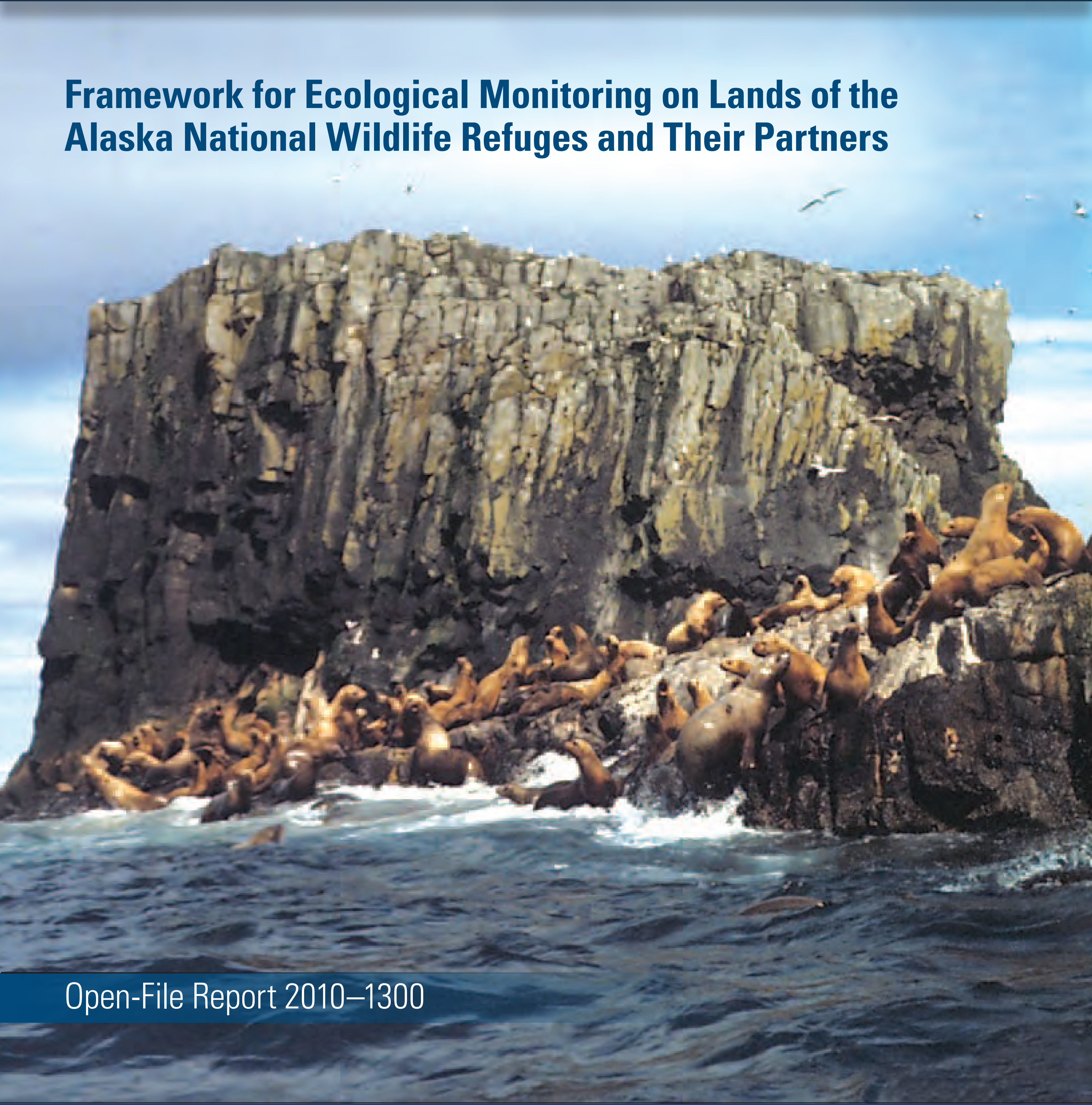
Framework for Ecological Monitoring on Lands of the Alaska National Wildlife Refuges and Their Partners



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U.S. Department of the Interior
U.S. Geological Survey

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By Andrea Woodward and Erik A. Beever

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Executive Summary

National Wildlife Refuges in Alaska and throughout the U.S. have begun developing a spatially comprehensive monitoring program to inform management decisions, and to provide data to broader research projects. In an era of unprecedented rates of climate change, monitoring is essential to detecting, understanding, communicating and mitigating climate-change effects on refuge and other resources under the protection of U.S. Fish and Wildlife Service. Moreover, monitoring results must address spatial scales broader than individual refuges. This document provides guidance for building a monitoring program for refuges in Alaska that meets refuge-specific management needs while also allowing synthesis and summary of ecological conditions at the ecoregional and statewide spatial scales.

Chapter 1. Context for Developing Broad-Scale Monitoring for the Alaska NWRs

The National Wildlife Refuge System (NWRS) of the U.S. Fish and Wildlife Service (USFWS) maintains and protects approximately 38 million ha (hectares) of wildlife habitat in 551 refuges and other units of the system[1]. More than 81 percent (that is, 31 million ha; 77 million acres) of the NWRS holdings occur in the 16 refuges in Alaska, and 24 percent of the Alaskan refuges is designated Wilderness. Refuges in Alaska provide critical habitat for resident and migratory animals. Their large size, relatively sparse human population, and Alaska's extremely low road density means that these refuges contain complete, comparatively intact ecosystems, in contrast with most refuges in the rest of the country. Besides being guided by legislation (The Refuge Administration Act, as amended) governing the entire refuge system, refuges in Alaska also are regulated by specific rules authorized by the Alaska National Interest Lands Conservation Act (ANILCA). In 1980, ANILCA created and/or expanded refuges and other conservation system units across Alaska. ANILCA mandated that these 16 refuges be managed to protect a wider range of characteristics than do other U.S. refuges, namely to conserve natural landscapes, wildlife species dependent on vast relatively undeveloped areas, and entire ecosystems; and to provide opportunities for subsistence use.

[1]These numbers exclude the area added by establishment of the Northwestern Hawaiian Islands Marine National Monument, which is co-managed with NOAA.

Chapter 2. Programmatic and Monitoring Objectives for Alaska NWRs

Multiple sets of objectives are required to underpin the development of a monitoring program. Programmatic objectives derive from the agency information needs and context, which in turn reflect the resources for which the agency is responsible, the nature of the responsibility, and available management tools as defined by statute. The Alaska NWR monitoring program will be embedded in the national program that is being developed concurrently. The draft programmatic objectives for the national program include:

1. Meet the Refuge System's legal mandate to monitor the status and trends of fish, wildlife, and plant populations on refuges, to preserve wilderness character, and to collect and manage information needed to maintain biological integrity, biological diversity, and environmental health, and to preserve the character of designated wilderness within the System.
2. Advance fish and wildlife conservation at refuge and broader landscape scales in an adaptive-management cycle by providing scientific information that supports conservation planning and design, guides learning through evaluation of conservation delivery, and provides a basis for hypothesis-driven research.
3. Implement monitoring of fish, wildlife, plants, physical resources, and ecological processes to reduce uncertainty in decisions related to impacts of climate change and other stressors, provide early warning of changing conditions, and guide development of management actions that facilitate adaptation to climate change.
4. Synthesize, interpret, and report on the condition of fish, wildlife, plants, and habitats conserved by the Refuge System in a manner that documents the contributions of the System within the context of the larger conservation estate and clearly communicates its value to the American public.

5. Enhance effectiveness and reduce costs by coordinating and integrating monitoring of natural resources at landscape scales through collaboration with other Service programs, agencies, and organizations.

Monitoring objectives derive from the programmatic objectives and specifically reflect the information needs of the agency to describe what should be monitored. Refinement of these objectives leads to measurable objectives and the identification of indicators, attributes, and sample plans. Potential program-level monitoring objectives include:

1. Determine trends in population size of species subject to subsistence use.
2. Determine whether intact ecosystems and natural processes are being conserved within and across refuges, especially in response to climate change.
3. Determine trends in populations of focal species, where focal species are determined by the agency and include a subset of 'trust' species plus other priority species (for example, species especially sensitive to climate change).
4. Determine trends in water quality and quantity relative to legal standards and levels necessary for ecosystem function.

These objectives express the most general information needs. There may be refuge-specific, ecoregional, statewide, and in some cases, international aspects to all of these objectives.

Chapter 3. Developing Monitoring Program Strategy and Structure

Examples of how extant broad-scale monitoring programs addressed necessary trade-offs in monitoring program design were presented at the Forum on Ecoregional Monitoring for the NWRS and other Public Lands across Alaska, held April 2009, in Anchorage. Conclusions regarding considerations relevant to monitoring program development by staff of the Alaska NWRs include:

- *Program commitment and relevance*. Achieving sustained support requires regular reporting of results, and champions of the program at multiple political and administrative levels, which are all aided by having clear objectives and an organizational commitment to efficiency and effectiveness of the program.
- *Linkage to management*. Monitoring results must provide relevant information and must be clearly communicated to management. Two classes of information needs exist for refuge managers: information regarding protection of biodiversity and ecosystem integrity, and information regarding management actions that are currently taken or are likely to be taken.
- *Investment in Planning*. The design of a monitoring program is not a trivial exercise, and its success depends on making carefully considered decisions. Rushing to the data-collection phase will compromise the program in the long term.
- *Investment in Data Management*. Monitoring results cannot be delivered promptly and accurately, nor can data be properly archived for future unforeseen uses, without a significant investment (about 30 percent of program budget) in data management.
- *Adaptive monitoring*. The monitoring program must be flexible to changes in information needs as resource condition changes in response to changes in system drivers; with changes in the political and social climate; as monitoring and research generate knowledge; and with changes in data collection technology.
- *Collaboration for efficiency*. Collaboration with other agencies, and with national and international programs, especially for treaty species, will enhance the value of the NWRS program of monitoring in Alaska, even if data can be combined only qualitatively.
- *Context for monitoring design and interpretation*. Ecosystem conceptual models identify important elements and articulate hypotheses regarding system function, and therefore are useful tools for planning monitoring, linking monitoring to adaptive management, and learning from monitoring results.
- *Spatial scales*. In general, refuge-specific monitoring plans will be most effective if embedded within an ecoregional and statewide monitoring framework so that results can contribute to, and be interpreted in, an ecoregional context. In some cases, monitoring projects may meet purely local needs, but that determination must be reached after consideration of the broader context.
- *Temporal scales*. An effective monitoring strategy recognizes that some monitoring objectives meet short-term, tactical needs and others meet long-term, strategic needs.
- *Survey and monitoring designs*. Probabilistic sample designs are necessary for extrapolating monitoring results from the sample to an entire population or region.

The structure of the monitoring program will reflect agency context and culture and must describe where responsibilities, capabilities and decisions reside both organizationally and spatially. Because monitoring objectives are hierarchical in time and space, a hierarchically designed monitoring structure is appropriate to consider.

Chapter 4. Identifying Monitoring Indicators

Unlike most of the refuges in the contiguous United States, the Alaska refuges are expected to protect natural landscapes and entire ecosystems; wildlife species dependent on vast, relatively undeveloped areas; and particular species of conservation interest. Consequently, they are faced with a challenge similar to that of national parks. Namely, they must develop a monitoring program to assess whether protective management is successfully conserving something as complex and open-ended as biodiversity. In addition, the NWRS in Alaska has specific resources for which it is responsible and around which managers undertake active management (for example, species subject to subsistence harvest) for which an adaptive-management approach may be appropriate. A potential approach, therefore, is to develop two monitoring programs (Timko and Innes, 2009), (1) to address the strategic information need for understanding of status and trends of ecological integrity, and (2) to address the tactical information need to assist managers in assessing the effectiveness of management actions. Sources for indicators of ecological integrity include conceptual models at the refuge and ecoregional scales; sources of indicators for management actions include refuge purposes, as specified in ANILCA. There will always be more potential indicators than the program can feasibly accommodate, and there are a number of options and strategies for determining priorities and incorporating cost considerations.

Chapter 5. Developing Sample Frames

The primary consideration for designing a sample frame for any particular indicator is a specifically stated objective. Frequently, the identification and framing of a question is the most difficult task faced during the design of monitoring programs. Although staff of the Alaska NWRs are several steps away from articulating monitoring objectives, our discussion in Chapter 4 suggests that it is likely that there generally will be both tactical and strategic monitoring needs. The type of need, along with characteristics of the indicator, detail and confidence desired, opportunities for collaboration, and budget, determine the sampling strategy. One of three strategies is most commonly used: index (reference sites), especially appropriate when there is a model to extrapolate results; census (comprehensive), such as can be obtained using remote-sensing; and probabilistic samples, appropriate when the goal is to extrapolate results from a subset of a population to draw conclusions about an entire domain of interest. If a probabilistic strategy is adopted, there are many ways to construct the sample frame to maximize inference while accommodating the logistical challenges of operating in the Alaskan environment.

Chapter 6. Building Blocks for Alaska NWRs Monitoring Program

Several building blocks of the foundation for developing a monitoring program for Alaska NWRs include:

- *Conceptual models*. Refuge-specific and ecoregional conceptual models have already been developed for Alaska, although they will need refinement to address specific monitoring questions.
- *Ecoregional Structure*. A potential structure describing ecoregionally based groupings among refuges and with management units of other agencies has been developed based on extant ecoregional maps of Alaska. Ecoregions include Polar, Interior Alaska, Bering Coast, and North Pacific Coast.
- *Existing Inventories from Alaska NWRs*. Alaska refuges have existing inventories of selected resources, which provide baseline information and background for monitoring planning.
- *Current Monitoring in and around Alaska NWRs.* Selected resources on all refuges are currently monitored by refuge staff members, other programs within USFWS, other agencies, or in collaboration with partners.
- *Priorities for Baseline Information Needs.* Refuge staff members have developed prioritized lists of needs for baseline information to create a context for monitoring.
- *Technical Capabilities*. Two data-management positions exist in Region 7 refuges, and two more regional-level positions will be hired this year (2010) to supplement the current data-management activities already being conducted by refuge staff.

Chapter 7. Road Map for Developing Monitoring Plan

A detailed list of decisions and activities, and the time needed for each, is provided. Given that this program is being instituted for the long term and it addresses both strategic and tactical information needs at multiple spatial scales in a rapidly changing and diverse environment, it is important to design it carefully. Although programmatic and monitoring objectives are yet to be developed by staff of Alaska NWRs, we nevertheless provide a list of potential monitoring topics and spatial scales based on statutory mandates and ecosystem conceptual models (table ES1). Our purpose is to provide a realistic example of a monitoring program as the basis for providing specific suggestions for sample frame and identifying partnerships with other agencies that are monitoring the same topic. This is not meant to discount the need for clearly stated monitoring objectives, nor the process of refining them to the detail of measureable objectives.

Table ES1. A potential suite of monitoring topics for which monitoring, assessment, and interpretation may occur at statewide, ecoregional and refuge-specific extents.

[Note that for all topics except invasive species we have listed only the broadest extent at which monitoring may be appropriate. At the statewide extent, we identified topics for which a statewide map for that topic would be relevant for regulatory, conservation, management, or other decisions]

Spatial scale	Monitoring topic
Alaska-wide	Climate
	Air quality, precipitation chemistry
	Land cover
	Phenology
	Water quality and quantity
	Deformities and contaminants in organisms
Ecoregion	Habitat mosaics
	Migratory species
	Permafrost-related events and resources
	Shoreline changes
	Invasive species
	Other landscape processes
Refuge	Subsistence resources
	Ecological keystones, ecosystem engineers, or key landscape modifiers
	Local stressors and responses
	Refuge-significant species not covered at ecoregional extent
	Special plant and animal communities

Chapter 8. Conclusions

Efforts to develop an effective monitoring program embedded in an ecoregional framework across the Alaska NWRs have recognized that development of monitoring programs requires careful thought, support from agency staff, development of an infrastructure within the agency, and learning from the experiences of other agencies. Important concepts include:

- Monitoring programs must be guided by a hierarchy of objectives, including programmatic, monitoring, and measureable objectives.
- Refuge managers have both tactical and strategic information needs, and they must be addressed in different ways.
- Information needs, and therefore program structure, are hierarchical in space and time, and occur on spatial (local to international) and temporal (short- to long-term) continua. Often, more-detailed information is needed in the short term at small spatial scales, compared to needs over longer time periods and at broad spatial scales.
- Maintaining flexibility to meet future needs and variable budgets, collaborating effectively with other agencies, and limiting the scope of monitoring projects to the actual information needs are challenging tasks.
- Effective data management is expensive, but crucial to success of monitoring.
- Efforts expended in planning and careful development of monitoring will be rewarded by an effective monitoring program that will inform management decisions.

Chapter 1. Context for Developing Broad-Scale Monitoring for Alaska NWRs

The National Wildlife Refuge System (NWRS) of the U.S. Fish and Wildlife Service (USFWS) maintains and protects approximately 38 million ha (hectares) of wildlife habitat in 550 refuges and other units throughout the USA[1]. More than 81 percent (that is, 31 million ha; 77 million acres) of the nationwide NWRS holdings occur in the 16 refuges in Alaska, and 24 percent of Alaskan refuges is designated Wilderness. Refuges in Alaska provide critical habitat for resident and migratory animals, including migratory passerines, shorebirds, waterfowl, and water birds arriving from distant parts of the world (for example, Southeast Asia, Africa, Mexico, Central and South America) as well as terrestrial and marine mammals. The refuges, which span millions of hectares, tend to be located at low elevations where they primarily protect tundra and boreal-forest biomes, and where wetlands and waterfowl are often prevalent. Their large size, in conjunction with Alaska's relatively sparse human population and extremely low road density, means that these refuges contain complete, comparatively intact ecosystems, relative to most refuges in the rest of the country.

