent of fishing. An innovative solution to the problem could be through small-scale manipulative studies simultaneously targeting multi-faceted aspects such as the physical environment, community composition, size-distribution, functional trophic groups and productivity.

❖ ***What are the effects of coastal development on living marine ecosystems?*** While harvesting practices appear to be the dominant anthropogenic influence exerting pressure on Alaskan marine ecosystems, there are other anthropogenic sources of change that need to be examined, especially in the context of long-term planning, modeling, and EBFM. For example, privatization of coastlines is a major driver of the physical alteration and destruction of marine habitats around the world, including in parts of Alaska, because it is linked to expanded coastal settlement, tourism, and industrial development. While Alaskan coasts and waters are still relatively pristine, there are local and occasional small and large-scale pollutant discharges linked to oil and gas development, to commercial activity, and to sewage outfalls, and these can be expected to increase as the human population expands and coastal areas undergo further development. We also know very little about the impacts of upriver developments on coastal estuaries, and while major contaminant sources to Alaskan waters are mostly remotely generated and transported into the region by the large-scale, quasi-permanent atmospheric and oceanic circulation systems (MacDonald et al. 2003), understanding ecosystem responses to these is an important research activity. Alaska is in the enviable position of being able to develop research and relevant management policy while vast coastal areas remain in near pristine condition and to prevent and/or remediate these through engagement with the local public, commercial developers and the state

Summary and Conclusions

In summary, we will offer the opportunity for students in the MESAS IGERT program to conduct collaborative research that transcends traditional disciplinary boundaries to address the challenge of how to structure ecosystem-based management and to research its possible consequences. While many of these avenues of investigation have been partially explored through discipline-based studies, there are opportunities to explore new dimensions of these questions using interdisciplinary teams. MESAS will, therefore, serve as a catalyst to stimulate interdisciplinary interactions among faculty as well as generate interdisciplinary student research. MESAS brings together a talented group of scientists at UAF to address these issues. We plan that our integrative research-based training engenders an interdisciplinary approach to how these students think, an approach that will permeate throughout their careers.

4. Education and Training

Our education and training program is designed to attract students from a variety of backgrounds and train them in a breadth of disciplines combined with interdisciplinary interactions so that they may be able to address real-world problems in marine ecosystem-based research and management. Our program will provide students a broad foundation of knowledge about ecosystem processes and their interface with people and the skills to address interdisciplinary problems. Our education and training program capitalizes on the strengths of existing marine-related graduate programs at the University of Alaska. Graduates of our program will be well-prepared to devise ecosystem-based solutions to critical research and stewardship questions in the sustainable use of living marine resources.

Required Courses MESAS students will be required to take a summer course, "*Integrating Oceanographic, Ecological and Social Perspectives in Marine Ecosystems*," immediately preceding their first fall semester, "*Marine Ecosystem Traditional Ecological Knowledge*," in their first fall semester, the "*Innovative Approaches to Marine Ecosystems*" seminar each spring, the "*Marine Ecosystems*" and "*Integrative Assessment*" courses in addition to a 3-4 credit course in statistical methods during their first academic year, and "*The North Pacific Fishery Management Council*" course in May following their first academic year. Course requirements are designed so

that they may be completed within a single year on campus with participation in later years possible via distance delivery.

1. *Integrating Oceanographic, Ecological and Social Perspectives in Marine Ecosystems (IOESP) (4 cr)* An intensive four-week, team-taught course in the summer semester, to be developed and offered by the IGERT Steering Committee and visiting scholars, will be required for all entering students immediately preceding their first fall semester. The course is intended to expose students from diverse backgrounds to fundamental principles and analytic approaches in core IGERT disciplines. The first two weeks of the course will focus on marine science disciplines: fisheries, oceanography, and ecology and be taught by Ginny Eckert, Bill Smoker, Gordon Kruse and Tom Weingartner. The second two weeks, taught by Keith Criddle and Maribeth Murray, will focus on social science disciplines: policy, economics, anthropology, and sociology. Workshops and discussions in communication, scientific ethics, group dynamics, and conflict resolution will be held in the evenings. IOESP is not intended as a "crash course" in 7 disciplines. Instead, it is intended to explore how the different disciplines might approach the definition, analysis, and resolution of a common problem, to teach the basic principles and basic methodologies that different disciplines might apply to a common problem. For example, one theme might explore the role of shellfish farming and ocean ranching in Alaska. An ecologist might address aspects of the relationships between farms and stock enhancements on natural communities. An economist might look at the role of shellfish farming and ocean ranching in local and regional economies or at the efficiency of alternative regulatory structures. An anthropologist might examine the social and cultural impacts and feedbacks of these activities in fishing communities, while a policy analyst might construct a risk analysis of alternative rules and regulations. We expect to integrate other IGERT faculty and visiting scholars into the four-week program, as time and availability allow. This summer course will be held at a University of Alaska facility, in Sitka, Kachemak Bay, Seward, Juneau or Kodiak. These locations offer the advantage of having research vessels, small boats, access to marine habitats, and outstanding amenity values, as well as offering an off-campus community-building experience for MESAS faculty and students. This course will be mandatory for first-year students enrolled in the MESAS program with participation funded within the program budget and will be open to participation by other students at their own expense. The MESAS retreat (see below), involving all MESAS students and faculty, will occur immediately following the IOESP course in the same location. (NEW course to be designed for this IGERT.)

