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Preface

Ecoregional-scale monitoring within conservation areas, in a rapidly changing climate

Long-term monitoring of ecological systems can prove invaluable for resource management and conservation. Such monitoring can: (1) detect instances of long-term trend (either improvement or deterioration) in monitored resources, thus providing an early-warning indication of system change to resource managers; (2) inform management decisions and help assess the effects of management actions, as well as anthropogenic and natural disturbances; and (3) provide the grist for supplemental research on mechanisms of system dynamics and cause-effect relationships (Fancy et al., 2009). Such monitoring additionally provides a snapshot of the status of monitored resources during each sampling cycle, and helps assess whether legal standards and regulations are being met.

Until the last 1–2 decades, tracking and understanding changes in condition of natural resources across broad spatial extents have been infrequently attempted. Several factors, however, are facilitating the achievement of such broad-scale investigation and monitoring. These include increasing awareness of the importance of landscape context, greater prevalence of regional and global environmental stressors, and the rise of landscape-scale programs designed to manage and monitor biological systems. Such programs include the US Forest Service's Forest Inventory and Analysis (FIA) Program (Moser et al., 2008), Canada's National Forest Inventory, the 3Q Programme for monitoring agricultural landscapes of Norway (Dramstad et al., 2002), and the emerging (US) Landscape Conservation Cooperatives (USDOI Secretarial Order 3289, 2009; Anonymous, 2011). This Special Section explores the underlying design considerations, as well as many pragmatic aspects associated with program implementation and interpretation of results from broad-scale monitoring systems, particularly within the constraints of high-latitude contexts (e.g., low road density, short field season, dramatic fluctuations in temperature). Although Alaska is the focus of most papers in this Special Section, we posit that many of the issues that characterize the remote, relatively undisturbed ecosystems of high northern latitudes are widespread and thus applicable to natural-resource management and conservation across northern portions of the Holarctic ecozone and indeed anywhere broad-scale monitoring is contemplated.

In the Alaska context in particular, many land-management units are suggested to contain entire functioning ecosystems. Management areas within Alaska span up to 9 million ha *each* and collectively constitute $\geqslant$85% of the conservation estate of the USA, in both the US National Park Service (NPS) and the US Fish & Wildlife Service (USFWS) (Beever and Woodward, 2011). Because of tremendous isolation and seasonal productivity, many resources within Alaska and other high-latitude areas are remarkable at the global scale, in both the numbers of individuals and their contributions to ecological diversity and function. In addition to this unique biological template, high-latitude areas have exhibited some of the most-dramatic contemporary departures from long-term means in climatic parameters since the mid-20th century (ACIA, 2005; Barber et al., 2009; IPCC, 2007). Examples of both biotic and abiotic resources in high-latitude ecosystems have exhibited rapid changes in status and trend, although broad-scale data on most biological resources and their responses to contemporary climate change are lacking (ACIA, 2005; Barber et al., 2009; Wolken, in preparation). In high-latitude areas such as Alaska, protected areas serve important roles not only for their current role in landscape and species conservation, but also as likely recipients of species whose geographic ranges are shifting northward due to contemporary climate change (Hitch and Leberg, 2007; Parmesan et al., 1999). As has been the case for conservation areas of many agencies throughout the world, USFWS refuges in Alaska have until recently performed monitoring with methods, sampling strategies, and objectives that are largely independent of each other and of adjacent lands under different jurisdiction. However, USFWS and its partners are seeking to improve coordination and compatibility across diverse monitoring programs, by balancing existing local monitoring efforts tailored to address smaller-scale questions with program continuity across the landscape.