National Wildlife Refuges in Alaska and throughout the U.S. have begun developing a spatially comprehensive monitoring program. Although individual units (refuges) have conducted inventory, monitoring, and research studies for decades, to date they rarely plan and conduct work collaboratively. Although questions and issues may be similar among refuges, sampling design and field protocols are often developed independently for each refuge, thus limiting the ability to share data efficiently among refuges and to extrapolate results across ecoregions. Yet especially in an era of global climate change, changes within any refuge must be considered in the context of larger scales. For example, a significant loss of habitat in one refuge may have no impact on a migratory bird population if the required habitat has shifted rather than disappeared. To address some of these shortcomings, the U.S. Geological Survey (USGS) is supporting USFWS in Alaska through analysis of past studies, conceptual modeling of ecoregions, and development of an ecoregional monitoring framework to address the challenges of contemporary climate change and other landscape-scale drivers. This assistance will inform USFWS staff as they design and implement refuge-specific inventory and monitoring (I&M) plans as well as a regional I&M program for Alaska refuges. The specific improvements sought by USFWS include:

[1]These numbers exclude the area added by establishment of the Northwestern Hawaiian Islands Marine National Monument, which is co-managed with NOAA.

1. Identification of refuge-specific gaps in existing I&M based on ecoregional-scale conceptual modeling and a better understanding of climate-change effects;
2. A stronger conceptual foundation for selection of monitoring indicators;
3. Consistency in study design for similar surveys on different units; and
4. An integrated and cohesive approach to address regionally-scaled ecological questions.

Additionally, USFWS seeks to identify gaps in natural-resource monitoring at the landscape scale, and to ensure that their inventory and monitoring efforts complement programs of other agencies. Other entities conducting monitoring in Alaska include other divisions within USFWS, other federal agencies, Tribes, and the State of Alaska, as detailed in Chapter 7 below. These efforts reflect agency-specific concerns at refuge, biome, state, and continental scales. Results from each scale can be used to inform management decisions at that scale, but not necessarily at other scales. A major challenge will be to work within this nested hierarchy of monitoring efforts. In table 1, we provide examples of statutory mandates, management decisions, and consequent information required at multiple spatial scales.

To support USFWS management activities, monitoring reports can: (a) inform management decisions regarding subsistence and sport harvest activities; (b) describe the status and trends of trust species; (c) provide data to larger research projects (for example, use data on marine bird colony productivity to indicate changes in ocean conditions and forage fish stocks; understand migratory bird populations); and/or (d) improve basic understanding of system drivers and processes. In an era of unprecedented climate change, monitoring is essential to detecting, understanding, communicating, and mitigating climate-change effects on refuge and other resources under the protection of USFWS. This information will aid conservation of resources, inform habitat management, support education and interpretation efforts, and generally sustain all aspects of refuge management.

In this report, we provide guidance for building a monitoring program that meets refuge-specific management needs while also allowing synthesis and summary of ecological conditions at ecoregional and statewide spatial scales. Considerations in the development of this framework include the characteristic features of the Alaska NWRs, such as their: unique legal mandates, distinctive setting (that is, more ecologically similar to other polar nations than to the rest of the U.S.) and size, and areal predominance in the national refuge system. The plan also incorporates lessons learned from other large-scale monitoring programs and current thinking on monitoring design. Finally, it considers the administrative context of the Alaska NWRs in terms of the monitoring plan emerging from the national program and the potential to collaborate with neighboring federal and state agencies.

Table 1. Examples of statutory mandates, management decisions, information needs, and monitoring objectives that potentially affect USFWS at four spatial scales.

[Abbreviations: AMBCC, Alaska Migratory Bird Co-management Council; ANCSA, Alaska Native Claims Settlement Act ; ANILCA, Alaska National Interest Lands Conservation Act; ESA, Endangered Species Act; MBPA, Migratory Bird Protection Act; MMPA, Migratory Mammal Protection Act; GMU, Game Management Unit]

	Continental/International	Regional/State	Ecoregional/LCC	Land Unit
Statutory Mandates	USFWS mandates (MMPA, ESA, MBPA)	ANILCA, ANCSA, AMBCC	Secretarial Order	Establishing legislation including ANILCA and original Executive Orders, Public Land Orders, and Proclamations
Management Decisions	Budget allocation, special initiatives, flyway harvest regulations	Land acquisition, budget allocation, initiatives	Information needs across agencies	Harvest limits, GMUs, predator management, refuge land use decisions
Tactical Information Needs	International Rusty Blackbird Technical Group investigating severe, unexplained range-wide decline	Distribution of migratory bird nesting habitat, resource inventories, for example, rusty blackbirds, marine mammals	Resource inventories, for example, rusty blackbirds, marine mammals	Size of caribou population sufficient to allow opportunity for subsistence; refuge resource inventories, for example, rusty blackbirds, marine mammals
Strategic Information Needs	Partners in Flight trilateral plan, Circumpolar Assessment of Flora and Fauna, Phenology	Changes in distribution of migratory bird nesting habitat	Climate-change effects on resources	Climate-change effects on resources
Monitoring Objectives	Understand status, trend, distribution, and phenology of migratory birds, marine mammals	Trends in statewide wetland distribution	Monitor health of eelgrass	Determine caribou population abundance in Alaska Peninsula/ Becharof NWRs

This effort ideally would complement and integrate with the national monitoring plan, providing valuable input to that process.

Throughout this document, the term ‘indicator’ refers to the elements of environmental composition, structure and function that sustain biological and ecological systems (Karr, 1981; Noss, 1990; Dale and Beyeler, 2001). ‘Attributes’ are characteristics of those elements that are amenable to measurement, and therefore to being monitored.

Legal Mandates Directing Management of the NWRS in Alaska

A fundamental purpose for monitoring of managed lands is to support management decisions, which are made to meet legislated mandates. Management of Alaska NWRs is guided by the Alaska National Interest Lands Conservation Act of 1980 (ANILCA), which recognizes the distinctive setting of these 16 refuges and gives them unique purposes. As a group, they are to be managed to preserve a wider range of characteristics than other U.S. refuges, namely “significant natural, scenic, historical, archeological, geological, scientific, wilderness, cultural, recreational and wildlife values.” [ANILCA §101 (a)]. Perhaps in recognition of possibilities afforded by their immense size, these refuges have the additional mandate to conserve natural landscapes, wildlife species dependent on vast, relatively undeveloped areas, and entire ecosystems. In recognition of the dependence of Alaskan native cultures and rural residents on harvest of natural resources, ANILCA also calls for refuge management to provide opportunities for subsistence use. ANILCA supersedes the National Wildlife Refuge System Improvement Act of 1997 (NWSRIA), if they should conflict (as stated in NWRSIA).

In addition to clarifying the general management goals, ANILCA also defines the purposes of each of Alaska's NWRs. Generally stated, the act established each refuge to: conserve populations of wildlife including, but not limited to, a refuge-specific list of species or species groups; fulfill international treaty obligations with respect to fish and wildlife; provide for subsistence uses (except Kenai NWR); and ensure necessary water quality and quantity within each refuge. The statutory mandate to provide opportunities for subsistence harvest is unique in the NWRS to Alaska, and the statutory listing of water quality and quantity is the legal basis for reserved federal water rights within Alaska refuges. Several refuges have additional purposes related to reindeer grazing, education, research, and boat access to large rivers.

ANILCA also requires that refuges publish and obtain public feedback on Comprehensive Conservation Plans (CCPs) at intervals not longer than 15 years. These plans describe how each refuge will fulfill its legal mandates within this time frame. The comprehensive plan is supported by step-down plans, which provide details for how specific management goals will be achieved, as needed, for each refuge. Example topics for step-down plans include fisheries management, wildlife inventory and monitoring, land protection, and fire management. Collectively, these CCPs define the approach each refuge will take to the full range of management decisions it will likely face.

Management of the entire NWRS (referred to as 'the System' in the relevant legislation), is guided by the National Wildlife Refuge System Administration Act of 1966 as amended by the NWRSIA. This law states:

> *The mission of the System is to administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations.*

Although putting 'wildlife first', other language in this law also states that wildlife-dependent recreational uses are the priority general-public uses of the System and shall receive priority consideration in refuge planning and management as long as they are compatible with conserving wildlife. It also requires managers to ensure that the biological integrity, diversity and environmental health of the System are maintained.

Finally, refuges are subject to other federal laws and treaties that address wildlife, and environmental and cultural protection. Examples of national and Alaska-specific laws include the Endangered Species Act (ESA, 1973), the Marine Mammal Protection Act of 1972 (MMPA), Migratory Bird Treaty Act of 1918 (MBTA), the Clean Water Act of 1977 (CWA), the Wilderness Act of 1964, the Coastal Zone Management Act of 1972, the Antiquities Act of 1976, and the Alaska Native Claims Settlement Act (ANCSA), as amended.

The need for management to be based on inventory and monitoring is identified throughout legislative directives. The NWSRIA states that "in administering the System, the Secretary shall monitor the status and trends of fish, wildlife, and plants in each refuge." ANILCA calls for a report to Congress every three years, which should include results of monitoring of subsistence use and the status of fish and wildlife populations subject to subsistence use. The policy on biological integrity (USFWS Manual Part 601 Chapter 3) states that refuge managers should assess current status of refuge resources through baseline vegetation and population surveys and should assess the effectiveness of management by comparing the results to desired outcomes. Using desired outcomes to assess management effectiveness is essentially the monitoring step in adaptive management (Holling, 1973, 1978; Williams, 1997; Nichols and Williams, 2006; Williams and others, 2007). The refuge planning policy (USFWS Manual Part 602) states that CCPs should be based on scientific literature and should identify conditions and trends of resources including habitats and wildlife. The monitoring policy for NWRS is detailed in USFWS Manual Part 701 Chapter 2, and a new draft calls for refuges to develop inventory and monitoring step-down plans to provide biologically and statistically robust data on trends of selected species and species groups in an ecosystem context.

Evolution of Perspectives on Management of the NWRS

Historically, refuges were established and managed for conservation of specific species or taxonomic groups and administered relatively independently (National Wildlife Refuge System Administration Act, 1966). The concepts of "trust species" and "trust resources" are terms commonly used by the USFWS to indicate species and resources statutorily subject to Federal management by the Service (for example, via the ESA, MBTA, refuge enabling legislation). They generally encompass migratory birds, threatened and endangered species, anadromous fish, some marine mammals, and refuge lands and waters. In the U.S., fish and wildlife populations generally are a state responsibility; thus the USFWS (and the National Oceanographic and Atmospheric Administration – National Marine Fisheries Service) are unique among federal land-management agencies in having special statutory responsibilities for many species.

This focus on individual species or species groups has steadily broadened to encompass other resources over time. For the first time in 1997, the NWRSIA gave the refuge system an organic act and a system-wide mission. This legislation set overall management direction of the NWRS, which emphasized wildlife, habitats, biological integrity and diversity, and environmental health. For Alaska refuges in particular, ANILCA called for management of natural landscapes and entire ecosystems, including cultural and many other values (see above). Moreover, the spatial scale of management was expanded by the policy regarding biological integrity (NWRSIA), which emphasized taking a broader spatial view when determining goals for population sizes. For example, landscape patterns such as flyways should be the basis for managing migratory birds. Finally, the prospect of climate change has created an impetus to manage all Department of Interior lands from a landscape-level perspective based on "Landscape Conservation Cooperatives" (Secretarial Order 3226, 2009; LCCs). LCCs are defined as science-based cooperative management programs at the ecoregional or regional scale (SHC EOC 2009; see http://www.fws.gov/science/SHC/lcc.html). This mandate recognizes that climate change will have impacts on broad-scale processes such as wildlife migration patterns, hydrology, phenology, spread of invasive species, risk of wildfire, and pattern of permafrost thaw that extend beyond the boundaries of individual management units. This is especially true at high-northern latitudes, where contemporary changes in climatic parameters have been more pronounced, and where climate change is predicted to have the most dramatic and imminent effects (IPCC, 2007). Therefore, management responses must be coordinated at an unprecedented spatial scale.

The recognition that refuge management must add an ecoregional dimension and take a comprehensive view of refuge resources also requires that refuge monitoring include an ecoregional and comprehensive perspective. Development of an appropriate monitoring framework to meet these needs should be informed by an evaluation of current monitoring efforts and lessons learned from other broad-scale monitoring programs.

2010 – A New National Monitoring Program for the NWRS

The impetus to develop long-term ecological monitoring for Alaska NWRs resulted from the increasing awareness that climate change is strongly influencing high-northern-latitude ecosystems. Alaska refuges began collaborating with USGS in 2005 to explore the potential consequences of climate change (for example, Climate Change Forum for Alaska, February 2007) and design an ecoregionally scaled monitoring program (that is, Forum on Ecoregional Monitoring for NWRS and other Public Lands across Alaska, April 2009). Immediately after the Ecoregional Forum, the USFWS Alaska Region Chief of Refuges proposed to the national NWRS leadership team that a small group of biologists be detailed to develop a national I&M strategy for refuges. The Core Team for NWRS I&M was chartered in June 2009 with an Executive Oversight Committee. Both teams met in August 2009, and the Core Team subsequently devoted most of the autumn 2009 to development of an I&M Framework for the NWRS. Eventually, a Technical Review Committee will be asked for critical input.

In September 2009, the USFWS published *Rising to the Challenge – Strategic Plan for Responding to Accelerating Climate Change* (USFWS, 2009). This document included an objective of developing 'monitoring and research partnerships' through an I&M strategy for refuges. Shortly thereafter, the next budget for the DOI included 20 million dollars over 2 years to fund USFWS to develop the aforementioned ecoregionally based and cross-programmatic science support units called Land Conservation Cooperatives. The DOI FY2010 budget also included 12 million dollars for the NWRS to develop a national I&M program on refuges. The refuge I&M program is being designed to support the agency's broader strategies to mitigate the effect of climate change on fish, wildlife, and plant populations. Furthermore, these efforts are encouraged to use an ecoregional perspective, as directed by the Secretary of the Interior (Ken Salazar) in an Executive Order adopting Landscape Conservation Cooperatives and expanding the concept to a Department-wide initiative (Secretarial Order 3226, 2009).

As of December 2009, the Refuge Core Team for I & M had developed an internal draft document entitled *Operational Blueprint for Inventories and Monitoring on National Wildlife Refuges* for FY 2010 and 2011 and a draft *Strategic Plan for Inventory and Monitoring on NWRS* targeting subsequent years. These plans are scheduled for release to the public in 2010. In the meantime, Region 7 (Alaska) Refuges have been authorized to hire two database managers and a regional refuge coordinator for I&M as part of the national USFWS monitoring program organized around LCCs.

Climate change is viewed by many as a major concern regarding natural resources in Alaska. This contrasts with the expectation that land-use change from human activities such as agriculture, forestry, and other forms of development will have a larger effect on species' survival at lower latitudes, especially in the short-term. However, several short-term change agents also have been identified for polar and boreal regions. These include pollution in the form of airborne nitrogen and phosphorus from agriculture elsewhere, and over-exploitation of polar areas (Millennium Ecosystem Assessment, 2005). Although concerns about climate change may have precipitated the development of a broad-scale monitoring program for Alaska NWRs, these other potential changes should not be overlooked (Murphy and Weiss, 1992; Hulme, 2005; Root and Schneider, 2006; Thomas and others, 2006).

Chapter 2. Programmatic and Monitoring Objectives for Alaska NWRs

Multiple sets of objectives are required to underpin the development of a monitoring program (fig. 1). We describe types of objectives; their roles and importance; and potential programmatic and monitoring objectives to underpin monitoring of refuges in Alaska.

Role of Objectives in Developing Monitoring

At the highest level, **programmatic objectives** state what the program strives to achieve. They derive from the agency information needs and the agency context (Chapter 1), which in turn reflect the resources for which the agency is responsible, the nature of the responsibility, available management tools as defined by statute, and relationships with the public. Agency context also includes the agency administrative structure and the feasibility of application of available management tools. In addition to being driven by agency context, agency information needs in Alaska are driven by need to understand the effects of climate change.

The purpose of programmatic objectives is to guide decisions regarding program strategy and structure (fig. 1), rather than identify what specifically should be monitored. Programmatic strategy refers to such decisions as the types of questions, spatial scale, and quality of information that will be collected. It reflects determinations of the audience for, and purpose of, the information. Programmatic structure refers to the staffing plan, organization chart, and funding allocation, which determine where responsibilities, capabilities, and authority for decisions reside in the organization and on the ground. Examples of decisions regarding programmatic structure made by a number of broad-scale monitoring programs are presented in Chapter 3.

Monitoring objectives derive from the programmatic objectives and specifically reflect the information needs of the agency (fig. 1). These objectives describe what should be monitored in very general terms. Refinement of these objectives results in **measurable objectives** (that is, monitoring questions), which are further refined to identify specific indicators and attributes, the survey design describing where and how often to monitor, and how data will be collected, managed, analyzed, and reported. Developing measurable objectives will be discussed in detail in Chapter 4.

Programmatic Objectives for Alaska NWRs

The Alaska NWR monitoring program will be embedded within the national I&M program, which is being developed concurrently. The draft programmatic objectives for the national program include (from draft *Strategic Plan for Inventory and Monitoring on NWRS*):

1. Meet the Refuge System's legal mandate to monitor the status and trends of fish, wildlife, and plant populations on refuges; collect and manage information needed to maintain biological integrity, biological diversity, and environmental health; and preserve the character of designated Wilderness within the System.
2. Advance fish and wildlife conservation at refuge and broader landscape scales in an adaptive-management cycle by providing scientific information that supports conservation planning and design, guides learning through evaluation of conservation delivery, and provides hypotheses to drive research.