2. *Marine Ecosystem Traditional Ecological Knowledge (METEK) (4 cr)* The course will examine the acquisition and utilization of knowledge associated with the long-term inhabitation of particular ecological systems and the adaptations that arise from the accumulation of such knowledge. Until recently there was very little attention given to how western scientists and educators might better understand local and indigenous worldviews, and even less on what it means for participants when such divergent systems coexist in the same person, organization or community. Indigenous and local communities have a long history of management of marine resources. In this context, attention will be given to the contemporary significance of traditional ecological knowledge and local knowledge of fishers as a complement to academic disciplinary fields of study. Students will examine ways in which traditional and local ecological knowledge is acquired and utilized in indigenous and local community contexts; will explore the potential for application of traditional ecological knowledge to expand our understanding of contemporary issues, locally and globally; will examine the epistemological structures typically associated with traditional ecological knowledge; will examine the relationship between traditional ecological knowledge and the

knowledge associated with Western academic disciplines; and will review various reports and documents illustrating the use of traditional ecological knowledge in addressing contemporary problems. (NEW course to be designed for this IGERT.)

3. *Innovative Approaches to Marine Ecosystems (IAME) (2 cr)* The cornerstone of the MESAS IGERT required coursework will be an interdisciplinary 2-credit discussion-based seminar held each spring semester and required for all MESAS students. MESAS faculty will moderate the seminar, and this responsibility will rotate among the faculty. The goal of the seminar is to reinforce an integrative perspective through exploring different dimensions of marine ecosystem sustainability. For example, the seminar might address the environmental, ecological, economic, and social impacts of cruise ships in Southeast Alaska or climate induced changes in the structure and function of biological and human communities in the Pribilof Islands. The seminar would examine different dimensions of the issue over several weeks. In the cruise ship example, one week might be devoted to an examination of interactions between cruise ships and whales, the next might examine economic or social impacts of cruise ship tourism, and other weeks might be focused on vessel safety, air and water pollution concerns, etc. Students would be tasked with picking topics at the beginning of the semester, and individual students would select the dimensions to be explored in each week through facilitated discussion of published articles or through presentations by invited speakers. This course is a key activity to integrate students from different disciplines to work together on a common problem and will involve all MESAS students each year. (NEW course to be designed for this IGERT.)

4. *Marine Ecosystems (3 cr)* This course is a synthesis of ecological processes that support the structure and functioning of marine ecosystems. It is taught by Gordon Kruse and Nicola Hillgruber. The course covers specifics about physiological and population levels of marine biological organization. Fundamentals of how populations interact with each other and their environment are reviewed. The mechanisms for maintaining marine communities and ecosystems over space and time are evaluated. The course considers principles of biogeography, ecological gradients, and biomes, as well as case studies for a few of the world's LMEs, with an emphasis on the Arctic, Bering Sea, GOA, Southern Ocean, and the world's major upwelling systems. This course will be required for all MESAS IGERT students, because it provides an understanding of the marine ecosystem processes that are affected by both climate and human interactions. Thus, the course provides a foundation for interdisciplinary studies, regardless of the particular orientation of each student. (Existing course)

5. *Integrative Assessment (3 cr)* Integrative Assessment focuses on methods and tools that link quantitative and qualitative analysis with models in applied interdisciplinary research. These tools are essential to implement resilience theory in policy and management. The course will be organized around the completion of a student-led integrated assessment that incorporates the downscale effects of global change, their attendant local and regional feedbacks, and policy implications. The course will include direct interaction with decision makers of a local community to explore aspects of the science-policy interface and challenges of community-science partnerships. This course was recently redesigned for the Resilience and Adaptation (RAP) IGERT at UAF, is required for all RAP IGERT students, and will be required of all MESAS IGERT students. This course, therefore, will provide an opportunity for integration among students in both the terrestrially-based (RAP) and marine-based (MESAS) sustainability IGERTS at UAF. (Existing course)