Effects of contemporary climate changes in Alaska are but one of several stimuli that have led to consideration by the USFWS of bolstering conservation monitoring at scales broader than that of individual management units, including collaboration with other agencies. Broad-scale monitoring, thoughtfully designed, can also provide practical benefits because: (a) contrary to purely local monitoring, it is able to distinguish between local anomalies and broad-scale patterns; (b) it allows greater area of inference and domain of applicability, as well as assessment, trend detection, and synthesis at broader spatial and temporal scales; (c) when using consistent methods, it can achieve greater collective sample size, higher statistical power, and thus greater sensitivity to detect any changes that may be occurring (i.e., serve as a more-sensitive early-warning indicator of ecosystem change); (d) it can detect phenomena such as thresholds, nonlinear dynamics, synergies, and cross-scale and hierarchical dynamics; and (e) changes in many processes can only be correctly interpreted from monitoring at broader spatial resolutions (Beever and Woodward, 2011). From a genetic perspective, thinking broadly is critical for avoiding: population bottlenecks, maladaptive Founder effects, and the narrowing and homogenization of genetic diversity. Examples of broad-scale processes relevant to contemporary climate change include fire regime that affects the availability of forage for migratory ungulates; storm seasonality relative to sea-ice melt, which in turn

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affects coastal erosion; shifting distributions of relatively vagile species that appear as local extinctions within boundaries of a single management unit; and the shifting mosaic of wetlands as some regions dry and others experience thawing permafrost.

Although there are many potential benefits of monitoring at broad spatial scales, successful monitoring at regional scales may be hampered by the substantial challenge of identifying monitoring objectives. Because monitoring is a science-based tool often connected to both management and policy decisions, its structure should ideally be tied to ultimate policy applications, which in turn determine monitoring objectives. To identify regional-level policy applications, increased efficiency could result if policy objectives were harmonized among agencies within (and when possible, across) regions, despite differing legislative mandates and spatial boundaries, to define a set of fundamental goals for the landscape as a whole.

The overarching goal of the Special Section is to examine the statistical, design, logistical, and pragmatic issues of monitoring ecological systems at scales broader than those of individual conservation units, often using examples relevant to contemporary climate change. The approaches and advances in landscape-scale ecology and conservation have enabled investigation of ever-broader dynamics and forecasting. Moreover, ever-increasing computing capacity and efficiency, and availability of freely available statistical packages that are iteratively expanded and refined (R Development Core Team, 2010) are enabling analysis of large datasets. Unfortunately, however, broad-scale quantitative assessment of the efficacy of conservation-area management (be it active or passive) remains largely lacking (Parrish et al., 2003). Contemporary climate change not only highlights the importance of thinking broadly (e.g., due to migration of species' distributions, and shifting mosaics of wetlands, permafrost, and other waters), but also is a lens that may focus discussions about future monitoring strategies. Although challenging to elucidate, understanding of *mechanisms* is especially critical in broad-scale investigations of climate-biology relationships, not only for assessments of which aspects of climate species are responding to (often in concert with other disturbances), but also for informing strategies of adaptation and mitigation (Beever et al., 2010; Beever and Belant, in press a). Consequently, such understanding allows prediction of which portions of the landscape may be especially vulnerable to climate-induced losses, which may act as refugia, and which are particularly likely to receive species whose ranges are migrating over time due to altered climate. We thus encourage incorporation of known or hypothesized mechanisms of ecological response to climate into monitoring-program development. Here, we briefly summarize some of the salient points from each of the constituent papers of the Special Section.

Beever and Woodward (2011) seek to address the full range of considerations, challenges, and benefits associated with establishment of ecoregional monitoring in high-latitude areas such as Alaska. From synthesis of seven broad-scale monitoring programs, they outline the lessons learned from their implementation, as well as key strategic questions that new programs must address in structure and design of ecoregional monitoring programs. Using local- and ecoregional-scale conceptual models, in conjunction with agency mandates and priorities, they derive possible overarching programmatic objectives that could be used to guide development of broad-scale monitoring across high-latitude conservation areas, as well as examples of monitoring indicators for each of three spatial scales. Finally, they outline tools especially relevant for high-latitude ecosystems that can be used to complement monitoring fieldwork, such as remote sensing, ecological forecasting, vulnerability assessments, and simulation modeling.

Barrett and Gray (2011) further discuss the issues related to developing a broad-scale monitoring program by describing the advantages and drawbacks of extending the US Forest Service's Forest Inventory and Analysis (FIA) program from its currently limited southern extent within the state to all of Alaska. They illustrate how the design of a monitoring program must reflect location-specific objectives, ecological conditions, and logistical constraints by describing how the FIA program might be adapted to the particular context of Alaska. Challenges to monitoring forests in Alaska include the highly unpredictable and potentially dramatic changes forecasted for high latitudes, as well as the difficulty of collecting data in vast, roadless areas. They also suggest approaches to address particular information needs: herbaceous vascular plants, invasive species, disturbance frequency and impact, habitat distribution, and carbon accounting. Finally, they emphasize the importance of collaboration among agencies to accomplish effective monitoring. In particular, the FIA program, while supplying only imprecise estimates for small land areas, can provide context for monitoring done by others at smaller spatial extents.

