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Design of ecoregional monitoring in conservation areas of high-latitude ecosystems under contemporary climate change

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ABSTRACT

Land ownership in Alaska includes a mosaic of federally managed units. Within its agency's context, each unit has its own management strategy, authority, and resources of conservation concern, many of which are migratory animals. Though some units are geographically isolated, many are nevertheless linked by paths of abiotic and biotic flows, such as rivers, air masses, flyways, and terrestrial and aquatic migration routes. Furthermore, individual land units exist within the context of a larger landscape pattern of shifting conditions, requiring managers to understand at larger spatial scales the status and trends in the synchrony and spatial concurrence of species and associated suitable habitats. Results of these changes will determine the ability of Alaska lands to continue to: provide habitat for local and migratory species; absorb species whose ranges are shifting northward; and experience mitigation or exacerbation of climate change through positive and negative atmospheric feedbacks. We discuss the geographic and statutory contexts that influence development of ecological monitoring; argue for the inclusion of significant amounts of broad-scale monitoring; discuss the importance of defining clear programmatic and monitoring objectives; and draw from lessons learned from existing long-term, broad-scale monitoring programs to apply to the specific contexts relevant to high-latitude protected areas such as those in Alaska. Such areas are distinguished by their: marked seasonality; relatively large magnitudes of contemporary change in climatic parameters; and relative inaccessibility due to broad spatial extent, very low (or zero) road density, and steep and glaciated areas. For ecological monitoring to effectively support management decisions in high-latitude areas such as Alaska, a monitoring program ideally would be structured to address the actual spatial and temporal scales of relevant processes, rather than the artificial boundaries of individual land-management units. Heuristic models provide a means by which to integrate understanding of ecosystem structure, composition, and function, in the midst of numerous ecosystem drivers.

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1. Introduction and background

Given that effects of contemporary climate change on climatic and abiotic conditions have been and are predicted to remain of greatest magnitude in far-northern latitudes (ACIA, 2005; Chapin et al., 2005, 2006; IPCC, 2007; Barber et al., 2009), there is urgent need to achieve a robust understanding of the status and trend of natural resources in the region, through monitoring (e.g., Table 1). Furthermore, the large uncertainties associated with this rapid change further underscore the importance of monitoring for informing management decisions (Suffling and Scott, 2002; USFWS, 2010). Juxtaposed with this great change and uncertainty, lands within Alaska and northern North America have natural resources that are widely renowned for their abundance and condition, and they act as a critical life-history stop for species that range widely (e.g., birds migrating from five continents via various flyways, caribou {*Rangifer tarandus*} herds numbering in the hundreds of thousands) (Barber et al., 2009).

In the midst of this, natural-resource managers of protected areas in the state of Alaska, USA face a distinctive mix of infrastructural, legal, socio-economic, and topographic conditions that shape their programs for monitoring resources. As is the case for many high-latitude areas, human settlement across Alaska is sparse. Although influence of various anthropogenic activities extends well beyond the infrastructural footprint of the cities, towns, and villages in the state, natural processes remain the predominant drivers of ecosystem composition, structure, and function in ecosystems of Alaska.

Here, we discuss the geographic and statutory contexts that influence development of monitoring; argue for the inclusion of significant broad-scale monitoring; discuss the importance of defining clear programmatic and monitoring objectives; and draw

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Table 1
Consequences of contemporary climate change of greatest concern to land managers within each of four ecoregions within Alaska. Prioritized lists were created by natural-resource managers and scientists participating in the April 2009 Forum on Ecoregional Monitoring.

Polar	Bering Coast	Interior Alaska	North Pacific Coast
Altered management of harvested species	Change in plant and animal community composition and structure	Altered fire regimes	Altered phenology (better understood in terrestrial ecosystems)
Altered distribution of invasive species (relating to detection and control)	Drying of wetlands	Changes in invasive species diversity and distribution	Water quality, especially melting of glaciers, surface water flow, water chemistry, and timing and quantity of fresh water entering marine systems (and consequent local effects on salinity)
Altered water quality and quantity	Changes in amount and timing of precipitation	Altered subsistence management (population sizes, reproduction, and demography; harvest regulations; phenology)	Altered animal community dynamics (terrestrial and marine), due to species' differential responses to climate change
Effects on biological diversity (and legal and statutory ramifications)	Alterations to terrestrial hydrology	Effects on rare and declining species and habitats (identify losses, determine conservation actions needed)	Changes in ocean dynamics (upwellings, acidification, altered currents, impacts on marine food webs, nutrient flows, effects on seabirds)
	Changes in the types, levels, and spatial distribution of anthropogenic activities	Alterations to water quality and quantity (including management of upstream activities)	Change in plant community composition and structure
		Effects on species covered by treaties (for which broad-scale coordination is essential)	Alterations to migratory and invasive species