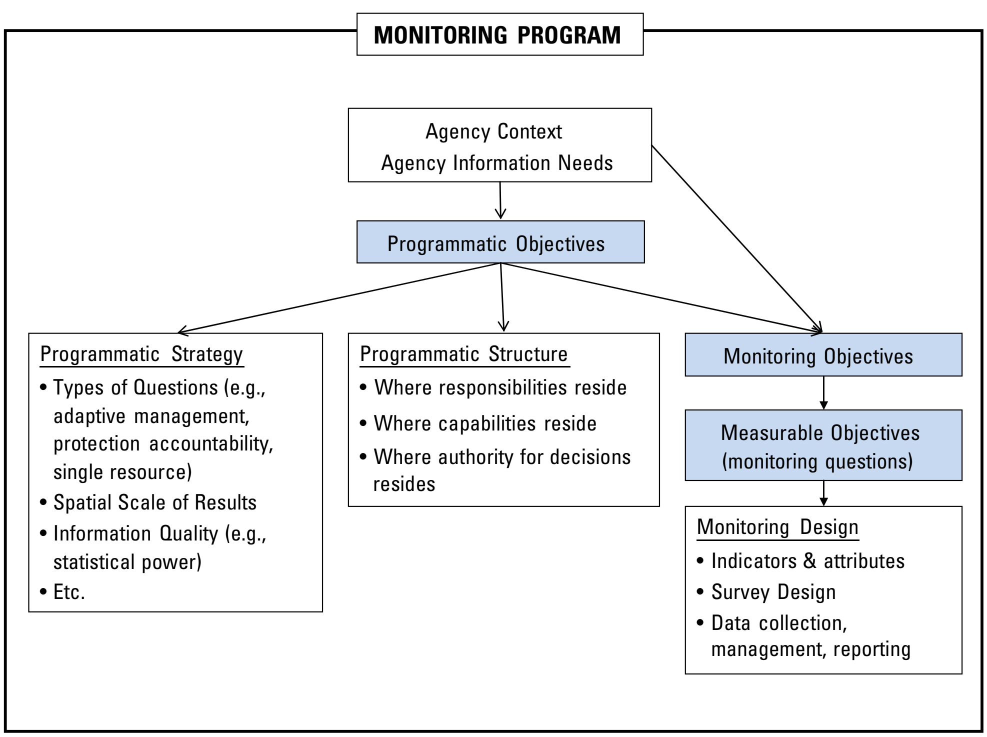

Figure 1. Conceptual framework describing relationships among three types of monitoring objectives and various aspects of monitoring-program structure.

3. Implement monitoring of fish, wildlife, and plants, physical resources, and ecological processes to reduce uncertainty related to impacts of climate change and other stressors, provide early warning of changing conditions, and guide development of management actions that facilitate adaptation to climate change.
4. Synthesize, interpret, and report on the condition of fish, wildlife, plants, and habitats conserved by the Refuge System in a manner that documents the contributions of the System within the context of the larger conservation estate and clearly communicates its value to the American public.
5. Enhance effectiveness and reduce costs by coordinating and integrating monitoring of natural resources at landscape scales through collaboration with other Service programs, agencies, and organizations.

Several considerations affect how these national objectives might be applied in Alaska. First, the geographic context for Alaska refuges includes the vast areal extent of individual refuges, few roads, and a matrix of large blocks of protected lands managed by multiple agencies with interspersed private lands. This context will constrain what constitute feasible monitoring methods, afford extensive opportunities for collaboration with other agencies, and define relationships between USFWS and the rest of the conservation community. Second, the vast land base, together with relatively few financial resources and personnel, and the mandate to protect ecosystem processes, means that management options are limited largely to protection, with very little practice of manipulative habitat management. This makes application of the adaptive-management cycle for identifying monitoring topics less straightforward than in cases of active management. Third, many Alaska refuges have subsistence-dependent resident human populations whose singular focus on particular resources may be in conflict with the need to protect entire ecosystems. Finally, the extreme weather conditions hamper monitoring efforts, even as the relatively rapid rate of climate change at northern latitudes intensifies the need for monitoring.

These objectives express the programmatic goals of monitoring, which reflect management information needs (for example, meet legal mandate to monitor, achieve adaptive management, collaborate with other agencies, etc.) and will determine how the national monitoring program will be structured. Instead of identifying specific ecosystem components that should be monitored, they indicate broad categories of resources, including fish, wildlife, plants, habitats, and ecological processes. Decisions regarding which elements within these broad categories should be monitored will be found in the monitoring objectives and will reflect the national programmatic goals and also refuge and regional resources, responsibilities, and information needs. Monitoring data will be combined with other considerations (for example, societal impacts) to lead to management decisions.

Monitoring Objectives for Alaska NWRs

The statutes and purposes of the Alaska NWRs have several logical consequences with respect to monitoring objectives. First, there are information needs that require monitoring at multiple spatial scales: statewide, ecoregional, and unit-specific. Second, better understanding of water quality and quantity is important not only because of ANILCA statutes, but also because USFWS' neighbors also are invested in monitoring indicators of water quality and quantity, thereby creating opportunities for collaboration. Third, resources subject to subsistence use are of critical management concern and responsibility. Finally, better understanding of ecological health and ecosystem integrity, including biodiversity, is needed to inform management decisions.

The Service must decide which aspects of these topics are most important for them to understand in order to meet management goals. Potential refined objectives that could guide development of a monitoring framework include:

- Determine trends in population size of species subject to subsistence use.
- Determine whether intact ecosystems and natural processes are being conserved within and across refuges, especially in response to climate change.
- Determine trends in populations of focal species, which are determined by the agency and are a subset of 'trust' species plus other priority species (for example, species especially sensitive to climate change).
- Determine trends in water quality and quantity relative to legal standards and levels necessary for ecosystem function.

These objectives are derived from ANILCA legal mandates and express the most general information needs. There may be refuge-specific, ecoregional, statewide, and in some cases, international aspects to all of these objectives (table 1). Consideration of multiple spatial scales and the information needs at each will lead to further refinement of the monitoring objectives (table 1, last row) and eventually the development of measurable objectives and specific monitoring protocols.

The monitoring objectives listed above also reflect a range of temporal scales underlying the management concern. Some objectives express immediate management information needs (for example, populations of species subject to subsistence use) while others relate to future information needs (for example, conservation of ecosystems and processes in the face of climate change, Martin and others, 2009). The immediate needs may be more amenable to a tactical, adaptive-management approach. In contrast, the longer-term needs may require a strategic approach. It is important to prevent the immediate needs from monopolizing monitoring resources to the point of leaving the agency unprepared for addressing future changes.

Chapter 3. Developing Monitoring Program Strategy and Structure

Many broad-scale monitoring programs have been developed around the world. Based largely on examples presented at the Forum on Ecoregional Monitoring for the NWRS and other Public Lands across Alaska, held in April 2009, we summarize lessons learned regarding the structure and development of monitoring programs in general. Then we discuss how some lessons can be applied to Alaska NWRs in particular. Finally, while program structure is a policy issue to be determined by USFWS, we outline decisions that must be made to determine the structure.

Lessons Learned from Other Large-Scale Monitoring Programs

The fundamental challenge for monitoring programs is to maintain consistency in both funding commitment and methods across many repetitions of data collection (Cauglan and Oakley, 2001). Threats to consistency include changes in personnel, in topics of interest, and in user groups; and competition with short-term urgent needs for resources. Support within the organization can be maintained only if monitoring results are useful and relevant, which means that they must address specific management information needs in a timely fashion and at the proper spatial scale. Several potential purposes of monitoring include assessing the outcome of management actions, verifying compliance with legal obligations, providing early warning before unacceptable effects occur, and providing information to influence policy made by other agencies (Noss, 1990; Dale and Beyeler, 2001; Niemi and McDonald, 2004). Specific trade-offs made in the design of a monitoring program that affect the cost and usefulness of the program include:

- *Scope of indicators* – the breadth and depth of ecosystem components included. For example, a monitoring program may address ecosystem health broadly or focus narrowly on water quality. In terms of depth, the same amount of monitoring resources can be distributed to learn a little about a lot of things or to learn a lot about a few things.
- *Statistical confidence* – acquiring high statistical confidence in the veracity of an observed trend often requires more time and sampling effort than that needed to obtain an early warning of the trend. Obtaining a high level of confidence may delay the delivery of a firm conclusion, but strengthens the justification for action. The level of confidence required must be evaluated in light of the potential costs of action versus inaction (Field and others, 2004; Reynolds in press).
- *Spatial resolution* – a sample intended to describe a large area may not be collected at a high enough spatial density to adequately describe any subregion within the larger area.
- *Timeframe of information need* – the information needs of management span the range from immediate and tactical to long-term and strategic. Tactical information needs inform imminent decisions; strategic information needs provide understanding of ecosystem function, provide early warning of system changes, and enable the agency to anticipate the need for management actions.
- *Autonomy of individual management units (if applicable)* – allowing complete local autonomy means that data collected using methods that answer locally relevant questions in one unit may not be easily synthesized with data from other units collected to address different local questions, thus preventing a broader view of conditions; however, without local autonomy, local staff cannot be expected to support monitoring with labor and local funds or to support the agency's investment in monitoring.

Examples of how extant broad-scale monitoring programs addressed these trade-offs were presented at the Forum on Ecoregional Monitoring for the NWRS and other Public Lands across Alaska, held in April, 2009, in Anchorage. The goal of the Forum was to learn from the experiences of other programs to inform the development of a statewide monitoring program by staff of the Alaska NWRs. Most of the programs that were presented are summarized in appendixes 1-7. We supplement these programs with a description of the USFWS Waterfowl Breeding Population and Habitat Survey (WBPHS). A summary of how each program allocated resources to the first four dimensions above is found in table 2.

The seven programs and the USFWS Waterfowl Breeding Population and Habitat Survey can be grouped into four categories:

1. Surveillance Monitoring, National Parks: [*U.S. National Park Service (NPS I&M; Appendix 1), and Parks Canada Agency (PCA; Appendix 2)*]. These two agencies share nationally distributed units of federal land managed primarily through protection, and monitoring is guided by broad goals such as (a) describing status and trends of ecologic integrity (PCA) and (b) providing broad-based understanding of park resources (NPS I&M). These programs recognize both the need to address park-level issues and that efficiency can be gained by developing and implementing standardized monitoring across groups of parks. In the case of PCA, the parks were grouped ecoregionally. NPS also grouped parks into networks somewhat ecoregionally, but groupings mainly reflected administrative rather than ecological concerns. Both developed a national structure for classifying indicators,

Table 2. Summary of characteristics of broad-scale monitoring programs along several dimensions of resource allocation.

[Abbreviations: CBMP, Circumpolar Biodiversity Monitoring Program; EMAN, Environmental Monitoring and Assessment Network;FIA, Forest Inventory and Assessment; LTEMP, Long-term Ecological Monitoring Program; NPS, National Park Service; PCA, Parks Canada Agency; UKCS, United Kingdom Countrywide Survey; WBPHS, Waterfowl Breeding Population and Habitat Survey. NPS and PCA sample some indicators at larger spatial scales than others]

Approach	Program	Information is needed to assess	Scope of resources	Timeframe	Spatial scale	Statistical confidence
Adaptive Management	WBPHS	Effectiveness of specific management action & specific resource status	Limited	Tactical	Broad	High
Targeted Resource	FIA	Effectiveness of national policy	Limited	Strategic	Broad	High
	NARS	Effectiveness of national and state policy	Limited	Strategic	Broad	High
	UKCS	Effectiveness of national policy	Limited	Strategic	Broad	High
	LTEMP	Effectiveness of protection	Intermediate	Strategic	Intermediate	High
Integrative	EMAN	Resource status	Broad	Strategic	Broad	Low
	CBMP	Resource status	Broad	Strategic	Broad	Low
Surveillance	NPS	Effectiveness of protection	Broad	Strategic	Narrow	High
					Broad	Low
	PCA	Effectiveness of protection	Broad	Strategic	Narrow	High
					Broad	Low

and PCA developed a framework for summarizing status of attributes at the national level. This framework produces a qualitative summary of the status (good, fair, poor) and trend (increasing, stable, decreasing) of numerous attributes to describe the biodiversity and ecological function of various habitat-based strata. Although the assessments are qualitative, they are based on quantitative thresholds to define categories of status (sensu Parrish and others, 2003). These assessments enable monitoring to be closely linked to management by clearly indicating management success. The PCA approach demonstrates how to allow local autonomy in choosing attributes, methods, and a sample frame, while retaining the ability to create national assessments of resource status.

Challenges for these monitoring programs include difficulty in narrowing their open-ended objectives and scope to a fiscally feasible list of indicators. Both programs wrestle with sustaining financial support for the tremendous amount of work required by these comprehensively oriented programs. Although both programs realize that they have a role as a benchmark for comparison with altered environments, PCA also sees a need for strengthening the current linkage to park management, possibly by coupling monitoring to adaptive management.

2. <u>Targeted-Resource Monitoring at National Extents</u> [Forest Inventory and Assessment (FIA; appendix 3), National Aquatic Resources Survey (NARS; appendix 4), and United Kingdom Countryside Survey (UKCS; appendix 5)]. These three programs monitor national samples of selected resources. The FIA and NARS programs target relatively narrow resource domains (forests and aquatic resources of the USA, respectively), although the UKCS has a broader resource domain (rural United Kingdom) but a focused set of measurements. All three have national-scale sample frames that are probabilistic and spatially balanced, enabling quantitative assessments of resources at regional and national scales. However, the sample densities are sparse enough that none of the programs can answer questions at scales finer than the multiple-county level (or country level in the case of the UKCS). All three have government funding, have a national and/or regional administrative structure, and address national-scale information needs.

In a unique collaboration, data collected from the FIA sample grid of forest plots in Kenai NWR have been supplemented by an inventory of breeding landbirds, vascular and non-vascular plants on non-forested plots, arthropods, and soundscapes (Long-term Ecological Monitoring Program, LTEMP; Morton and others, 2009). The inventory is planned to be repeated so that it will be possible to assess changes in species distribution and abundance at Kenai NWR; after an inventory is repeated, it can begin to be considered monitoring. Integration with FIA ensures that LTEMP achieves some cost-efficiencies for data collection, and has a probabilistic sampling strategy. Furthermore, the increased breadth of indicators allows for species-habitat modeling and other spatial analyses (Morton and others, 2009) of those resources well represented by a systematic sampling grid (for example, common species). However, this program has the same limitations as do all grid samples. Specifically, rare communities are often inadequately sampled and common communities are over-sampled for most objectives of a comprehensive inventory. This can make grid samples of questionable value for creating efficient and effective inventories.

3. Integrative Monitoring Programs: [Circumpolar Biodiversity Monitoring Program (CBMP; appendix 6), and the Environmental Monitoring and Assessment Network of Canada (EMAN; appendix 7)]. These programs are dependent on data collected by others. The programs add value to these data by synthesizing results across indicators and across broad spatial extents. They try to standardize protocols, data analysis, and reporting across space and time, in general to inform high-level policy makers. The data summaries are qualitative and provide early warning, but the lack of statistical rigor provides relatively weak justification for action to address threatened resources. Nevertheless, 'weight of the evidence' arguments are recognized as valuable means to integrate across locally independent programs such as NPS and PCA.

4. Adaptive Management [*USFWS Waterfowl Breeding Population and Habitat Survey (WBPHS)*]. This program was not presented at the April 2009 Forum, but provides an excellent example of using monitoring data to support adaptive management. Each year, hunting regulations are set to achieve the objectives of maximizing cumulative harvest of waterfowl over the long term while maintaining populations above a specific number (Nichols and Williams, 2006). An aerial survey is used to compare the population size each spring with the predictions from several models; these predictions are based on population size and harvest level in the previous year. The models represent different hypotheses about the combinations of factors that determine response of bird populations to harvest (for example, two hypotheses regarding effects of hunting mortality on annual population survival, and two other hypotheses involving density dependence). Confidence in each model is expressed by the weight garnered by each model. In turn, each model's weight reflects the fit of the model to the observed data over the years, as well as parsimony (namely, models with more variables are penalized). In this example, monitoring results are used to assess the status of the population, model the outcome of potential harvest limits, set the harvest limits, and evaluate the relative support for the competing models. Ideally, this process leads to more effective assignment of harvest limits, thereby achieving agency goals.

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Certain elements necessary for an effective broad-scale monitoring program were identified in all programs. These include the need for: a structure that reflects the types of management decisions required, clearly defined goals and objectives (Noon and others, 1999; Busch and Trexler, 2003; Niemi and McDonald, 2004), a carefully constructed sample design (Cochran, 1977), and as much standardization of protocols as feasible. All agree that data management, analysis, and reporting must be timely (Palmer, 2003) and that these require a significant part of the budget (33 percent, NPS; 20 percent, FIA). They also identified the need to monitor at a hierarchy of spatial scales for program efficiency. Above all, these programs required an extensive initial effort to develop detailed objectives at several levels of specificity (for example, from national overarching to network-wide to indicator-specific objectives) and at appropriate temporal and spatial scales. Moreover, detailed planning and significant investment in data-collection protocols and data management – including plans for data processing, archiving, analysis, and reporting – are essential before data collection occurs.

The need to closely link monitoring to management decisions (Noon and others, 1999; Noon, 2003; Niemi and McDonald, 2004) is another lesson learned from monitoring experience. Management of natural areas usually takes one of two forms: active manipulations (for example, habitat restoration), which generates tactical information needs regarding the effectiveness of the action; or protection (for example, prohibit motor vehicle use), which generates strategic information needs regarding system status. The threat of human activities to conserved lands in recent times has motivated the institution of "surveillance" monitoring programs, which attempt to detect the results of those threats. This type of monitoring program has been criticized as an inefficient use of agency resources that could be used elsewhere (Nichols and Williams, 2006), or as ineffective because it does not logically inform management decisions (Lyons and others, 2008). Consequently, some recommend that monitoring be applied in an adaptive-management process in which monitoring is used strictly to evaluate the effectiveness of management actions (Williams and others, 2007; Lyons and others, 2008). Examples of appropriate scenarios usually involve an objective to change something (for example, maximize the population size of a given species) and an action to meet that objective (for example, create additional habitat in some specific way; see WBPHS description above).

The adaptive management approach is well suited to address tactical information needs, but is harder to apply when the management action consists of protection to achieve resource conservation, as is generally the case in national parks and the Alaska NWRs. However, as already noted, success using an adaptive-management approach to address these strategic needs can be achieved using quantitative thresholds to define whether attributes indicate good, fair, or poor condition of resources. Critical to this is a clear statement of desired conditions – the management target. An example of a criterion related to extent of forest fires might be to compare annual area burned with the 50-yr average and conclude that good is within 15 percent, fair is within 15-30 percent, and poor is more than 30 percent above or below the long-term average. Using these thresholds, success or failure of management can be clearly and objectively evaluated (Timko and Innes, 2009). These thresholds are often difficult to define, but they are an important step in developing a monitoring program for protected areas.