6. *The North Pacific Fisheries Management Council: a case study (2 cr)* The NPFMC is one of eight regional councils established by the MSFCMA. With jurisdiction over the EEZ off Alaska, the Council has primary responsibility for fisheries management in the GOA and the BSAI. The NPFMC leads the other regional FMCs in integrating science and management. In this 2 week intensive course, students will attend a week-long NPFMC meeting with evening debriefings by members of the SSC and NPFMC staff. In the week preceding the NPFMC meeting, faculty will lead a directed review of briefing materials and provide background on issues (Draft Environmental Assessments, Regulatory Impact Reviews, Regulatory Flexibility Analyses, and miscellaneous reports). Students will be expected to prepare a critical review of the briefing materials prepared for at least one agenda item. (NEW course to be designed for this IGERT)

Research and Stewardship Internship An integral educational component of this program is an 8 to 12 week internship at the end of the first academic year. Students will be required to make contact with prospective mentors at partner organizations (Table 1), at least six months in advance of the internship, and explore opportunities of joint interest to the student and the organization. This experience will provide career-development exposure to non-academic careers as well as an experience outside the student's degree program and is not intended to be an opportunity to collect data for a dissertation. Alaska is rich with ocean-based agencies and organizations that can provide a diversity of experiences. These organizations range from national and state government agencies, industry associations, conservation groups, native organizations, and academic organizations. Each of these organizations is actively pursuing marine ecosystem-based research and/or management. Partner organizations will provide a mentor and space for the intern and a meaningful short-term project that is of utility to the student and the organization. Student stipend and transportation to the internship will be funded by the MESAS IGERT program. Students will be expected to report on their internship projects during the fall retreat.

*Table 1. Planned partner organizations. * indicates letter of commitment included in the six that were allowed for this proposal. We plan to expand this list of partners over the lifetime of the program.*

*Alaska Department of Fish and Game
*Barrow Arctic Science Consortium
*International Indigenous Graduate Institute
*NOAA National Marine Fisheries Service - Alaska Fisheries Science Center
*North Pacific Fishery Management Council
*Western Alaska Community Development Association
Alaska Board of Fisheries
Alaska Commercial Fisheries Entry Commission
Alaska Federation of Natives
Alaska Marine Conservation Council
Alaska Ocean Observing System
Alaska Sea Grant, including the Marine Advisory Program
Alaska Seafood Marketing Institute
Alaskan Private Not-for-Profit Aquaculture Associations
Census of Marine Life/CORE
Institute for Social and Economic Research at the University of Alaska Anchorage
International Pacific Halibut Commission
National Center for Ecological Analysis and Synthesis
National Park Service
National Research Council – National Academy of Sciences
Native Harbor Seal Commission
Nature Conservancy
North Pacific Research Board
Oceana
Rasmuson Foundation
US Coast Guard
US Fish and Wildlife Service
US Geological Survey, Alaska Science Center

Fall Retreat All MESAS IGERT students and participating faculty will be required to attend a 1-2 day retreat immediately before the start of fall semester during which incoming students will share their experiences from the summer course, second-year students will present an overview of their internship project, and students in their third-year and beyond will present research results. The goal of the retreat is to keep students engaged in interdisciplinary activities throughout their graduate career and to facilitate interaction, both formal and informal, among MESAS students and faculty.

MESAS Students as Mentors Our MESAS IGERT students will have the opportunity to serve as mentors for undergraduate students in several capacities. We will assign two Native and/or rural Alaskan undergraduate students to each graduate student who is actively receiving MESAS funding. It will be the responsibility of the MESAS-funded student to act as a mentor to these undergraduates throughout the academic year. The undergraduate students, who have expressed an interest in marine ecosystem science, will be selected with the assistance of the Native Student Services program at the University of Alaska Southeast in Juneau and the Alaska Native Science and Engineering (ANSEP) program at the University of Alaska in Fairbanks and the College of Rural and Community Development in rural areas. MESAS students will be expected to serve as an informal advisor and tutor for these undergraduates; their time commitment will be a minimum of five hours per week when they are receiving MESAS funding. The goal is to have MESAS students serve as role models to encourage these undergraduates to pursue degrees in marine science fields, as well as have the rural and native undergraduate student share their experiences and challenges with western cultures and rural and native cultures. The University of Alaska Southeast in Juneau is a Research Experience for Undergraduates (REU) site, and several of the faculty associated with this proposal have served as faculty mentors in the REU program. It is expected that MESAS students who work with these faculty will serve as mentors for REU students during the summer.