from lessons learned from existing long-term, broad-scale monitoring programs. We describe how the Alaska context informs the process of developing multi-faceted monitoring that supports inference and has implications beyond individual management units, and balances monitoring objectives related to resource conservation with those related to numerous active-management decisions. We focus on the characteristics of, and theoretical and pragmatic lessons learned from, large-scale monitoring programs from around the northern hemisphere (Table 2) that were featured in a Forum on Ecoregional Monitoring in April 2009 (http://alaska.usgs.gov/science/biology/ecomonitoring/index.html). These programs include: Parks Canada Agency (PCA), US National Park Service Inventory & Monitoring (NPS I&M), Circumpolar Biodiversity Monitoring Program (CBMP), US Forest Service Inventory & Analysis Program (FIA), Kenai National Wildlife Refuge's Long-Term Ecological Monitoring Project (LTEMP; Morton et al., 2009), Great Britain's Countryside Inventory (CI), Norway's 3Q Agriculture monitoring, National Aquatic Resource Surveys (NARS), US Environmental Protection Agency Environmental Monitoring & Assessment Program (EMAP), Environmental Monitoring & Assessment Network (EMAN), and Bonanza Creek Long-term Ecological Research site. We use this focus and these examples to consider how broad-scale monitoring in northern latitudes will inform adaptation to contemporary climate change, which is shifting baseline conditions; increasing uncertainty in the amount, distribution, and timing of ecosystem goods and services; and changing the dynamics of spatially integrative resources (e.g., long rivers, migratory ungulates).

All monitoring programs reflect the suite of statutory, logistical, legal, and natural-resource conditions that provide context for and guide their development. In Alaska, the land-use pattern consists of a patchwork of many large, federally managed areas (Fig. 1). Lands managed by four federal agencies (i.e., USFWS, BLM, NPS, and USFS) span 89.1 million ha, and collectively constitute 52.5% of the Alaskan land base (Table 3). The importance of these lands for the four respective agencies is substantial, because they constitute up to 81% of each agency's land holdings, nationally (Table 3). Among these four agencies, notable differences in mandate and management philosophy exist; differences can be greater still, however, between these and other non-federal landholders in the state. Difficulty in finding shared monitoring objectives and indicators across jurisdictions also reflects the agencies' constituencies and the historical legacy of how lands were allocated to meet agency mandates: national forests were established in heavily timbered areas, wildlife refuges encompass waterfowl-supporting wetlands and connecting low-elevation habitats, and national parks typically protect areas having unique geology, history, or often-mountainous scenic beauty (Fig. 1).

Logistical implementation of monitoring faces several challenges in Alaska. Road density is very low in the state – 0.0023 km of major highway per square km of Alaskan land, and 0.14 km of paved roads (including urban areas) per square km. This implies that: (a) all of the ecological effects associated with roads (Trombulak and Frissell, 2000; Havlick, 2002) are very limited in scope, across Alaska (though effects of ORV use can be locally pronounced), and (b) transportation costs to sampling sites can constitute >85% of monitoring-program budgets. Logistics in Alaska are further complicated by the fact that crevassed glaciers, dangerously steep slopes, and nearly impassable areas (e.g., deep bogs, dense forests) can increase travel time and costs. The time available for fieldwork is typically shorter than in more-southern latitudes due to the region's marked seasonality and snow cover that can prevail for 8 months of each year in some areas.

In addition to these natural attributes that affect monitoring, several legislative, legal, and socio-economic contexts also figure heavily in design considerations for broad-scale monitoring in the region. At the broadest ideological level, resource conservation in Alaska and northern Canada is much more comprehensive, compared to wildlife refuges or reserves in the contiguous USA and southern Canada within the same agency. To date, active management of habitats (which would permit manipulative experiments in an adaptive-management context) has occurred much less frequently in conservation areas of Alaska than in more-developed portions of the globe. In contrast, however, wildlife-population management is relatively common, as evidenced by the greater prominence of subsistence and sport harvest for meat (of ungulates, other furbearers, and fishes) in Alaska and northern Canada, relative to most of the contiguous USA or southern Canada. Another distinctive wrinkle to land management is that within conservation areas, private landholdings constitute legacies of past settlement patterns, and can locally affect resource dynamics. For example, the state's 16 USFWS national wildlife refuges contain