Monitoring Principles for Potential Application to Alaska NWRs

The NWRS in Alaska has features in common with the agencies whose monitoring programs were presented at the (2009) Forum on Ecoregional Monitoring for the NWRS and other Public Lands across Alaska. As with the U.S. and Canadian systems of national parks, the NWRS in Alaska is composed of individual protected areas with a sweeping mandate to conserve landscapes and biodiversity. Furthermore, management is based primarily on protection rather than on specific active-management actions. In common with NARS, FIA, and UKCS, the NWRS in Alaska also is responsible for the abundance and quality of specific resources (that is, water and specific wildlife species) that have spatial extents that are larger than individual management units. Like the integrative monitoring programs, the NWRS in Alaska has interests in (but not responsibility for) synthesizing monitoring data collected by others, either by neighboring agencies or in other parts of the ranges of migratory species, which may be continents away. Lessons learned from other large-scale monitoring particularly relevant to the NWRS monitoring program in Alaska are:

- *Program commitment and relevance*. Maintaining a long-term monitoring program will require a sustained financial commitment by the Service. Achieving sustained support requires regular reporting of results and champions of the program at multiple political and administrative levels. These, in turn, are all aided by having clear objectives and an organizational commitment to efficiency and effectiveness of the program as a whole (Caughlan and Oakley, 2001).

- *Linkage to management.* Monitoring results that provide relevant information that is clearly communicated to management will usefully inform management decisions and provide early warning of upcoming management issues.

- *Adaptive monitoring.* Information needs will vary as resource condition responds to changes in system drivers, as the political and social climate fluctuates, and as monitoring and research generate knowledge (Ringold and others, 1996; Lindenmayer and Likens, 2009). Additionally, the existence and feasibility of monitoring tools will change with new technology. Maintaining flexibility, especially for resources dedicated to tactical information needs (Ringold and others, 1996), will enable timely response to changing conditions.

- *Collaboration for efficiency.* Collaboration with other agencies, and with national and international programs, especially for treaty species, will extend the utility of the NWRS program of monitoring in Alaska by contributing to the description of a larger context, even if data can only be combined qualitatively.

- *Context for monitoring design and interpretation.* Ecosystem conceptual models are simply diagrams describing relationships among the components and processes constituting the system. Because they identify important elements and articulate hypotheses regarding system function, conceptual and quantitative models (usually less available) are useful tools for planning monitoring, developing consensus around appropriate indicators, linking monitoring to adaptive management, and learning from monitoring results (Maddox and others, 1999; Fancy and others, 2009). Development of refuge-specific and ecoregional conceptual models has been initiated for Alaska NWRs.

- *Spatial scales.* A multi-scaled monitoring program will monitor some indicators at statewide or coarser resolutions, some at the ecoregional level, and some at the refuge level (tables 3 and 11) to put refuge resources into the larger contexts needed to manage them in an era of global-scale environmental change. Consequently, refuge-specific monitoring plans will be most effective if embedded within an ecoregional and statewide monitoring framework, such that results can contribute to, and be interpreted in, an ecoregional context. A multi-scale program can be best facilitated by a regional or statewide planning staff.

- *Temporal scales.* Some monitoring objectives meet short-term, tactical needs, whereas others meet long-term, strategic needs. Recognizing these differences will result in appropriate resources being applied in an appropriate sample design for the appropriate amount of time to any given objective.

- *Survey and monitoring designs.* Probabilistic sample designs are necessary for extrapolating monitoring results from the sample to an entire population or domain. It is not efficient to try to design one sample frame to answer all questions, given the diversity of topics and spatial scales reflected in potential monitoring objectives for refuges in Alaska (see tables 1 and 3). That is, various abiotic and biotic processes and components occur at differing spatial scales and asynchronously with other components, such that it is not possible to have a single "silver-bullet" design that is optimal for monitoring everything, everywhere. Designs can be modified to reflect a spatially restricted target domain or for specific objectives of the monitoring question (Niemi and McDonald, 2004).

Table 3. Examples of monitoring topics and analyses relating to the purposes of refuges dictated by Alaska National Interest Lands Conservation Act and the Refuge Improvement Act, at multiple spatial scales relevant to Alaska National Wildlife Refuges.

	SPATIAL SCALE		
Information Need	**Refuge**	**Ecoregion**	**State/International**
Natural diversity, biological integrity, and ecosystem health	Distribution and abundance of species and communities within refuges; any ecosystem process (for example, pollination, erosion control, herbivory, nutrient cycling)	Distribution and abundance of species and communities with ecoregional ranges (for example, Griffith and others, 2002)	Integration of ecoregional data, and data from other parts of species' ranges
Stressors	Off-road vehicles	Climate change, species-specific diseases	Climate change, air pollution, marine harvest
Subsistence resources	Berries, wood, small furbearers	Species with home ranges outside of refuge	Species with range outside of ecoregion (for example, salmon)
Water quality and quantity	Aspects (for example, acidity, turbidity) subject to legal requirements	Integration of data	Integration of data
Species subject to treaty obligations and named in refuge purposes	Aleutian Shield fern, species with limited geographic ranges	Species with ecoregional home ranges	Species with statewide and broader home ranges

Potential Monitoring Program Structure for Alaska NWRs

The structure of the monitoring program for Alaska NWRs is a policy decision to be made by the USFWS, in concert with development of the structure of the national-level monitoring program and the evolution of the LCCs. In terms of agency structure (that is, land management units with significant local autonomy), the refuge system is most like NPS and PCA, and can learn from the successes and shortcomings of their monitoring programs. We can list some important decisions and considerations:

- *What is the question?* A monitoring program whose structure is guided by clear objectives will allocate program resources, capabilities, and responsibilities at the appropriate organization levels and physical locations to efficiently meet agency information needs.
- *Where do the responsibilities reside?* In other words, who is accountable and how is accountability measured? Specifically, it must be determined which position in the organizational structure is responsible to produce each of the products of monitoring, including: data collection (and perhaps data acquisition from other agencies), quality assurance, analysis, archiving, as well as reporting. There are also required outputs from planning, notably protocols, and support functions such as GIS, database and analytical support. Consideration also may be given to accommodate the additional burden on current administrators, especially in the realms of hiring, contracting, and budget tracking. Many monitoring programs hire a few positions that require highly technical skills (for example, GIS, database management) to cover broad spatial and thematic domains while assigning implementation of the many phases of monitoring and reporting to many people at local levels.
- *Where does the accountability reside?* In other words, what is the governance structure? People may have the responsibility to complete various tasks, but unless they answer to someone for whom completing those tasks is a high priority, the tasks may be neglected in favor of other pressing needs. Based on experiences with a variety of structures used by different networks, NPS I&M has determined that the most effective governance structure includes: network coordinators who are directly supervised by a regional program manager rather than a park superintendent; who supervise the monitoring staff; and who are accountable to a Board of Directors, which includes superintendents of many or all parks in the network (John Gross, National Park Service, written commun., 2010).
- *Where do the capabilities reside?* Decisions regarding where responsibilities reside will affect where staff members are physically located and who supervises them.

- *Where do the decisions reside?* In other words, who has the authority to make various decisions? These will include such decisions as budget allocation, prioritization of monitoring objectives, hiring, acceptance of protocols, and many others. Within NPS I&M, the national program has authority to allocate money among its 32 networks and approve compliance with steps in the planning process (including structure and content of planning documents and protocols). Decisions about choice of monitoring indicators and allocation of funding to each indicator are made at the network level. In contrast, FIA and NARS make all decisions at the national or regional levels.

Further Considerations

- Measures of accountability at every level of the monitoring-program structure will ensure that no level becomes a bottleneck in the production of information from monitoring.
- Alternative ways to infuse insights from monitoring results into management decision processes (for example, Interdisciplinary Teams of USFWS, in addition to traditional line authority) will better ensure that the right information reaches the right people at the right time and in the right format.
- Carefully considered funding priorities at each step will ensure limited resources are efficiently used. At the moment, national monitoring funds are being evenly distributed among USFWS regions, so priorities are not needed. At the local level, however, priorities may need to be set regarding distribution of funds among LCCs or refuges within regions, and then to protocols at the regional, ecoregional and refuge levels.
- Existing agency culture and organization will drive many of these decisions about monitoring program structure. New agency features include the efforts to design a national monitoring program and the newly forming LCC offices. LCCs also have a mandate to engage in monitoring, so there is an opportunity to create synergy.
- Protecting funding from alternative uses will help preserve program integrity over the long term. NPS I&M has achieved this by having dedicated funds and high levels of accountability at all levels from the national office to the park, insuring that the money be spent only on monitoring.

Importance of a Hierarchical Monitoring Plan

Monitoring objectives are hierarchical in both time and space. Specifically, there are short-, medium-, and long-term needs for decisions and understanding; and refuge, ecoregional, regional, and broader spatial scales of resource distribution and effects of system drivers. Addressing these needs can be best accomplished by a hierarchical monitoring plan. The objectives will naturally motivate spatially hierarchical sample frames so that locally collected data can be put in a larger spatial context to answer questions at broader spatial scales. Short- and long-term questions will require that the temporal dimension be considered in funding allocation.

Chapter 4. Identifying Monitoring Indicators

Once a monitoring program structure is in place, efforts will focus on determining monitoring objectives and refining them to create measureable objectives, which specify indicators. Given that management staff of Alaska NWRs has both strategic and tactical information needs, we discuss how to choose indicators of ecological integrity for strategic needs, and how to choose indicators of effectiveness of management actions to address tactical needs. We also list potential indicators that come from consideration of ANILCA, and of conceptual models of refuges and ecoregions. Finally, we address options and approaches to prioritizing the inevitably lengthy list of indicators including the importance of incorporating cost.

Developing Measurable Objectives

Setting monitoring objectives for a broad-scale, multifaceted monitoring program is a critically important step in program development, as it directly informs all subsequent steps in program development and implementation (Noon and others, 1999; Noon, 2003; Niemi and McDonald, 2004; Keeney and Gregory, 2005). The process of developing monitoring objectives is one of refining broad statements of information needs (such as the potential objectives for Alaska refuges given in Chapter 2), which results from close collaboration with decision- and policy-makers (Noon and others, 1999; Dale and Beyeler, 2001; Noon, 2003; Niemi and McDonald, 2004). The process is based on the purposes and guiding legislation associated with individual refuges and the USFWS system at regional and national scales, as detailed in Chapter 1. Specifically, it is necessary to consider the context of all factors that will affect management decisions (in addition to science), what trends and triggers will support management decisions, and the conceptual basis for indicators. The first level of refinement results from considering how these factors vary in space and time, and will usually identify specific indicators. Further refinement must proceed until objectives are specific and detailed enough to provide clear guidance regarding: selection of the temporal and spatial monitoring domains, relative importance of understanding trend vs. status (and thus nature of the sampling re-visit strategy), attributes of interest, level of sampling needed to detect changes with a selected level of confidence, subset of relevant options for methods that may be appropriate, and the suite of analytical approaches needed to address the questions. These highly refined objectives are ‘measurable objectives’. A hypothetical example regarding tactical monitoring to assess effectiveness of management actions to influence the population size of a caribou herd follows:

Alaska NWR Monitoring Objective: Determine whether population levels of species subject to subsistence use are above the minimum required to allow subsistence use.

Refined Monitoring Objective: Determine whether removing predators for a 4-year period will increase the size of the caribou population to a level that supports some subsistence harvest.

Further Refined Monitoring Objective: Determine whether removing predators from caribou calving grounds for a four-year period will increase the number of caribou adults to a level that supports some subsistence harvest.

Measureable Objective: Determine whether the population of the (*name*) caribou herd exceeds (*number determined to be adequate to support subsistence harvest*) adults in (*season*) at (*place*) following 4 years of predator removal within (*specified*) confidence limits.

Developing a measurable objective from a monitoring objective is a highly iterative process. Budget constraints may dictate that the ultimately desired information is not feasibly obtained, so that the objective may need to be revised to reflect the minimum information required to meet the information needs of managers. Measurable objectives should be developed in collaboration between managers, refuge biologists and scientists, to aid in translating management questions to strategies for effective data collection (Stokols and others, 2008).

Strategic Versus Tactical Monitoring Needs

As previously noted, managers of Alaska NWRs undertake both passive (protective) and active (manipulative) management actions. An approach in this situation is to develop a two-part monitoring program (Timko and Innes, 2009), to both (1) address the strategic information need for status and trends of ecological integrity, and (2) to address the tactical information need to assist managers in assessing the effectiveness of management actions.

Choosing Indicators of Ecological Integrity for Strategic Needs

Monitoring ecological integrity is a daunting goal. Ecological integrity has been described as having three components: indicators of biodiversity, ecosystem processes, and stressors (Woodley, 1993; Parks Canada Agency, 2005). Monitoring of biological diversity must pay attention to all levels of ecological organization, according to Noss (1990). Notwithstanding this guidance, few protected areas have established systems to assess whether they are protecting biodiversity (Yoccoz and others, 2001; Parrish and others, 2003; Hockings and others, 2004). To provide more-specific direction, a global framework has been promoted by the IUCN World Commission on Protected Areas to help managers of protected areas develop effective monitoring of conservation efforts (Hockings, 2003; Hockings and others, 2003). The framework recommends that the biological diversity of a region can be represented by a limited number of ecological communities or ecosystems (Noss and Cooperrider, 1994; Poiani and others, 2000), plus a selection of species with unique ecological requirements not captured by those communities or ecosystems. Key ecological attributes used by The Nature Conservancy (TNC) to measure success in protected areas include biological composition, biotic interactions and processes, environmental regimes and constraints, and landscape structure and architecture (Parrish and others, 2003). According to the TNC guidance, attributes for assessing these indicators can be determined using conceptual models to describe the ecology of the indicator, thereby identifying characteristics that determine the long-term persistence of the indicator (Parrish and others, 2003). Linkage of monitoring to management and the effectiveness of conservation depends on establishing the limits of an acceptable range for each attribute (Parrish and others, 2003). These are determined by considering the range within which each attribute represents ensured persistence of the indicator. A weakness of this approach is the need for a fairly sophisticated understanding of system function.

Monitoring of ecological integrity can also be focused around changes that are anticipated with contemporary climate change (see table 4) and might be addressed by changes in

Table 4. Consequences of climate change that are of greatest concern to land managers within each of four ecoregions within Alaska, as identified at the (April 2009) Forum on Ecoregional Monitoring.

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

management philosophy, policy, or actions, once they are detected. Examples of climate-related information needs to which monitoring may contribute include:

- Understanding the effects of extreme-weather events, and consequences of extreme levels of a particular ecosystem component or process.
- Understanding species' current habitat associations and conservation status, to forecast future distributions and set conservation priorities, based on current and future vulnerability to climate change and other stressors. This also has implications for habitat-management decisions, and the potential acquisition of conservation easements.
- Re-defining natural diversity – for example, if moose were present 60 years ago but have increased dramatically in density, what is the appropriate density of moose to sustain as a target? It is necessary to acknowledge that most management targets can now no longer be considered static through time (Morgan and others, 1994; Kessler, 2010).
- Determining when the forecasted conservation status is so poor that cost to conserve a species may be infeasible. This has ramifications for complying with the Endangered Species Act and other legislation.
- Informing education and outreach efforts, both internally and externally – under increased levels of uncertainty associated with climate change. These efforts should honestly and explicitly acknowledge that uncertainty.
- Determining the limits of natural diversity, and the range of environmental health and integrity conditions that are permissible without resulting in unacceptable levels of species or habitat degradation. This informs the decision regarding when managers may want to intervene.

Because it is challenging to select indicators of biological integrity, it is important to consider published guidance. Based partly on compiling the suggestions of others, Noss (1990:357-358) has suggested that:

"Ideally, an indicator should be [Cook, 1976; Sheehan, 1984; Munn, 1988]:

(1) sufficiently sensitive to provide an early warning of changes;

(2) distributed over a broad geographical area, or otherwise widely applicable;

(3) capable of providing a continuous assessment over a wide range of stress;

(4) relatively independent of sample size;

(5) easy and cost-effective to measure, collect, assay, and/or calculate;

(6) able to differentiate between natural cycles or trends and those induced by anthropogenic stress; and

(7) relevant to ecologically significant phenomena."

Dale and Beyeler (2001) further suggested that indicators should: respond to stress in a predictable manner; predict changes that can be averted by management actions; be integrative; and have a known response to disturbances, anthropogenic stresses, and changes over time. Few, if any, indicators meet all of these criteria, but all indicators should be linked to ecosystem function through conceptual models (Busch and Trexler, 2003).

Choosing Indicators of Effectiveness of Management Actions to Address Tactical Needs

Some have advocated monitoring the effectiveness of management actions in the context of structured decision making, of which adaptive management is a subset (Nichols and Williams, 2006; Lyons and others, 2008). There are three roles for monitoring in this iterative process, including: (1) providing data for state-dependent decisions (for example, given the state of the harvested population, how much harvest will be allowed?), (2) evaluating management performance (for example, did harvest restrictions result in expected productivity?), and (3) facilitating improved management through learning (for example, which of the hypotheses regarding species response was most accurate?). Choosing indicators for adaptive management or other forms of structured decisions is driven by the specific management decision needed and the requirements of the models, which represent different hypotheses, used to predict the outcomes of the decision.

Although active management is not commonly undertaken currently in most refuges in Alaska, the following are some potential management actions that may be appropriately evaluated in an adaptive-management framework:

- Creating and maintaining habitat – fire suppression, prescribed fire, planting trees along streamsides, habitat enhancement, habitat protection or conservation.
- Managing people – regulatory actions will affect most of the change (for example, road closures, permitting of other anthropogenic activities such as overflights); the exact manner in which these actions are implemented may evolve, given that resource distributions will shift in the future.
- Setting of harvest dates, bag limits, and acceptable age and gender of harvest, by type of harvest equipment (bow vs. rifle vs. muzzle-loader), for both subsistence and sport (or non-federally qualified) harvesters.
- Allocation of water rights, or permitting of upstream anthropogenic activities that may affect water quality or quantity.
- Predator control, and resulting ecological cascades.

Implementing a monitoring program can itself be seen as taking a management action. Knowledge gained from the monitoring program should be used to iteratively refine the monitoring design, in what has been termed 'adaptive monitoring' (Ringold and others, 1996; Lindenmayer and Likens, 2009). This could be accomplished by implementing the plan in pilot areas, or by using monitoring results to refine ecosystem models, thereby focusing attention on the most-informative indicators. An outcome to be avoided, however, is the loss of long-term continuity of comparable data (Ringold and others, 1996).