Small Grants Program We will establish an MESAS IGERT small grants program to provide small grants ($1K to $3K each) for travel to conferences to present interdisciplinary work, travel to other research laboratories/universities to broaden/expand skills and disciplines, purchase research supplies for pilot interdisciplinary studies, pay page charges for journal publications, and other small requests. Students will be required to submit short proposals on how the funds will be used with an estimated budget. Priority will be given to requests that involve interdisciplinary and innovative research. A MESAS faculty subcommittee will review requests once per semester. With this program, students will practice grant writing skills and budget management, training that is currently lacking in many graduate programs.

Career Development Opportunities Graduates of this program will have rich opportunities for careers. The recent reports of the Ocean Policy Commission (2004), Pew Oceans Commission (2003), and the NRC (2000) demonstrate the national need for graduates of programs such as this and a renewed national interest in improving the conservation of marine resources. In Alaska alone, public agencies (ADFG, NMFS, USGS, USFWS, etc.) and non-governmental organizations (conservation groups, tribal organizations who are developing capacities for co-management of resources, etc.) already recruit 10-12 entry-level PhDs each year. The School of Fisheries and Ocean Sciences, Department of Anthropology, School of Natural Resources, and School of Management have excellent records of placing their advanced-degree graduates in academic institutions, research institutions, and federal and state agencies.

Invited Scholars Program A major opportunity to expand the breadth of disciplines to which MESAS IGERT students are exposed is through inviting visitors from other academic institutions and partner organizations to present seminars, provide guest lectures in courses, assist with the

summer course, and interact with MESAS graduate students in informal settings. We anticipate including 2-5 scholars per semester that will spend one to five days on campus. MESAS students will select and host invited scholars during their visit.

Student Pathway and Support Required elements in the MESAS IGERT training program are outlined in Table 2. Students will be supported by an IGERT fellowship in their first year and by a Teaching Assistantship (TA) in their advisor's department in their second year. TAs will expose students to teaching experience at the university level as an important career-building element of their graduate education. Students will be expected to develop a dissertation proposal during their second year. Third-year students will be supported by MESAS while fourth- and fifth-year students will be supported by fellowships, TAs, or Research Assistantships (RA) in their advisor's department.

Table 2. A representative graduate program for a PhD student in the MESAS IGERT program

Year 1 (IGERT fellowship support)

- August preceding Fall semester
  - FISH/ANTH/ECON/NRM/MSL 6XX IOESP
- Fall semester
  - Fall retreat
  - CCS 6xx Marine Ecosystem Traditional Ecological Knowledge
  - MSL 652 Marine Ecosystems
  - 3-4 credit course in statistical methods
  - Mentor Native/rural Alaskan undergraduate student (all year)
- Spring semester
  - FISH/ANTH/ECON/NRM/MSL 6XX IAME seminar
  - BIOL/ANTH/ECON/NRM 649 Integrative Assessment
  - Arrange internship
- Summer
  - FISH/ANTH/ECON/NRM/MSL 6XX NPFMC class
  - Internship (see *Research and Stewardship Internship* above)

Year 2 (TA support)

- Serve as teaching assistant
- Classes at the discretion of the graduate committee, must include IAME seminar
- Fall retreat
- Develop research plan and initiate dissertation research

Year 3 (IGERT fellowship support)

- Classes at the discretion of the graduate committee, must include IAME seminar
- Fall retreat
- Mentor Native/rural Alaskan undergraduate and/or REU student
- Conduct dissertation research

Years 4 and 5 (Fellowship, RA or TA support)

- Classes at the discretion of the graduate committee, must include IAME seminar
- Fall retreat
- Mentor Native/rural Alaskan undergraduate and/or REU student (encouraged but not required)
- Conduct research and complete dissertation

Recent Initiatives at UAF
Several recent research and education initiatives at UAF provide increased opportunities for MESAS IGERT students for funding, collaboration, and integrated research and training in areas related to marine ecosystem sustainability in the Arctic and Subarctic.

- The 4th International Polar Year (IPY), which began in March of 2007 and will continue through 2009, is a campaign of intense, internationally coordinated research and training to gain new knowledge about Earth's polar regions, how those regions are changing, and how such changes are impacting the health of our biosphere. IPY activities at UAF are extensive and include enhanced funding for polar-related research, funding for post-doctoral researchers, guest speakers, and additional polar-related activities.