Reflecting several years of effort to implement a broad-scale monitoring program for vegetation in national parks in remote areas of southern Alaska, Thompson et al. (2011) provide one solution to addressing the trade-offs involved in monitoring a multi-scale, diverse system. The authors summarize the iterative process by which they refined their monitoring objectives (e.g., through defining a target population, sampling frame, and the sampled population of specific land-cover classes), given the particular logistical constraints involved in broad-scale monitoring at high northern latitudes, and walk the reader through the process of calculating needed sample size to achieve objectives (e.g., involving process variation and a rotating-panel design). Phases for developing sampling designs to achieve these objectives included (a) empirical definition of a sampling frame (using Path Distance analysis tools) that delineated feasibly accessible portions of each park, (b) simulation analyses to determine the size and configuration of ground sampling units (single plots vs. grids of plots), and (c) additional simulations to determine the sample size and re-visit frequency needed to achieve adequate statistical power to obtain a specified likelihood of detecting at least a pre-determined level of true change in vegetation over a given time period. Without such effort, the authors suggest that programs may either be unable to detect management-relevant changes by having too few samples, or waste precious resources by having too many samples. Their experience provides a 'worked' example of some of the many trade-offs that must be made, in these ecoregional-monitoring contexts.

Whereas Thompson et al. considered *how many* samples were needed across space to achieve a desired threshold of statistical ability to detect change (i.e., power) across broad spatial scales, Reynolds et al. (2011) discuss *how long* monitoring must be sustained to be effective and efficient at meeting ecoregional monitoring objectives, such as detecting a decline meriting the International Union for Conservation of Nature (IUCN) 'vulnerable' criterion. They use analysis of monitoring data on densities of declining brown bear (*Ursus arctos*) populations in southwest Alaska to illustrate the process of implementing planning studies to assess the likelihood of meeting conservation-monitoring objectives. Brown (grizzly) bears are a conservation focus not only in their own right, but also affect numerous other high-profile ecosystem components (e.g., salmon, caribou, moose) through the ecological roles they play, and the management decisions they require. The authors preface the implementation process by highlighting the importance of planning studies, describing their main components, and discussing potential challenges that may arise. As with the Thompson et al. article, they underscore the importance of defining clear monitoring objectives, especially when encompassing greater physiographic and biotic diversity as monitoring expands to ecoregional extents. The authors walk the reader through many of the

trade-offs and specific steps needed to realize an effective and efficient monitoring design, such as identification of biologically and management-relevant level of change that monitoring should be able to detect, and allocation of finite resources to more-intensive, less-frequent surveys versus less-intensive, more-frequent surveys. Given the uncertainties of response of many ecosystem components to contemporary climate change (Beever and Belant, in press b), planning studies can be used to bound expectations on the length of monitoring required to detect a specified level of true biotic change.

Collectively, these articles address the decisions and processes across a range of specificity and detail that are needed to develop ecoregional-scale monitoring. At the most-general level, the articles illustrate how monitoring-program strategy reflects high-level objectives by using a number of extant examples of ecoregional monitoring programs. Additionally, the role that pragmatic considerations play in determining program strategy is exemplified by issues arising around the expansion of the national FIA program to all of Alaska, and issues associated with implementing vegetation monitoring within large, remote national parks across southern Alaska. In terms of specific indicators, effectively addressing information needs derived from programmatic objectives can be accomplished by developing appropriate spatial and temporal sampling frames. Development of a successful monitoring program requires carefully balancing the trade-offs that inevitably arise at each decision point, whether addressing general or specific issues. Ironically, many of the factors that provide strong impetus for broad-scale organization of conservation monitoring in the face of contemporary climate change are the same factors that constrain and complicate implementation of such monitoring of the globally remarkable biotic and abiotic resources that define northern latitudes.

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