Potential Monitoring Indicators Suggested by ANILCA

In addition to protecting water quality and quantity, providing for subsistence resources, and ensuring that treaty obligations are met, ANILCA identifies species and resources that constitute refuge purposes (table 5). These are not the only resources that concern refuge managers, but the list can be used to identify some common interests (see fig. 3 for location of ecoregions mentioned):

Migratory birds – statewide, but especially waterfowl in Interior Alaska and shorebirds for refuges with Arctic, Bering Sea, and North Pacific coastlines

Caribou – statewide

Moose – especially in Interior Alaska

Furbearers – especially in Interior Alaska

Bears – especially polar bears in the Polar ecoregion, and brown bears on the North Pacific Coast

Salmon – especially in coastal refuges and Interior Alaska.

Potential program-level monitoring objectives for these resources are given in Chapter 2. While these species have complex dynamics and require long-term monitoring to be accurately understood, management tends to require immediate, tactical information regarding the species.

Table 5. Species, taxonomic groups and resource categories listed in refuge purposes identified in ANILCA.

[Terminology was not used consistently among refuges, so that a higher taxonomic group might be listed for one refuge and a species within that taxonomic group might be listed for another. Resources are grouped by category and refuges are grouped by ecoregion. Arctic and Selawik NWRs each appear in two columns because a large proportion of each refuge occurs in two ecoregions]

		Polar	Interior Alaska									Bering Coast			North Pacific Coast				
		Arctic	Arctic	Innoko	Kanuti	Kenai	Koyukuk	Nowitna	Selawik	Tetlin	Yukon Flats	Selawik	Togiak	Yukon Delta	Alaska Maritime	Alaska Peninsula	Becharof	Izembek	Kodiak
Birds	Black brant													X					
	Canada goose													X					
	Canvas back							X			X								
	Emperor goose													X					
	Non-migratory birds					X													
	Marine birds												X		X		X		
	Migratory birds	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Peregrine falcon	X	X	X															
	Raptors									X						X			
	Sea Birds													X					
	Shorebirds								X			X		X		X		X	
	Snow goose	X	X																
	Trumpeter swan							X											
	Waterfowl			X	X	X	X	X	X	X		X						X	
	Whistling swan													X					
	White-fronted goose				X			X						X					

Table 5. Species, taxonomic groups and resource categories listed in refuge purposes identified in ANILCA.—Continued

[Terminology was not used consistently among refuges, so that a higher taxonomic group might be listed for one refuge and a species within that taxonomic group might be listed for another. Resources are grouped by category and refuges are grouped by ecoregion. Arctic and Selawik NWRs each appear in two columns because a large proportion of each refuge occurs in two ecoregions]

		Polar	Interior Alaska									Bering Coast			North Pacific Coast				
		Arctic	Arctic	Innoko	Kanuti	Kenai	Koyukuk	Nowitna	Selawik	Tetlin	Yukon Flats	Selawik	Togiak	Yukon Delta	Alaska Maritime	Alaska Peninsula	Becharof	Izembek	Kodiak
Terrestrial Mammals	Bears					X					X				X				
	Brown bear															X	X	X	X
	Black bear			X															
	Caribou	X	X		X		X	X	X	X	X	X			X	X	X		
	Dall sheep	X	X			X					X								
	Furbearers			X	X	X	X	X		X	X								
	Grizzly bear	X	X																
	Large Mammals												X						
	Marten							X											
	Moose			X	X	X	X	X		X	X					X			
	Mountain goat					X													
	Muskox	X	X											X					
	Other Mammals			X											X				
	Polar bear	X																	
	Wolverine	X	X					X			X								
	Wolf	X	X			X					X								
Marine	Marine Mammals												X	X	X	X	X		X
	Marine Resources														X				
	Sea lion																		X
	Sea otter																		X
Fish	Arctic char	X	X																
	Dolly varden									X									
	Fish					X										X			
	Grayling	X	X																
	Northern pike							X											
	Salmon			X		X	X	X	X	X	X	X	X	X			X	X	X
	Sheefish							X	X			X							

Potential Monitoring Indicators Suggested by Conceptual Models

A preliminary list of potential indicators of ecosystem integrity comes from the ecoregional workgroups at the Forum on Ecoregional Monitoring for the NWRS and other Public Lands across Alaska (tables 4 and 6). These indicators are based on ecoregional conceptual models that describe the (1) processes and distribution patterns that emerge more clearly at broader spatial extents, and (2) potential effects of climate change on natural resources of Alaska NWRs. Concerns varied by ecoregion, but generally fell into the following categories:

Water quality and quantity – including hydrology; and wetland distribution and abundance

Biological diversity and community structure – including distribution and abundance of invasive species, rare species and habitats, and migratory species

Species with legal mandates – including subsistence and harvested species, and species associated with treaty obligations or other statutory mandates

Fire regime – especially in Interior Alaska

Phenology – specifically, the potential loss of synchrony across trophic levels

Ocean dynamics – for refuges with coastlines

Many of these potential indicators relate to the program-level objective (Chapter 2) of determining whether intact ecosystems and natural processes are being protected. Specific information needs for them will tend to be met by strategic, long-term monitoring.

Prioritization of Monitoring Objectives and Indicators

When addressing issues as broad as the management purview of the NWRS in Alaska, it is inevitable that more objectives and indicators will be identified than can possibly be monitored. Basically, at every point when decisions are made about the distribution of resources (that is, funds and personnel), some sort of prioritization process must occur. This will involve identifying selection criteria and applying them. The more transparent and objective the process, the less contentious the decision is likely to be.

We have described (Chapter 2) the need for developing a series of iteratively more highly-refined monitoring objectives that are derived from program-level objectives. Agency management must decide at which levels to prioritize these objectives. For example, the most general monitoring objectives (Chapter 2) might be prioritized based on the importance of strategic versus tactical information needs, the public visibility of various issues, etc. The purpose of this prioritization might be to determine the relative allocation of funds among them. Within each of these broad objectives, it will likely be necessary to prioritize sub-objectives. In most monitoring programs prioritizing sub-objectives is done using indicators rather than formally stated objectives. For example, what are the priority subsistence or focal species? What are the priority indicators of ecosystem health? Prioritizing indicators has been an effective approach, but program staff of the Alaska NWRs might consider developing different selection criteria for each program-level objective. For example, the criteria for determining where and how to monitor water quality are likely different than are the criteria for identifying priority focal species. Developing different criteria for each objective and applying them to appropriate potential indicators would alleviate the tendency of most prioritization processes to compare unrelated indicators using vague criteria. However, no prioritization process is perfect, because they all suffer from the following pitfalls:

- Items to be prioritized must have equivalent scope (for example, ‘forest processes’ will rank higher than ‘decomposition’ as an indicator because it is more inclusive; however, it is too general to be useful for selecting particular attributes to measure).
- Respondents tend to rank highly those topics about which they are familiar and knowledgeable.
- No list of criteria can take into consideration all concerns and issues.
- The uncertainty about how climate will change and how ecosystems will respond complicates prioritization.
- There is no good way to include cost as a factor early in the prioritization process, because any monitoring objective can be addressed with a variety of budgets, depending on the choice of attributes, and intensity and domain of sampling. Laying out all of the options for all of the potential indicators is usually too onerous until the list of indicators has been reduced. However, budgetary limitations must be considered when designing a monitoring program as discussed below.
- A monitoring program should amount to more than the sum of its parts, but it is difficult to evaluate the entire program by prioritizing individual components.

Several methods can be used to prioritize monitoring objectives and indicators. No method is perfect and it should be realized from the outset that subjectivity will necessarily be applied to the list that emerges from a prioritization process. Nevertheless, a formal process is an effective tool to reduce the list of potential objectives and indicators to a manageable number.

Table 6. List of potential monitoring indicators suggested by ecoregional-scale conceptual models.

[These models feature ecosystem components and processes that span broad spatial extents, and thus would inform organization and interpretation of monitoring at ecoregional resolutions]

	Polar	Bering Coast	Interior Alaska	North Pacific Coast
Air and Climate	Climate	Climate	Climate	Climate
			CO_2 levels (release by melting permafrost, fires; sequestration by plant growth)	
	Sea ice distribution, phenology Shorefast ice distribution, phenology	Sea ice distribution, phenology Shorefast ice distribution, phenology		Sea ice distribution, phenology
	Beaufort Gyre	Ocean currents		North Pacific current
Geology and Soils		Marine-derived nutrients (chemistry)	Marine-derived nutrients (chemistry)	Marine-derived nutrients (chemistry)
			Permafrost distribution and melting	Isostatic rebound
				Volcanism
Water quality and quantity	Freshwater	Aspects of Kuskokwim River water	River flow and flood risk	
	Lake drying	Aspects of Yukon, Kobuk Rivers	River-ice breakup	Marine conditions (pollutants, acidification, climatic influence
	Marine conditions	Marine conditions		
Biological Integrity		Beluga whales and other migratory marine mammals		
	Migratory birds	Migratory birds	Migratory birds	Marine food webs
		Anadromous fishes	Anadromous fishes	
	Caribou herds (Western Arctic, Central Arctic, Porcupine)	Caribou herds (Western Arctic, Mulchatna)	Caribou herds (Western Arctic, Forty-mile, Porcupine, Mulchatna)	
	Phenology (insects, sea ice, vegetation green-up, migratory birds)	Phenology (ice, vegetation, migratory birds)	Phenology (insects, river ice, vegetation green-up, migratory birds, fire season)	Phenology (Whale migrations, vegetation green-up, migratory birds)
Anthropogenic stressors	Harvest of migratory animals	Harvest of migratory animals	Harvest of migratory animals	Harvest of migratory animals (marine, terrestrial)
	Fire management	Fire management	Fire management	Fire management
	Industrial activities			Oil and gas development

Delphi Process. This is a group decision-making process in which participants are not required to interact directly. Working independently eliminates some of the possibly negative aspects of group interactions in which some voices can dominate the group, the discussion can ramble, or the desired number of respondents can be too unwieldy for a discussion. Also, it can be conducted electronically, so that travel is unnecessary (Delbecq and others, 1975). This process was used effectively by Oliver (2002) to identify indicators of vegetation condition in low-gradient, open forest and woodlands of Australia. A preliminary list of indicators categorized by composition, structure, and function was provided to vegetation experts. The experts were provided background on program objectives and asked to add to the list. In some cases, a Delphi process can be iterative until a consensus is reached. In the Oliver (2002) example, they used one process to identify indicators and planned to use a second phase to prioritize them. Delphi processes are most often used to obtain input from experts, but can also be useful when respondents are distant, as is the case among refuge biologists in Alaska. Negative aspects include the large amount of administration needed and the fact that the process may work best for generating ideas rather than setting priorities (Oliver, 2002).

Weighted Criteria. Several similar prioritization methods can be used to generate a list of criteria and then score all indicators according to how well they meet the criteria. Scores accumulated across all criteria are used to rank the indicators. The methods differ in the scale used for ranking, the complexity of the structure of the criteria (that is, how many hierarchical levels are allowed) and the complexity of the calculations needed to score the indicators. Examples of criteria might include how well an indicator can provide early warning of unacceptable change, or how closely it is linked to a management decision.

Prioritization Matrices. This method uses a two-way matrix to first compare the relative importance of pairs of criteria, where 'importance' must be defined. The matrix is used to develop weights for the criteria. Next, each indicator is compared to each of the other indicators relative to each criterion. The outcome is a ranked list of the indicators in which the relative importance of the criteria has been incorporated (Anjard, 1995; Wang and others, 1998). This method has the advantage that only pairwise comparisons need to be made simultaneously to rank a long list of items. Even though this process can be conducted using a spreadsheet, if there are many indicators and criteria, the many permutations of all the possible pair-wise combinations make full implementation of this method very tedious.

Analytical Hierarchy Process. This method allows for a hierarchical structure to describe priorities. In other words, there can be sub-criteria within criteria. The user makes pair-wise comparisons among indicators, but the computation of rank involves calculus; hence, it requires specific software that uses algorithms that are opaque to the user. However, it provides satisfactory results and has been used for inventory and monitoring program planning (Schmoldt and others, 1994; Peterson and others, 1994).

Simple Multi-Attribute Ranking Technique (SMART). This is a simple and robust ranking method. Instead of comparing indicators to each other, all are rated on a standard scale (for example, 0-100) for each criterion (Ralls and Starfield, 1995; Goodwin and Wright, 2009). Thus, indicators are rated relative to their position on the scale, not by which one is higher than the other (when in fact they may not be very different). Scores for indicators can be weighted by the importance of each criterion to calculate a final rank.

NPS I&M Process. The NPS program advocates a hybrid system in which criteria are developed and weighted and a scoring system is defined. Subsequently, each indicator is rated (by both resource managers and research scientists) for each criterion and the final score is weighted by the importance of each criterion (see Suggestions for Prioritizing Vital Signs at http://science.nature.nps.gov/monitor/). It can be conducted in one round or two rounds. If using two rounds, the first round is used to prioritize indicators and a second round is used to prioritize attributes. This allows for different criteria to be used for each round (see appendix 8 for example criteria). It also may be advantageous to develop different criteria for each spatial extent and for indicators of ecosystem integrity versus adaptive management. If the NPS approach is adopted, criteria used by USFWS should reflect the differences in objectives of the monitoring programs for the two agencies. Sources of potential criteria include Noon (2003), Mueller and Lenz (2006), Patten (2006), and Niemeijer and de Groot (2008).

The ranking process should not be the final word regarding the choice of indicators and attributes (Fancy and others, 2009). One likely outcome is that some indicators will receive very different ranks, depending on the expertise of the respondent. These discrepancies can be addressed in a group setting where very high or very low ranks can be defended, ideally with the help of conceptual models, hopefully leading to consensus.

Even if there is consensus around the ranks of individual indicators, none of these ranking methods addresses the fact that no monitoring indicator possesses all of the desirable properties; consequently, a set of complementary indicators are needed to create an effective monitoring program (Noss, 1990; Niemi and McDonald, 2004). In other words, a monitoring program is more than the sum of its parts and the value of an indicator is contingent on what else is included in the set. An approach to evaluating sets of indicators based on their inter-relationships has been proposed by Neimeijer and de Groot (2008). They explain the use of causal networks to facilitate the identification of the most relevant indicators for addressing a specific objective.

Ultimately, the final list of indicators will also be based on an evaluation of each indicator for: the value of unique information it provides; cost in relation to range of inference; partnership opportunities; availability of methods, expertise, and facilities; practicality; clarity of linkage to management issue; and negotiations with refuge biologists and managers. As was pointed out by Dr. T. Barrett (presentation Day 1 http://alasks.usgs.gov/science/biology/ecomonitoring), good leadership is required to navigate this process.

Incorporating Cost Considerations into Indicator Selection

There will always be more to monitor than the budget will allow, and the program will be sustained only if it is creating value when both budgetary and opportunity costs are considered. Therefore it is necessary to choose individual indicators and design the overall monitoring program to be cost-effective (Caughlan and Oakley, 2001). In terms of individual indicators, there are several means to achieving cost-effectiveness:

- Monitor only those attributes that answer a specific objective (U.S. Environmental Protection Agency, 1995).
- Replace costly attributes with easily measured surrogates (Burbidge, 1991; MacDonald and others, 1991; Silsbee and Peterson, 1993).
- Use a carefully designed sample frame that avoids wasteful over-sampling and inconclusive under-sampling (see Chapter 5).

In terms of the overall monitoring program, it is especially important to consider cost in the design phase, and then check the program's financial feasibility in the testing and implementation phases (Caughlan and Oakley, 2001; see table 15). Tools that can be used to evaluate cost-effectiveness include a cost-benefit (when benefits can be quantified) or a cost-effectiveness (when benefits are intangible) analysis to compare elements in the monitoring program. Both methods essentially express a measure of benefit (monetary or non-monetary) per unit of cost (Saaty, 1980; Loomis and Walsh, 1997). However, the challenge of valuing outcomes from monitoring when they are often intangible (for example, provide early-warning, clarify species status, etc.) and manifest over long time periods is not insignificant. An alternative perspective is to consider the relative costs among indicators of not monitoring each.

Another tool for incorporating cost into indicator selection and program design is to consider three levels of budget (Caughlan and Oakley, 2001). Tier 1 assumes the lowest level of anticipated funding, and may consist of existing budgets and staff; tier 2 assumes a moderate level of program funding; and tier 3 assumes that additional, possibly one-time, funding becomes available. If protocols for individual indicators and the program as a whole include strategies for each level of funding, the program will be flexible to most scenarios. Planners should anticipate that annual costs of monitoring will increase faster (especially due to cost-of-living adjustments to pay) than the budget available to pay for them.

Chapter 5. Sample Design Considerations

Although staff members of the Alaska NWRs are several steps away from articulating ecoregional monitoring objectives, we can anticipate some of the options and constraints that will contribute to determining sample designs. Once measurement objectives are determined from the monitoring objectives, sample-design considerations include several factors that determine which class of sample frame is appropriate. We discuss how decisions regarding sample design will be influenced by the specific context of Alaska, and how some of the inherent constraints can be alleviated through collaboration with partners. Finally, we provide examples of sample designs appropriate to potential monitoring questions for Alaska NWRs.

Design Considerations

The primary requirement for designing a sample frame for any particular indicator is a very specifically stated objective for monitoring that indicator (Noon and others, 1999; Noon, 2003; Niemi and McDonald, 2004). Frequently, the identification and framing of a question is the most difficult task faced during the design of monitoring programs (Silsbee and Peterson, 1993; Pastorok and others, 1997). If the monitoring questions are poorly developed, no amount of sophisticated analysis will produce the needed information. Therefore, it is critically important that researchers and managers work together to identify and frame the questions that will drive the development of monitoring questions.

Our discussion in Chapter 4 suggests that it is likely that there will generally be both tactical and strategic monitoring needs. Tactical needs will tend to be shorter-term, of smaller spatial scale, and possibly amenable to an adaptive-management approach. In contrast, strategic needs will tend to be longer-term, possibly of ecoregional or broader scale, and concerned with the effectiveness of protective management. Based on these conclusions, we can describe the fundamental decisions that must be made and some options that are available for sample design.