- The third phase of Alaska EPSCoR (Experimental Program to Stimulate Competitive Research) was funded by NSF for 2007-2010, titled, "Resilience and Vulnerability in a Rapidly Changing North: The Integration of Physical, Biological and Social Processes". The theme of this EPSCOR is well-suited to our theme, and it is anticipated that Alaska EPSCoR may be able to provide additional opportunities for funding graduate student fellowships, travel and guest speakers.

- The Rasmuson Foundation awarded in January 2007 the UAF School of Fisheries and Ocean Sciences (SFOS) a $5 M grant to elevate the fisheries program to national prominence with the vision that UAF SFOS will be *"one of the premier fisheries and ocean sciences programs in the nation and will educate the professionals necessary to guarantee the sustainability of Alaska's vast and healthy marine and freshwater resources."* The University of Alaska has provided matching funds for this effort. This initiative will provide for new faculty positions, invigoration of the undergraduate Fisheries program, an emphasis on the connections between oceanography and fisheries, and improvement of SFOS facilities and infrastructure.

- A new PhD graduate program in Indigenous Studies is in development at UAF, with funding requested from the NSF and Mellon Foundation. Once this degree is formalized (expected 2008), it will be added to the list included in the MESAS IGERT. Indigenous Studies students whose research interests address coastal and marine ecosystem topics would be invited to apply to the MESAS IGERT program.

5. Organization, Management, and Institutional Commitment
Organization and Management The MESAS IGERT will be administered by the Director, Program Coordinator, and Steering Committee. The Director (Smoker) will have overall responsibility for management of the project and budget and interactions with NSF. The Program Coordinator (Eckert) will run the summer course, fall retreat, admissions, and small grants program. The Steering Committee will teach the summer course, approve student admissions and study plans, and assess the program (in conjunction with the External Advisory Committee) including making improvements over time. The Steering Committee represents the disciplines within marine ecosystem research and management and consists of Bill Smoker, Director, Chair of the Fisheries Division; Ginny Eckert, marine ecologist; Gordon Kruse, fishery management and oceanography expert; Keith Criddle, fishery economist and marine policy expert; Tom Weingartner, physical oceanographer, Maribeth Murray, human ecologist and anthropologist; and a student representative, to be selected annually.

The University of Alaska is uniquely positioned to develop an outstanding interdisciplinary curriculum in marine ecosystem-based research and management. Faculty with interdisciplinary marine ecosystem research and teaching expertise are found at the University of Alaska Fairbanks (UAF) in the School of Fisheries and Ocean Science (SFOS), the College of Liberal Arts (CLA), the School of Management (SOM), and the School of Natural Resources and Agricultural Sciences (SNRAS). SFOS offers traditional MS and PhD degrees in Fisheries, Marine Biology, Oceanography, and Seafood Science and Nutrition. SFOS faculty include oceanographers, marine biologists, fishery scientists, and marine policy analysts that advise over 100 graduate students. SFOS students are evenly split between fishery sciences and marine sciences, with ~40% pursuing PhDs. The CLA Department of Anthropology offers MA and PhD degrees and currently houses over 40 graduate students, ~50% at the PhD level. Anthropology faculty pursue archaeological approaches to marine science, fisheries anthropology, and human ecology, with long-standing experience working in rural and Native Alaskan communities. Anthropology considers issues related to subsistence and community development world-wide, while its graduate students increasingly conduct research on the human dimensions of marine and coastal issues within a interdisciplinary curricula. The SOM Economics Department offers an MS degree in Resource Economics (RE) with a curriculum driven by the department's fisheries economists and participates in the Interdisciplinary Studies PhD degree. Many of the program's 10-15 graduate students write theses related to fisheries and other living marine resources. The Resources Management Department represents the social science and policy center for SNRAS, and participates in the graduate program in Natural Resources Management (NRM). The NRM program has 20-30 MS students and 5-6 PhD students. NRM faculty and graduate students have participated in numerous studies regarding the use and allocation of Alaska natural resources, including its marine resources.

UAF facilities available to IGERT students are distributed throughout the state and include:

1) The main Fairbanks campus (SFOS, CLA, SOM, SNRAS), with comprehensive library, laboratory, and computing resources.
2) The Juneau Center of SFOS (JCSFOS), which will include a new, 30,000 square foot research and teaching facility to be completed in 2008 adjacent to the recently completed NOAA Alaska Fisheries Science Center Ted Stevens Marine Research Institute (TSMRI). Students and faculty will share some NOAA facilities including their large fisheries and marine sciences library. Researchers from the TSMRI and from the Alaska Department of Fish and Game (ADF&G) hold affiliate appointments in the SFOS and serve on graduate advisory committees.
2) The Alaska Sea Life Center (ASLC) and the Seward Marine Center (SMC), in Seward, which include analytical and live tank laboratories for maintaining invertebrates, fish, marine mammals and seabirds. The SMC provides shops, small boats, and temporary housing for researchers working at the SMC and ASLC.
3.) The Fisheries Industrial Technology Center (FITC) in Kodiak, which includes the University's seafood and fisheries technology center. In addition, FITC is home to faculty engaged in marine ecology research and provides housing, office, and analytical laboratory space to resident and visiting faculty and students. FITC is adjacent to the NOAA Kodiak Fisheries Research Center.
4) The Kasitsna Bay teaching and research laboratory near Homer, which includes lab and dormitory facilities in support of teaching and research opportunities. The laboratory focuses on intertidal and coastal subtidal studies and the enormously productive fisheries of Lower Cook Inlet.
5) The Alaska Regional Research Vessel (ARRV), which will replace the retired R/V Alpha Helix. The new 236 ft vessel, based at the SMC, will be the state-of-the-science research vessel in the UNOLS fleet. Its design combines traditional oceanographic

sampling capabilities with the ability to assess fish stocks both acoustically and by trawling. With a science party of 25, the vessel can work year-round in Alaskan waters, including in seasonally ice-covered seas. Funding for this UAF initiative was approved by NSF in 2007.

6) The JCSFOS, SMC, FITC and Fairbanks campus are linked by a videoconferencing system that is used for distance delivery of classes, seminars, faculty meetings, thesis defenses, and meetings of graduate advisory committees. The videoconferencing system can be connected to additional sites on the UAS branch campuses in Sitka and Ketchikan and the UAA campus in Anchorage.

Institutional commitment UAF will provide faculty workload credits for the Program Coordinator to ensure institutionalization and continuation of the program beyond the period funded by NSF; administrative workload credits for the PI who will serve as Director; teaching workload credits for faculty that teach IGERT courses, including the IOESP and NPFMC summer courses; a guaranteed Teaching Assistantship provided by a student's home department in the student's second year; two Graduate School fellowships for IGERT students each year; administrative support; a supportive environment for interdisciplinary education and research; and office space for IGERT graduate students;

Funding for student stipends and research outside the scope of this IGERT and beyond the life of NSF funding will be possible from existing Graduate School fellowships, departmental Teaching Assistantships, fellowships from the UAF Rasmuson Fisheries Research Center, as well as extramural research grants. Several funding agencies within Alaska, including the North Pacific Research Board (NPRB), the Pollock Conservation Cooperative Research Center (PCCRC), the Alaska-Yukon-Kuskokwim Sustainable Salmon Initiative (AYK-SSI), Alaska Sea Grant, and the Gulf Ecosystem Monitoring (GEM) program of the Exxon Valdez Oil Spill Trustee Council (EVOSTC) have a strong commitment to marine ecosystem sustainability and building capacity in rural Alaska. Successes achieved during the life of NSF funding will provide leverage to attract ongoing support from these other entities.

Interactions with the existing UAF IGERT The MESAS program will complement the existing Resilience and Adaptation (RAP) IGERT that is currently housed at UAF and led by Gary Kofinas, Terry Chapin, Craig Gerlach, and Bernice Joseph. They are active collaborators in MESAS. RAP is terrestrially focused, but shares many of our themes. MESAS and RAP will share courses and faculty and encourage student interaction. Specifically, we plan to house MESAS students who work with Fairbanks faculty in offices with the RAP IGERT students as well as require our students to take the Integrative Assessment course that was developed for the RAP program. To the extent that internship opportunities overlap with the RAP IGERT at UAF, we will coordinate between IGERTs so as to best share existing opportunities. We will cross-advertise seminars and other visiting scholars' activities. We will share a common portal for the public and prospective students. We will jointly recruit students and refer prospective students to each other's programs, and IGERT faculty will serve on each other's student committees. Future collaboration will occur as we develop our program.

6. Performance Assessment / Project Evaluation

We plan to evaluate the program internally on an annual basis. We plan to administer anonymous year-end student evaluation questionnaires to assess the success of the program and identify the emergent needs of students. Concurrently, we will have a student-led program evaluation meeting each spring. On a more individual student basis, we will review the progress of each student and provide individualized support in addition to that received from the student's academic committee. We will establish an outcomes assessment framework for evaluating the

training and education provided to our graduates. This assessment will focus on professional, research, publishing, outreach, and leadership criteria. Internship hosts will also be asked to complete a brief survey regarding the performance of interns and the internship process. We will hold annual spring conferences with all MESAS participating faculty to review faculty satisfaction with the program and faculty perceptions of the overall preparation and performance of the students. All of these assessment instruments will be reviewed by the Steering Committee and adjustments made to the program as needed.