In general, factors that affect the monitoring design include:

- Desired domain of inference (that is, to what spatial areas and time periods should results be applicable?).
- Availability of mechanistic or other models to extend results.
- Spatial resolution(s) at which the indicator occurs or acts across the landscape (which determines where independence of samples effectively occurs).
- Available methods for measurement, and the expertise required to conduct them.
- Relative time and costs associated with travel to each site, performance of sampling, and processing of samples (for example, chemical analyses).
- Degree of confidence in monitoring results, or the minimum level of change that is desired to be detected with a given level of certainty.
- Existing designs in use in adjacent jurisdictions, if comparability and collaboration with those efforts is of importance.
- Available budget.

Based on the evaluation of these factors, the first decision regards the sampling strategy. Specifically, there are three main types of options to consider: index (reference sites), census (comprehensive), and probabilistic samples. All have an appropriate role in monitoring.

Index sites have been used to monitor numerous resources across protected areas of Alaska for several decades (for example, weather stations, stream gages). Such sites have been non-randomly selected, and results from their sampling cannot be justifiably extrapolated beyond the individual collection of points from which the results were derived, except through use of model-based inference. The value of continuing to monitor at these sites typically derives from lower monitoring costs associated with their usually higher accessibility, and more importantly from the long time-series that allow for long-term perspectives on trend, albeit at only one or a few points that do not represent any larger domain. In cases in which models have been developed in an attempt to extend results, there may be benefits to adding sites to improve the accuracy of the model (for example, high-elevation validation is often weak for weather models).

Comprehensive sampling – that is, a **census** – is measurement of every member of a population. Given the vastness of even each ecoregion within Alaska, censuses (for example, via remote sensing) will likely be feasible only within smaller domains (such as a particular refuge) or at a coarse resolution of information.

Probabilistic sampling is appropriate when the goal is to apply results from a subset (that is, a sample) of a population to make inferences about an entire domain of interest. Besides allowing for defensible inference, probabilistic samples also enable unbiased estimates of status and trend of an indicator, as well as of the associated measure of uncertainty with each estimate. They furthermore allow appropriate use of inferential statistics to analyze and interpret status and trend. This type of sampling will likely be the most appropriate method for sampling many indicators proposed by staff of Alaska NWRs, especially those whose status and trend must be estimated over refuge-wide, ecoregional, and larger spatial scales.

Sample size is determined by the desired level of statistical power, which indicates the probability of committing a Type II error. A Type II error entails concluding that no change has happened when, in fact, it has. This contrasts with a Type I error, important to null-hypothesis testing, of concluding that a change has occurred when, in fact, is has not. In a monitoring context, Type II errors are potentially more costly than Type I errors (Peterman, 1990; Fairweather, 1991). While a Type I error may trigger an unnecessary response, it will likely be recognized quickly and result in only short-term costs. In contrast, a Type II error has the potential to result in irreparable damage to resources. Prospective (*a priori*) power analyses of sampling designs can insure that adequate sample size is used (Steidl and others, 1997; Legg and Nagy, 2006).

Among the many types of probabilistic samples, simple random, cluster, and systematic sampling are the most commonly used (Lohr, 1999; table 7). In simple random sampling, each point is randomly selected from the whole sampling domain, independent of the locations of all other points. These samples often occur in a somewhat clumped spatial distribution, especially at relatively small sample sizes. In systematic sampling, sample points are evenly spaced across the entire domain, often on a grid after a random start. A potential weakness is that the grid spacing may be in synchrony with naturally occurring patterns, such that only ridges or valleys are sampled, for example. This would provide a biased representation of the domain. A grid sample also has the potential to miss rare elements entirely, especially at small sample sizes. Cluster sampling begins with a random or systematic sample of points and at each point a cluster of samples is taken (for example, subplots on a transect). Cluster sampling is conducted to (a) improve the precision of each point estimate (which represents a cluster of subsamples), and (b) quantify uncertainty around that point estimate (Sarndal and others, 1992). Cluster sampling is an effective sampling design especially when (a) elements of the target population occur naturally in clusters or groups (for example, caribou and colony-nesting birds, anglers in boats), or (b) the cost of obtaining observations increases markedly as the distance separating the sample units increases. If the same total number of plots is sampled across designs, however, cluster sampling typically results in lower precision. Generalized Random Tesselation Stratified designs (GRTS; Stevens and Olson, 1999, 2003, 2004) involve a spatially balanced random sample. The approach was developed as part of EMAP and it overcomes the tendency of simple random samples to clump spatially. Furthermore, it does not distribute points in a regular pattern, and thereby avoids the complicated computation of variance involved with systematic sampling.

Any of these sample types (that is, simple random, cluster, or systematic) can be distributed probabilistically throughout the sampled domain using equal-probability, stratified, or unequal-probability sampling (Lohr, 1999; table 8; fig. 2). In equal-probability sampling, all areas are equally likely to be selected. In stratified sampling, the domain is divided into relatively homogeneous areas called strata. Equal-probability sampling is often used within strata; the selection probabilities and sample densities can be different for different strata. With unequal-probability sampling, the probability of selection and sample density can vary continuously across the domain. Stratified sampling is a special case of unequal-probability sampling in which probabilities of selection differ among strata. Finally, especially in cases in which a particular variable (for example, elevation, latitude, distance from water) is known to account for much of the variation in an indicator's values, arranging sample units across gradients can be a valuable design approach to quantify the range of trajectories that sites may experience through time. Such approaches explicitly acknowledge that contemporary climate change is not the only driver influencing resource condition; rather, climate change will typically interact with other factors to affect ecological resources (Thomas and others, 2006; Root and Schneider, 2006; Rowe, 2007).

Table 7. Characteristics of simple random, cluster, and systematic sampling methods, in the context of long-term ecological monitoring.

	Pros	Cons
Simple Random	• Simple and has straight-forward statistical properties	• The distribution is often clumped, especially at small sample sizes
Cluster	• Most useful when travel costs among sites are high • Produces more-accurate point estimates	• Degrees of freedom for analysis are based on the number of sites (that is, plot clusters) rather than the number of plots (that is, requires sampling more plots than with other sampling designs)
Systematic	• Spreads sample evenly in space; avoids biases associated with small-sample-size random sampling	• Under-samples rare resources and over-samples common ones • Produces bias if spacing corresponds to any environmental gradient or periodicity • Can be difficult to compute variance due to lack of randomness in sample

Table 8. Advantages and disadvantages of equal-probability, stratified, and unequal-probability sampling designs, in the context of long-term ecological monitoring.

	Pros	Cons
Equal- probability	• Simple to implement • All areas are equally important • Emphasizes importance of common ecosystem components or processes •	• Can be inefficient • Provides little information on less-common ecosystem components or processes
Stratified	• Sample density can be increased, within some strata, to provide adequate sample size for less-common species • Selection probabilities can be designed to reflect site accessibility, to increase overall sample size •	• More complicated analysis than for equal-probability sampling • Membership of sites within strata must remain fixed forever, although one can switch to unequal probability sampling, which will allow for changes in membership •
Unequal-probability	• It has the advantages of stratification without need to define discrete strata • One can add samples without regard to the initial strata • Probability of selection can vary according to any suite of constraints	• More complex analysis than for stratified sampling • One must keep track of the selection probabilities •

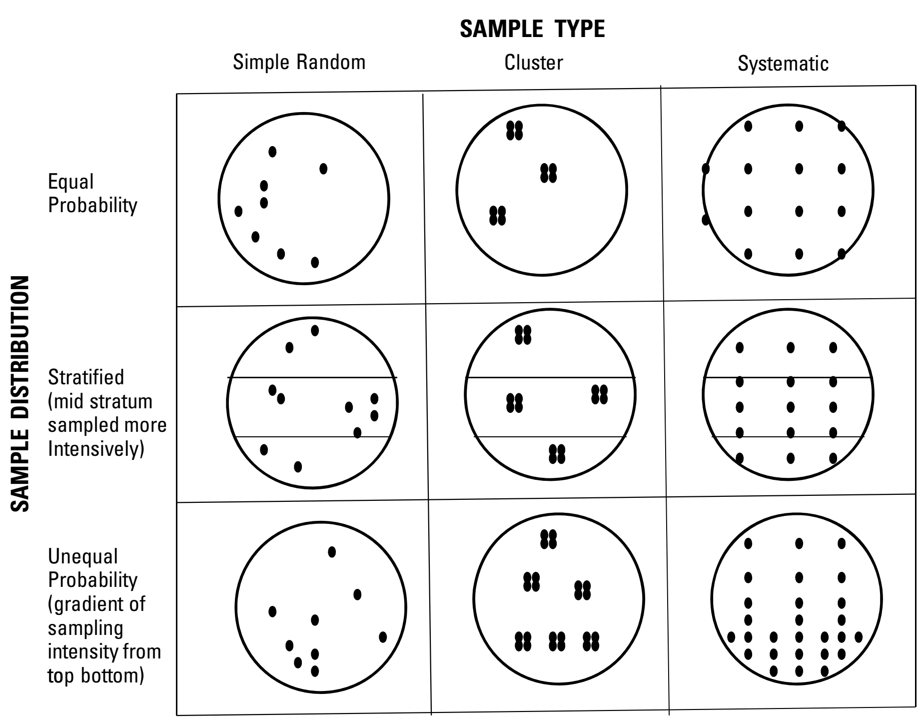


Figure 2. Primary methods and strategies for distributing samples (from Jenkins and others, 2003).

Besides distributing sampling through space, decisions must be made about how to distribute sampling through time (for example, across years), which is also known as the re-visit strategy. Though it may be desirable to revisit every site on every sampling occasion, this is rarely feasible, especially for samples covering large areas. Panel designs are an alternative distribution of site visits through time that allow for the allocation of groups of sites (that is, panels) to specific re-visit schedules such that not all sites are re-visited every year (table 9). The specific schedules and allocation of plots to them depend upon the relative perceived importance of several factors. First, greater numbers of re-visits to the same site(s) provides improved understanding of trend at those site(s); whereas the larger the number of sites visited in any one year (and across the cycle of all sites sampled), the better is the understanding of an indicator's status within the domain during the year (or cycle). Second, the greater the inter-annual variability in a given indicator, the more important it is to have repeat sampling at sites to precisely estimate long-term trend. In highly variable environments, sampling often occurs in two to four successive years, rather than just one year within a cycle (tables 9*B* and 9*C*). Finally, if all sites are very costly to access from the monitoring office but travel among sites is relatively less costly, then sampling of all or most sites in fewer years is recommended (table 9*A*). The rotating-panel re-visit design (table 9*C*) represents a balance between understanding trend and status. A final consideration is that of monitoring-induced alteration of the target resource (for example, trampling of vegetation, disturbance of the nesting process for shorebirds); in cases where alteration is unavoidable to accurately measure condition of the target, less-frequent visits to sample points are worth considering.

Table 9. Allocation of visits to 20 hypothetical sites, across 5 years of monitoring. In each re-visit strategy, there are a total of 40 site-visits. A) presents the case in which all visits occur in 2 years; a more-extreme case of optimizing understanding status within a given domain would be to sample 40 sites all in one year. B) represents, for this hypothetical time period and available number of visits, a strategy that maximizes understanding of trend, at a random sample of 8 sites. C) represents a rotating-panel design, which balances understanding of status and trend.

A

Site #	2010	2011	2012	2013	2014
1	X			X	
2	X			X	
3	X			X	
4	X			X	
5	X			X	
6	X			X	
7	X			X	
8	X			X	
9	X			X	
10	X			X	
11	X			X	
12	X			X	
13	X			X	
14	X			X	
15	X			X	
16	X			X	
17	X			X	
18	X			X	
19	X			X	
20	X			X	

B

Site #	2010	2011	2012	2013	2014
1	X	X	X	X	X
2					
3	X	X	X	X	X
4					
5					
6	X	X	X	X	X
7	X	X	X	X	X
8					
9					
10					
11	X	X	X	X	X
12					
13	X	X	X	X	X
14					
15					
16					
17	X	X	X	X	X
18					
19	X	X	X	X	X
20					

C

Site #	2010	2011	2012	2013	2014
1	X	X			
2		X	X		
3			X	X	
4				X	X
5	X	X			
6		X	X		
7			X	X	
8				X	X
9	X	X			
10		X	X		
11			X	X	
12				X	X
13	X	X			
14		X	X		
15			X	X	
16				X	X
17	X	X			
18		X	X		
19			X	X	
20				X	X

Determining Sampling Domains in Alaska

Conducting monitoring and research in the remote, relatively undisturbed ecosystems of protected areas in Alaska involves numerous constraints. These sampling constraints include: typically high transport costs due to lack of any roads in most refuges; harsh, unpredictable weather for much of the year; short day lengths during winter and adjoining seasons; inaccessibility of some resources during periods of snow and ice cover; short growing seasons; and impassability of some portions of the landscape (due to cliffs, crevassed glaciers, large water bodies, etc.). Especially for strategic monitoring objectives, thoughtfully designed broader-scale monitoring has several advantages over purely local-scale monitoring, which include: (a) encompassing a greater range of variability in the factors that influence the variable or phenomenon of interest; (b) increased sample size, when sampling is performed using compatible methods and design across units, allowing for a more-powerful ability to detect broad-scale trend (all other things, especially variability, being equal); (c) expansion of the sampled area to broaden the area of understanding and inference; and (d) possible illumination of hierarchical, cross-scale, or non-linear emergent dynamics.

In particular, there are several characteristics that affect the domain in which resources will be sampled. First are safety, logistical (that is, weather- and travel-related), and fiscal constraints. Unless these can be mitigated by combining monitoring with other existing work of the USFWS or its collaborators, sampling must either: (a) rely on a smaller sample size, (b) define the domain of inference as areas within an accessible distance from points of access (for example, boat docks, appropriate shorelines, water bodies that can accommodate float-equipped planes, flat areas where a propeller plane can land), or (c) monitoring fewer natural resources, more comprehensively. To adequately define the sampling frame to which results have inference, accessibility must be a quantitative criterion, such as within 2 km of any road or a threshold value in a GIS-based Path Distance Analysis (Thompson and others, in press).

In addition, domains may be dictated by ANILCA purposes or the nature of the indicator. For example, monitoring results for water quality and quantity, a key resource for many waterbirds and whose protection is one of four guiding purposes for all refuges in Alaska, are most informative if considered in the watershed context even if investigated at smaller than watershed resolutions. This is because smaller-order headwaters are unavoidably connected to higher-order rivers that pass through refuges. Similarly, species that are mentioned in treaties between the U.S. and other nations (for example, salmon, sea otters, Northern fur seals, migratory birds) are mandated by ANILCA to be managed and monitored at those international extents. Not coincidentally, most of these species travel across vast areas during their lifetime, and their survivorship and reproductive success depend upon habitat conditions that they experience at those very broad spatial extents. In similar fashion, indicators such as climate-related or landcover metrics are best understood and interpreted at extents beyond that of individual management units, due simply to the nature of the phenomena and drivers underlying those metrics. For example, because of shifts in distributions of both species and permafrost, as well as the landscape mosaic of water-body drying and creation via melting, contemporary climate change provides strong impetus to design, implement, and interpret monitoring at ecoregional or broader scales. In contrast, trends in other indicators such as narrowly distributed plants and insects or unique, rare habitat types will likely be interpretable only at more-localized extents such as that of an individual management unit.

Potential Benefits of Collaboration

Collaboration with other agencies offers a means to alleviate some of the constraints on conducting monitoring in Alaska. For example, close collaboration with neighbors allows for the assessment of complementarity among monitoring efforts, subsequently allowing synergy in understanding by (a) filling in gaps that are not monitored by neighboring landowners, and (b) increasing total sample size, for resources that are shared. In addition to the statistical advantages of such collaboration, staffing can become more specialized when shared; resources such as aircraft can be utilized more cost-effectively; and numerous socio-economic benefits accrue, as evidenced in a growing number of conservation efforts across jurisdictions and international boundaries (Mittermeier and others, 2005). In Alaska, nearly every refuge abuts conservation lands administered by other federal agencies (table 10, fig. 4), and Tetlin NWR is part of the world's largest contiguous protected-area complex, which also includes portions of British Columbia and Yukon Territory (Mittermeier and others, 2005). Profound differences in monitoring objectives for adjacent jurisdictions tracking the same resource rightfully prescribe some tailoring of methods or the suite of attributes measured; nonetheless, compromises that still allow comparability across the landscape are often possible.

For resources monitored across broad spatial extents yet at finer resolutions, hierarchical organization of sampling allows for results to be obtained for multiple areas (and thus, diverse stakeholders at refuge to international scales; Raudenbush and Bryk, 2002). For example, the systematic sampling designs of FIA and NARS allow provision of results at county, state, regional, and national extents; however, sample size within individual management units (even those as extensive as Alaska NWRs) is typically too limited to make robust inference about resource status within the unit, especially if the sample is stratified into different soil types

Table 10. Federal and state lands in Alaska by ecoregion.

[Abbreviations: BIA, Bureau of Indian Affairs; BLM, Bureau of Land Management;USFWS, U.S. Fish and Wildlife Service; NCA, National Conservation Area; NP, National Park; NHP, National Historical Park; NM, National Monument; NRA, National Recreation Area; NPS, National Park Service; FS, U.S. Forest Service]

Ecoregion	Unit	Agency
Polar	National Petroleum Reserve	BLM
	Dalton Highway Corridor	BLM
	Alaska Maritime NWR	FWS
	Arctic NWR	FWS
	Cape Krusenstern NM	NPS
	Gates of the Arctic NP	NPS
	Kobuk Valley NP	NPS
	Noatak NP	NPS
Interior Alaska	White Mountains NRA	BLM
	Steese NCA	BLM
	BLM units	BLM
	Arctic NWR	FWS
	Innoko NWR	FWS
	Kanuti NWR	FWS
	Kenai NWR	FWS
	Koyukuk NWR	FWS
	Nowitna NWR	FWS
	Selawik NWR	FWS
	Tetlin NWR	FWS
	Yukon Flats NWR	FWS
	Cape Krusenstern NM	NPS
	Denali NP	NPS
	Kobuk Valley NP	NPS
	Lake Clark NP	NPS
	Noatak NP	NPS
	Wrangell-St. Elias NP	NPS
Bering Coast	Wood Tikchik State Park	Alaska
	BLM unit	BLM
	Becharof NWR	FWS
	Selawik NWR	FWS
	Togiak NWR	FWS
	Yukon Delta NWR	FWS
	Bering Land Bridge NP	NPS
North Pacific Coast	Annette Is. Indian Reservation	BIA
	BLM unit	BLM
	Alaska Maritime NWR	FWS
	Alaska Peninsula NWR	FWS
	Becharof NWR	FWS
	Izembek NWR	FWS
	Kenai NWR	FWS
	Chugach National Forest	FS
	Tongass National Forest	FS

or vegetative communities. To address this need, managers have often elected to collect samples or make measurements at sampling points using the same methods and systematic grid (for example, LTEMP in Kenai NWR; Morton and others, 2009), but increase the density of sample points within each grid cell to provide results that have greater power to detect change within such smaller extents. In contrast to nested and hierarchical sampling, sampling of some indicators (for example, citizen monitoring) may not be nested within (nor co-located with) frameworks for other resources.

Applying Design Considerations to Monitoring for Alaskan NWRs

Given this suite of considerations, we have listed one or two strategies (table 12) that could be employed to address examples of potential monitoring questions for each indicator listed in table 11. (These are examples of the potential questions and indicators that may result from a careful indicator-selection process based on management information needs.) Note that even within a given extent, highly divergent designs may be appropriate to assess status and trend of the different target resources. In addition to the spatial designs, table 12 also contains possible re-visit strategies that could be used to allocate monitoring effort through time. See table 9 for examples of how sampling of units through time can be distributed to maximize understanding of status, trend, or a balance between the two. Strikingly, there may be very different optimal re-visit strategies across indicators, even among indicators organized at the same extent (for example, statewide, or ecoregional). Note that many other options for spatial and temporal allocation of effort may also be appropriate. The 'best' approach for any indicator depends strongly on the nature of the monitoring question being asked, as well as (among other things) the technical resources to analyze the data. Ultimately, selection of monitoring designs reflects tradeoffs among a suite of design considerations. Determining the importance and consequences of various choices requires collaboration among field biologists and technicians, biometricians, and decision-makers, as well as communication and sufficient lead time to thoughtfully design and implement monitoring, in a manner that solidly meets objectives.

Table 11. A potential suite of indicators for which monitoring, assessment and interpretation may occur at state-wide, ecoregional and refuge-specific extents within Alaska.

[Note that for all metrics except invasive species, we have only listed each indicator at the broadest extent at which results might be usefully summarized. The criterion for deciding to consider an indicator at the state-wide or ecoregional extent was whether one would want a state-wide or ecoregional map for that indicator, for regulatory, conservation, management, or other management decisions. **Abbreviations:** NDVI = Normalized Difference Vegetation Index, FIA = Forest Inventory and Assessment]

	Indicator(s)	Notes
State-wide Extent	Climate	Accumulate data from existing weather stations and climate networks; supplement by filling gaps that will improve climate models at various extents; attributes include temperature, precipitation, snow depth, snow-water equivalent, freeze-thaw events, length of growing season
	Air quality, precipitation chemistry	Accumulate data from existing air-quality stations; fill gaps to improve model accuracy
	Landcover	Include attributes of vegetation mosaic, distribution of water bodies, glaciers, sea ice; create a seamless map every 5–7 years (perhaps with panel design) using satellite imagery, ground-truthing, or maybe a systematic grid of ground plots; collaborate with FIA
	Phenology	Is already being done by others; surrogate for other species' dynamics; example attributes include vegetation greening and browning using NDVI, ice-out and ice-in, and other metrics organized by the National Phenological Network (for example, budburst, arrival of migrants, first nesting dates)
	Water quality and quantity	Most cost-effective to organize at statewide extent, but may need to parameterize at ecoregional or finer resolution; includes wetlands, riparian areas, and lentic systems
	Deformities and contaminants in organisms	Bird beaks, amphibians; contaminants in seabirds, other taxa
Ecoregional Extent	Habitat mosaics	Composition of habitat types important to primary monitoring entities in the ecoregion (for example, as determinants of distributions of species monitored by those entities)
	Migratory species	Includes birds, large mammals (ungulates, carnivores, anadromous fishes, and marine species)
	Permafrost-related events and resources	Example attributes: thermokarst, filling and draining of lakes and wetlands
	Shoreline changes	May need local-scale normalization
	Invasive species	
	Other landscape processes	Examples: fire and subsequent succession
Refuge Extent	Subsistence resources	Examples: plant parts, animals
	Ecological keystones, ecosystem engineers, or key landscape modifiers	Examples: sea otters, beavers, moose, and (cyclically) lagomorphs
	Local stressors and responses	Examples: roads, snow-machine use, non-subsistence harvest, localized sites of recreation, etc.
	Refuge-significant species not covered at ecoregional extent	Examples include species in refuges purposes and other statutes with home ranges smaller than the refuge (for example, furbearers)
	Special plant and animal communities	Examples; Eelgrass, rare habitat, endemic or narrowly distributed animals

Table 12. Examples of monitoring designs and temporal re-visit strategies that could be used to guide monitoring of indicators listed in table 11.

[Note that individual indicators have from 1-4 example questions with which they are associated, as indicated by the letters in the second-leftmost column. Note that although we have tried to illustrate the intimate connection between the monitoring question and both the monitoring design and re-visit strategy, space limitations have precluded us from explicitly specifying the specific spatial and temporal domains associated each monitoring question, which will be necessary for each indicator, before program development can begin. Some indicators are so inclusive that we could not provide a meaningfully comprehensive set of examples to illustrate connection of question(s) with spatial design and temporal strategy. **Abbreviations:** LiDAR = Light Detection and Ranging, BBS = Breeding Bird Survey, SPOT = Satellite Pour l´Observation de la Terre, IKONOS is not an acronym]

	Indicator(s)	Monitoring Design	Temporal (re-visit) strategy
State-wide Extent	Climate	Collection of index sites with time series of varying antiquity and continuity	Continuous data collection (recorded or summarized at sub-hourly, hourly, sub-daily, daily, monthly, seasonally, and annually)
	Air quality, precipitation chemistry	Collection of index sites with time series of varying antiquity and continuity	Continuous data collection (recorded or summarized at sub-daily, daily, monthly, seasonally, and annually)
	Land cover	Patchwork of strips of locally censused area; re-sample across years at several index strips (randomly selected, initially), to quantify inter-annual effects	State divided into 5-7 randomly selected samples of strips; rotating-panel design
	Phenology	Varies by attribute; probably a collection of volunteer locations, for many attributes; most sites likely to be in easily-accessible locations, for easy re-visits	Re-visits daily or weekly, within range of target date (varying by indicator)
	Water quality and quantity	Gage stations are a network of index sites; seasonal chemistry should be sampled across gradients of remoteness	Continuous data collection (recorded or summarized at sub-hourly, hourly, sub-daily, daily, monthly, seasonally, and annually)
	Deformities and contaminants in organisms	Opportunistic, in the midst of other research and monitoring projects	Contingent upon existing study designs
Ecoregional Extent	Habitat mosaics	Obtain Landsat or other remotely sensed imagery; supplement with ground-based sampling or finer-resolution imagery (for example, SPOT, LiDAR, IKONOS), to validate	Ecoregion (or interested management units) divided into 5-7 randomly selected samples of strips; rotating-panel design
	Migratory species	Across gradients of remoteness (at least occasionally); maintenance of existing BBS route time-series	Annually, within target season (migrant arrival, breeding , rutting, pre-migration)
	Permafrost-related events and resources	Opportunistic, in the midst of other research and monitoring projects; use these to inform subsequent monitoring designs; stratified random sampling across gradients at least several km away from big population centers (for example, heat sources); sample across elevations and aspects; use Landsat imagery as a coarse-resolution census	Opportunistic sampling varies by project; Censuses: ecoregions divided into 5-7 randomly selected samples of strips; rotating-panel design
	Shoreline changes	Stratified random sampling	Split-panel design (to balance understanding of status and trend)
	Invasive species	Divided effort: smaller effort in systematic or random sampling (stratified by accessibility); greater effort at most-likely vectors (for example, trailheads) of invasion and known population sites	Annually, within target season
	Other landscape processes	Opportunistic, depending on where events occur (mapping)	Annually, within target season; split-panel design (to balance understanding of status and trend)
Refuge extent	Subsistence resources	Most effort at most-likely locations (for example, near population centers, trailheads, roadsides) of likely and known harvest or collecting sites	Annually, within target season; split-panel design
	Ecological keystones, ecosystem engineers, or key landscape modifiers		
	Local stressors and responses	Most effort at most-likely locations (for example, near population centers, trailheads, roadsides) of likely and known transportation corridors and recreation sites	Annually, within target season
	Refuge-significant species not covered at ecoregional extent	Varies by indicator	Varies by indicator
	Special plant and animal communities	Varies by indicator	Split-panel design (to balance understanding of status and trend)

Chapter 6. Building Blocks for Alaska NWRs Monitoring Program

Some building blocks are already in place for developing a monitoring program for Alaska NWRs. These include refuge-specific and ecoregional conceptual models and the rationale for that ecoregional structure. Additionally, inventories and monitoring are currently occurring in and around refuges. These monitoring projects are being conducted by refuge staff, other divisions of USFWS, and other agencies. Inadequacies in inventory data have already been identified and prioritized. Finally, current staff members already have some of the needed technical capabilities to conduct monitoring.

Conceptual Models

Conceptual models inform monitoring programs in a number of ways, including summarizing important ecosystem components and processes as well as facilitating communication, discussion, and debate about the nature of the system and important management issues. This process can lead to hypotheses regarding future changes, likely results of alternative management actions, and identification of monitoring indicators. Ultimately, conceptual models can help managers and scientists interpret monitoring results. Recently, staffs of the 16 National Wildlife Refuges in Alaska created a conceptual model of their refuge and the landscape context to support development of long-term ecological monitoring. Models include prominent ecosystem components, drivers, and processes by which components are linked or altered. Ecoregional models were then developed to describe linkages among refuges sharing the same broadly-defined climate. Ecoregional boundaries are derived from the 32 unified ecoregions of Alaska, which are hierarchically nested into eight Level-1 groups, and further into four terrestrial ecoregions for modeling (Polar, Interior Alaska, Bering Coast, and North Pacific Coast; see below). Conceptual models were also developed for adjacent marine areas, designated as the North Pacific, Bering Sea and Polar Marine Ecoregions. The process of developing and refining monitoring objectives will include further refinement of the conceptual models so they provide more detail about specific resources and processes within ecosystems.

The process of conceptual model development for the system to be monitored, and the discussion that leads to acceptance of these models by everyone involved in the monitoring program is critical to engendering agreement about how the system operates (National Research Council, 1995; Busch and Trexler, 2003). Without this process, there can be a tendency to simply adopt approaches favored by a subset of experts, or to work from lists of potential indicators without adequate consideration of their ecological role and connections. By hypothesizing which indicators might represent pivotal stressors, drivers, or responses, these models may provide the basis for indicator selection. Because they are a mechanism for integrating often highly sophisticated, but disparate, views about the ecosystem, they can support the prioritization process, which seeks to identify the most fruitful set of indicators to monitor.

Ecoregional Structure

Ecoregions define areas with common ecological components and processes, and therefore could be used to describe regions with the potential for common monitoring objectives (Busch and Trexler, 2003). Classifying ecoregions is complicated by the difficulty of determining strict categories for natural systems characterized by multivariate gradients. Consequently, there are multiple ways to define ecoregions, reflecting differences in the parameters considered and their relative weights. Moreover, the fact that different levels of discrimination are possible leads to classifications that are commonly hierarchical, with smaller spatial units grouped into larger ones by increasing the range of variability used to define a class (Nowacki and others, 2001; Omernik, 1987; Bailey, 1995). Notwithstanding the complexity and ambiguity of ecoregional boundaries, an ecoregional classification is a useful tool for organizing monitoring and putting local results into a larger context.

Nowacki and others (2002) attempted to unify the extant ecoregional maps of Alaska (Gallant and others, 1995; Nowacki and Brock, 1995) of Alaska by combining them and using additional data to resolve discrepancies. This map was the basis for delineation of ecoregions for organizing conceptual models of Alaska NWRs. Meanwhile, the national NWRS has been organizing management according to Landscape Conservation Cooperatives (LCCS), which are ecoregions defined by Bird Conservation Regions (BCRs). Because the BCRs were developed with a priority on bird distributions, they differ somewhat from the ecoregions based on the work of Nowacki and others (2002) (figs. 3 and 4). Both have ecoregions bordering on the Arctic Sea, Bering Sea, and northern Pacific Ocean, plus an interior region. The only significant difference relevant to the grouping of refuges is that the BCR map includes the Alaska Peninsula and Kodiak Island with western Alaska, whereas the Nowacki-based map included the Alaska Peninsula and Kodiak Island with southern Alaska. However, it has also been determined that there is insufficient staff in Alaska to separately administer the five BCRs in Alaska. Consequently, they may be grouped in the Northern Alaska LCC (NAK-LCC), including Arctic plus Northwestern Interior Forest, and the Southern Alaska LCC (SAK-LCC) including Aleutian/Bering Sea and Western Alaska. The North Pacific LCC will be administered by Region 1. In this case, the Alaska Peninsula and Kodiak Island will be grouped with both western and southern Alaska in the SAK-LCC. However, this structure is still in flux.

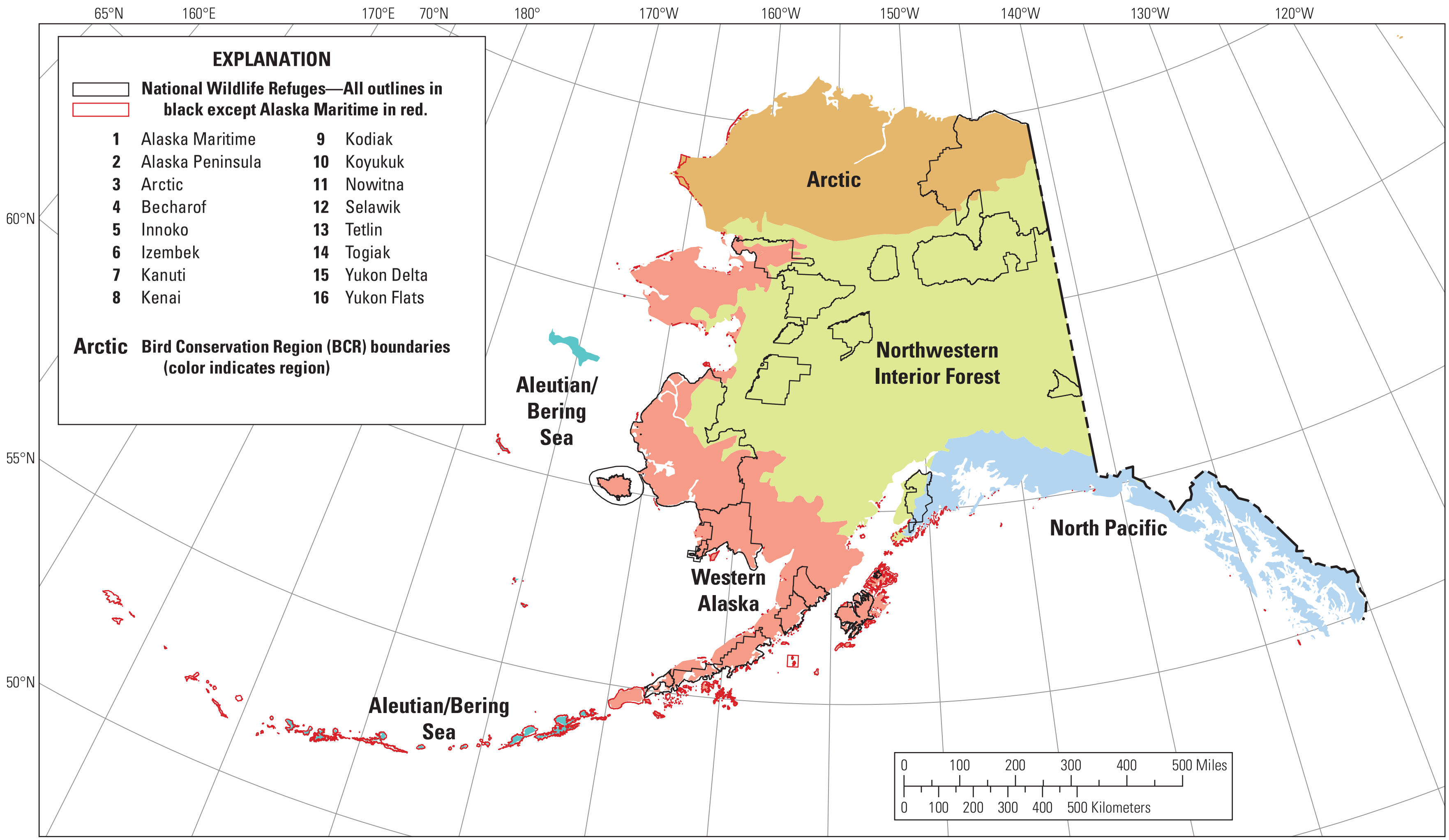
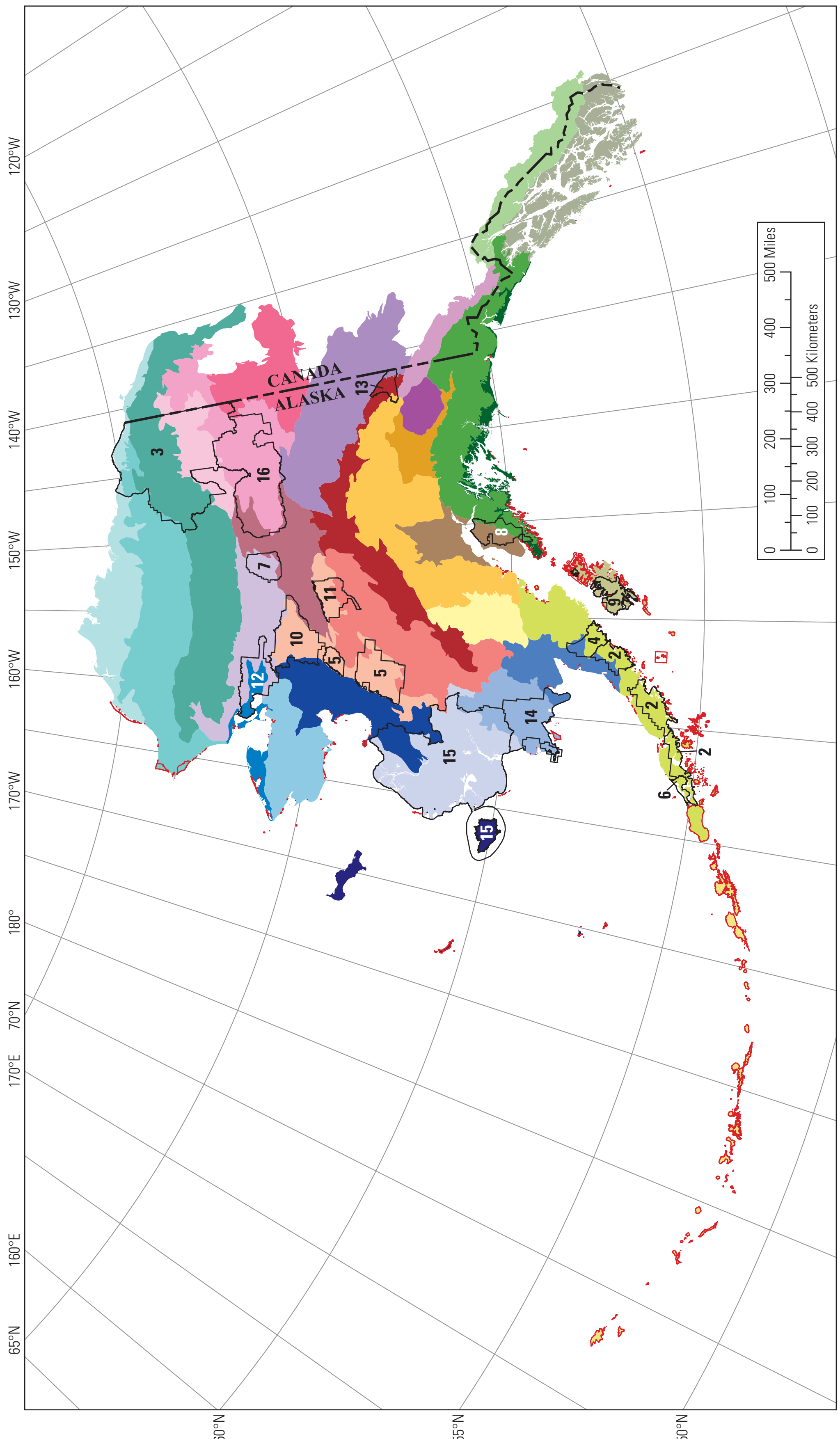