In addition to an internal annual evaluation, we will establish an **External Advisory Committee,** assembled with representatives from 1) a marine-oriented IGERT program outside Alaska, 2) the UAF RAP IGERT program, 3) a state management agency (likely ADFG), and 4) a federal management agency (likely NOAA Fisheries). The External Advisory Committee will meet in years 2 and 4 and will conduct a site visit, review results of the program questionnaire, interview students, faculty, administrators, and the program management team separately, and provide feedback on past performance and pathways for improvement. Our External Advisory Committee will also serve in our on-going program evaluation and refinement, to address how well our program is bridging with minorities, linking with the public and making a meaningful contribution to Alaska.

All academic programs at UAF, including the PhD programs cooperating in this IGERT, are reviewed every five years by a panel including members of the sponsoring faculty, members of other faculties in the University, and expert reviewers from outside the University. These reviews consider the implementation of outcomes assessment plans required by the University; all academic programs are required to remediate shortcomings identified by these reviews. Although not possible in the 5-year timeframe of this proposal, it is our intention to conduct periodic surveys of the employers of our graduates to gain insight into particular strengths or weaknesses in their preparation for post-graduate employment.

7. Recruitment, Mentoring, and Retention

We seek to enroll 20 new IGERT-supported PhD trainees. We will attempt to enroll 5 new trainees in years 1-4 of the program, although this number may vary slightly from year to year. Our goal is that 20% of these IGERT trainees will be Alaska Natives. Each UAF PhD student will receive two years of IGERT funding. Each of the participating Departments will commit to offering each IGERT trainee one year of TAship. As UAF builds its capacity to self-fund students with non-IGERT sources, we anticipate that additional students will be a part of the program through time. We will work with other IGERTs with programs in our area of focus to explore the possibility of cross-funded student exchanges. The enrollment of students on non-IGERT funding is key to our plans to institutionalize fully the program at UAF, and to this end, we will vigorously pursue the recruitment of Masters and PhD students funded by research grants and private foundation fellowships, and exchange programs to MESAS.

Student recruitment. Our recruitment will target three populations that we think are most likely to benefit from the UAF MESAS: (1) students distributed nationally, but most likely to be enrolled in interdisciplinary programs with a sustainability emphasis; (2) minority students and professionals, especially Alaska Natives; and (3) members of rural and subsistence-based communities.

1) The likely most effective recruiting tools for national recruitment will be through the web and word-of-mouth from students or faculty who know about the program. We will develop these recruiting tools by creating and regularly updating the web page with information about the

program and about student research (the most effective recruitment component of the webpage), and by sending an email each year to about 150 colleagues who are engaged in marine ecosystem research, encouraging them to tell exceptional undergraduates about our program. We will also post descriptions of the program on list-serves of societies and research networks that represent the major disciplines.

We will strongly encourage prospective students to contact either the MESAS leadership or MESAS faculty in their area of interest prior to applying. The resulting e-mail and telephone discussions, although time-consuming, will provide an opportunity for prospective applicants to determine whether this program is a good match for their interests and provides us with the opportunity to encourage appropriate applicants and discourage inappropriate ones. This pre-admission discussion will be the critical aspect of recruitment that convinces our best applicants to apply and enter the program. Prospective students will apply for funding from this IGERT program as well as apply to degree programs in departments that include IGERT-participating faculty. Applications will be reviewed by faculty in the student's major field. Students will be selected by the Steering Committee in order to balance major fields and advisors as well as with an eye to enhancing diversity. Students who are not sufficiently prepared to begin a PhD will be encouraged to pursue a MS in an MESAS department, take MESAS courses, and later reapply to the PhD program.

2. We place a strong focus on minority recruitment, particularly on Alaska Native students. We acknowledge that targeting Alaska Natives is a difficult task. For example, in Juneau, the urbanized, well-educated state capitol, less than half of the Alaska Native high school students graduate. Over the past decade, UAF has developed a number of successful programs to increase the access of Alaska Natives to higher education. During this time the UAF College of Science, Engineering and Math has tripled the number of science majors who are Alaskan Natives. Consistent with University's 2010 strategic plan for doubling the number of Alaska Native students, we propose to build on previous successes by providing a unique opportunity to those interested in marine ecosystem science to continue their education in their home state. The NSF-supported Alaska Natives in Science and Engineering Program (ANSEP) at UAF has been successful in recruiting rural and Alaska Native students into undergraduate engineering programs with a high graduation rate; recently ANSEP is expanding its efforts to include students in biological sciences, particularly fisheries; the School of Fisheries and Ocean Sciences is formally cooperating with ANSEP through their recruitment and retention program. Graduates of ANSEP will be particularly targeted for recruitment into the MESAS Program. We wish to continue UAF's cross-cultural approach to education in which Alaskan students exchange scientific and social perspectives with students from throughout the world, and therefore we will also actively recruit students nationally and have MESAS students mentor Native and rural Alaskan undergraduates (see *IGERT Students as Mentors* above). Additionally, we will recruit PhD students from existing resource management positions and from faculty positions in rural colleges throughout Alaska. Both of these target audiences already have MS degrees and have expressed an interest in pursuing a PhD. Coursework will be arranged so that student could spend as little as one year on campus and complete the remainder at their degree program from a remote location, conducting research at that location and participating in MESAS activities via distance-education modalities. Having students that are concurrently employed by agencies is common at UAF. We will hold annual information sessions for students of the UAF Rural Development Masters Program, enrolled primarily with adult professionals who are Alaska Natives. We will also hold information sessions with organizations like the First Alaskans Institute and various for- and not-for-profit native organizations, such as the Western Alaska Community Development Association (and its six associated groups), the Arctic Slope Regional Corporation, and the Sealaska Institute.

Mentoring and retention Many interdisciplinary programs fail because students fall through the cracks between traditional departments each of which may have support systems to mentor their own disciplinary students. We therefore will put substantial effort into student mentorship through the following steps: (1) development of a sense of community among MESAS students by providing a common curriculum in the first year including a four-week intensive course, a retreat, and interdisciplinary office space identified explicitly for MESAS students; (2) development of a working relationship between MESAS leadership and incoming students during the summer class; (3) attendance of the first meeting by a member of MESAS leadership of each student with their graduate committee to ensure that the committee understands what is entailed in an IGERT degree program and to educate MESAS leadership about the needs and concerns that each committee and student may have about the design of his/her academic program [From this point onward, the advisor and graduate committee assume primary responsibility for mentorship, as in most PhD programs]; (4) annual evaluation of the progress of each student; (5) general encouragement that students contact MESAS leadership about any issues of concern; and (6) annual meetings of all faculty who advise MESAS students to discuss the special challenges and needs of students pursing an interdisciplinary track. This mentoring program is modeled after the UAF RAP IGERT program, and it has generally worked well. MESAS students will be required to have at least one appropriate committee member from a disciplinary field outside their degree program.

8. Recent Traineeship Experience and Results from Prior NSF Support

The first federally funded graduate traineeship program in Alaska, *Regional Resilience and Adaptation: Planning for* Change (NSF #0114423), was awarded to the University of Alaska Fairbanks (UAF) in 2001 and was renewed in 2007. Each of the leadership team of the current RAP IGERT (Kofinas, Chapin, Gerlach, Joseph) is included in our proposal as a Collaborator, and four faculty (Barnhardt, Greenberg, Herrmann, and Murray) will serve as both MESAS and RAP faculty participants, offering great potential for cross-IGERT interaction. RAP was initiated to train graduate students to study regional sustainability through the integration of social and natural science. Today RAP is regarded at UAF and in Alaska as a vanguard effort in this area and is internationally acknowledged as a leading graduate program contributing to the interdisciplinary fields of resilience theory and sustainability science (Starzomski et al. 2004). Questions of sustainability for Alaska and the Circumpolar North are the focus of RAP, exploring this topic through an investigation of global-local interactions, up- and down-scale effects, important feedbacks, adaptive capacity, and critical thresholds of social-ecological change. In the first RAP IGERT program, 51 students entered the UAF RAP, 36 as PhD students (33 of them as IGERT supported PhD trainees), and 15 as masters students. Of RAP students 71% were women, 16% minority (primarily Alaska Native or American Indian). Because Alaska has a small population with massive responsibilities for managing natural resources, RAP students have played unusually important roles during their graduate careers. For example, Susan Hazlett wrote the Coastal Zone Management Plan for the State of Alaska, a length of coastline greater than that of the contiguous states. Colin Beier wrote the congressionally mandated evaluation of the Tongass Wilderness Plan for the USFS. Martin Robards synthesized data on contaminants in Alaskan marine mammals, as input to decisions on the safety of subsistence foods. La'ona DeWilde (Alaska Native graduate) manages water quality assessment for the Yukon River Drainage (the second largest watershed in North America). The continuation of the RAP program and creation of the MESAS program offers a great opportunity to explore sustainability and resilience in the marine and terrestrial realms.

9. International Collaboration

An international component is not currently planned.