Figure 3. Boundaries of Alaska National Wildlife Refuges in relation to Bird Conservation Region (BCR) boundaries.


CANADA
ALASKA
120°W
130°W
140°W
150°W
160°W
170°W
180°
170°E
160°E
70°N
65°N
60°N
55°N
50°N
0 100 200 300 400 500 Miles
0 100 200 300 400 500 Kilometers
1
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16

EXPLANATION

National Wildlife Refuges—All outlines in black except Alaska Maritime in red.

1 Alaska Maritime
2 Alaska Peninsula
3 Arctic
4 Becharof
5 Innoko
6 Izembek
7 Kanuti
8 Kenai
9 Kodiak
10 Koyukuk
11 Nowitna
12 Selawik
13 Tetlin
14 Togiak
15 Yukon Delta
16 Yukon Flats

Ecoregions—from Nowacki and others, 2001. Ecoregions are organized into major bioclimatic groups.

BOREAL

Bering Taiga
- Ahklun Mountains
- Bristol Bay Lowlands
- Nulato Hills
- Yukon-Kuskokwim Delta

Intermontane Boreal
- Davidson Mountains
- Kobuk Ridges and Valleys
- Kuskokwim Mountains
- North Olgivie Mountains
- Ray Mountains
- Tanana-Kuskokwim Lowlands
- Yukon-Old Crow Basin
- Yukon River Lowlands
- Yukon-Tanana Uplands

Alaska Range Transition
- Alaska Range
- Cook Inlet Basin
- Copper River Basin
- Lime Hills

POLAR

Arctic Tundra
- Beaufort Coastal Plain
- Brooks Foothills
- Brooks Range

Bering Tundra
- Bering Sea Islands
- Kotzebue Sound Lowlands
- Seward Peninsula

MARITIME

Aleutian Meadows
- Alaska Peninsula
- Aleutian Islands

Coastal Rainforests
- Alexander Archipelago
- Boundary Ranges
- Chugach-St. Elias Mountains
- Gulf of Alaska Coast
- Kodiak Island

Coastal Mountains Transition
- Kluane Range
- Wrangell Mountains

Figure 4. Boundaries of Alaska National Wildlife Refuges, in relation to ecoregions based on Nowacki and others (2001).

The National Park Service has also grouped land management units in Alaska for purposes of organizing monitoring (fig. 5). Only the Southeast Alaska Network falls completely in one Nowacki-based ecoregion or LCC. The Central Alaska Network falls mainly in the interior ecoregions of the two other two classifications, but also has significant area in the north Pacific ecoregions. The Southwest Alaska Network occupies the Alaska Peninsula, but the Lake Clark National Park and Preserve is in the interior ecoregion. Finally, the Arctic Network falls mainly in the Polar (Nowacki-based system) and Arctic (BCR system) with the exception of Bering Land Bridge National Preserve, which lies in western Alaska. Given how much cooperation already occurs between refuges and national parks, it is unlikely that the discrepancies in ecoregional groupings will prevent further collaboration.

The Bureau of Land Management, U.S. Forest Service, other federal agencies and the State of Alaska have significant land holdings throughout Alaska. Their location relative to refuges is detailed in table 10.

Existing Inventories and Current Monitoring on Alaska NWRs

Inventories of natural resources have been conducted by various agencies throughout Alaska over a long period. An effort to enter all of the information, or even a summary covering what, when, how and who, would benefit all agencies. Having a current and historic record of resource distribution would provide an important context to assess future trends. Alaska refuges could begin to create this database by compiling the many inventories that have occurred on refuge lands. In fact, the Arctic NWR already does this by contributing the results of studies to North Slope Science Initiative and the Arctic LCC.

In fiscal year 2010, the refuge program in Alaska developed an assessment of the work effort expended by the refuge field stations and their staff on biological surveys and studies. Analysis of these results is pending. Ultimately, this annual survey will be a useful tool in tracking inventory and monitoring efforts on refuges.

In addition to current efforts by refuges themselves, other monitoring efforts are being conducted in and around these areas by other agencies. The following three sections of this chapter, as well as appendixes 9-11, describe much, but not all, of what is being done. We were able to gather more complete information from some agencies than others. Nevertheless, these summaries provide some guidance regarding potential sources of collaboration with refuges. Lists of other agencies that are monitoring indicators that may be of interest to USFWS are provided in table 13.

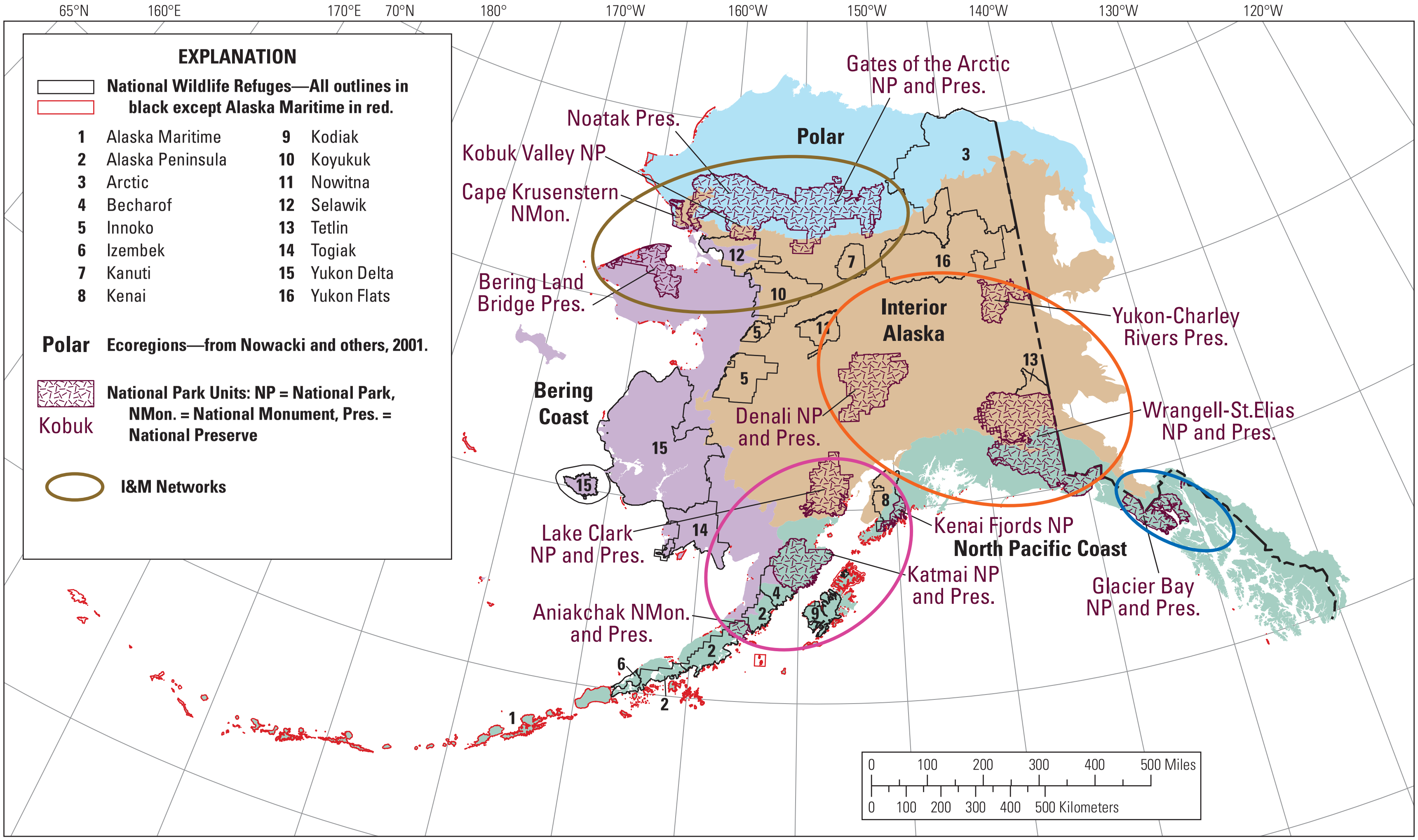

Figure 5. Comparison among Nowacki-based ecoregions, boundaries of Alaska NWRs and NPS units grouped by the four I&M networks in Alaska. Nowacki-based ecoregions are denoted by shading as in Fig. 4; NPS I&M networks are identified by ovals. ALAG, SITK, and KLGO (all in the North Pacific Coast ecoregion; abbreviations as in appendix 12) are not indicated, in this figure.

Table 13. Entities within or adjacent to Alaska that perform monitoring of indicators in table 11, and those that participate collaboratively, but are not the lead in monitoring of each indicator (including entities that may monitor the indicator in the future).

[ADF&G = Alaska Dept. of Fish & Game; ASC = Alaska Science Center; ARCN = Arctic I&M Network; CAKN = Central Alaska I&M Network; NOAA = National Oceanographic and Atmospheric Administration; NWS = National Weather Service; PCA = Parks Canada Agency; SEAN = Southeast Alaska I&M Network; SWAN = Southwest Alaska I&M Network; USFS = U.S. Forest Service]

	Indicator(s)	Other entities monitoring the indicator	Other collaborating entities that consider the indicator part of their monitoring program
State-wide Extent	Climate	NWS, NOAA, NPS-ARCN, NPS-CAKN, NPS-SWAN, NPS-SEAN, PCA	BLM, ADF&G, NPS-ARCN, NPS-CAKN, NPS-SWAN, NPS-SEAN
	Air quality, precipitation chemistry	NPS-ARCN, NPS-SWAN, NPS-SEAN, USFS	NPS-CAKN
	Landcover	NPS-CAKN, NPS-SWAN, NPS-SEAN, USFS, PCA	BLM, ADF&G
	Phenology	Various public and private entities, PCA, NPS	National Phenological Network-USA
	Water quality and quantity	NPS-CAKN, NPS-SWAN, NPS-SEAN	NPS-ARCN (future)
	Deformities and contaminants in organisms	USGS-ASC, USFS	
Ecoregional Extent	Habitat mosaics	BLM Wildlife, ADF&G, USFS, PCA	
	Migratory species	Boreal Partners in Flight, CARMA, ADF&G, USGS-ASC, BLM, NPS-ARCN, NPS, CAKN, USFWS Migratory Birds	NPS-SWAN (collaborator), NPS-SEAN (future), ALMS, BBS
	Permafrost-related events and resources	NPS-ARCN, NPS-CAKN, USGS-ASC	NPS-ARCN, NPS-CAKN
	Shoreline changes	NPS-ARCN, NPS-SWAN, USGS-ASC, PCA	
	Invasive species		NPS-SWAN (collaborator), NPS-ARCN (future), NPS-CAKN (future), NPS-SEAN (future)
	Other landscape processes	BLM, USFS	USFWS Regional Office
Refuge Extent	Subsistence resources	BLM, USFWS OSM, USGS-ASC (fishes, ungulates), USFWS Fisheries	
	Ecological keystones, ecosystem engineers, or key landscape modifiers	ADF&G, BLM	
	Local stressors and responses	Individual refuges, NPS-ARCN, NPS-CAKN, NPS-SWAN, NPS-SEAN, BLM, PCA	BLM
	Refuge-significant species not covered at ecoregional extent	Individual refuges, USGS-ASC, NPS-ARCN, NPS-CAKN, NPS-SWAN, NPS-SEAN, BLM, PCA	
	Special plant and animal communities	Individual refuges, USGS-ASC	

Ecological Monitoring on Refuges in Collaboration with Other Agencies

Although most monitoring within Alaska NWRs occurs independently of other refuges, several monitoring efforts span broader extents and encompass several refuges (appendix 9). Most of the monitoring of large-bodied mammals undertaken on refuges is conducted by, or in collaboration with, the Alaska Department of Fish and Game (ADF&G). Caribou, and black and grizzly bears, are monitored aerially based on survey units (caribou) or line transects (bears). ADF&G also occasionally monitors wolves and wolverines (appendix 9).

Two programs monitor birds extensively in Alaska, the Breeding Bird Survey (BBS) and the Alaska Landbird Monitoring Survey (ALMS). BBS is a national, road-based program and many refuges have at least one BBS route on or near the refuge. The system of BBS routes in Alaska has had enough routes to be meaningful since 1993. Currently there are 142 routes in Alaska, some of which use motor boats to supplement the little area accessible via the state's sparse road system. The ALMS program was also established to supplement BBS by tracking bird species and abundances in roadless areas. It was launched in 2003, and the initial sample came from Interior and North Pacific Rainforest Bird Conservation Units (appendix 9).

Several programs monitor plants in Alaska. These include, among others, the U.S. Forest Service Forest Inventory and Analysis Program (FIA, appendix 3, 11), the USGS eelgrass and macroalgae monitoring program, Global Observation Research Initiative in Alpine Environments (GLORIA) and the International Tundra Experiment (ITEX). The FIA program has been implemented in southeast and south-central Alaska using methods of the national program, which covers all U.S. forested lands. It features a spatially-balanced sample with 10 percent of the plots measured annually. Data collection is focused on trees, with additional vegetation metrics measured on a 1/16 subsample. Eelgrass and macroalgae monitoring was initiated by USGS in 2009. Sampled areas included embayments in or adjacent to four Alaska NWRs (Izembek, Togiak, Alaska Peninsula-Becharof, and Yukon Delta). Vegetation monitoring also is performed by the U.S. National Park Service and the Bureau of Land Management (appendix 19).

Monitoring Efforts by Other USFWS Programs

Various treaties and legislative acts require USFWS to monitor a number of species, all of which are important to various refuges (appendix 10). Refuges already collaborate with most of these efforts and have the potential to augment sampling for the benefit of the refuge and for the larger USFWS program. The USFWS Marine Mammals Management Office monitors the status and trends of polar bear, Northern sea otter, and Pacific walrus populations in all Alaska marine habitats, and performs a census of subsistence harvest. The information directly applies to the eight coastal refuges. In addition, the Office is beginning to monitor interactions between polar bears and humans (appendix 10).

USFWS monitors key fish populations in collaboration with the Alaska Department of Fish and Game and the refuges. Although the monitoring program meets high standards of sample design and data collection and analysis, the large area of the State, as well as logistic and budgetary constraints have limited the effectiveness of the program. Consequently, the effort has been insufficient to meet the information needs, and data have not been readily available to decision-makers. Monitoring developed for the Alaska NWRs has an opportunity to help fill this gap.

The Migratory Birds Branch of USFWS monitors seabirds, waterfowl, raptors, and shorebirds. Seabird monitoring consists of counting individuals at index sites located approximately every 500 miles along the coast, as well as kittiwake monitoring in Prince William Sound in response to the Exxon Valdez oil spill. Abundance, trend, and distribution of waterfowl are monitored in the spring using aerial transects, both on and off refuges. Raptor monitoring is limited to bald eagles, mainly on the southern coast of the State. Shorebird monitoring is dependent on "soft" money, so is conducted inconsistently. Status and trend of multiple shorebird species is monitored via a standardized protocol (PRISM). The effort began in 2002 and occurs irregularly at Canning River, near Arctic NWR, near Barrow and near Prudhoe Bay, and on the Yukon River Delta. Additionally, more-intensive demographic investigations track attributes such as nest success, site fidelity, and adult survival at a limited number of sites (see appendix 10).

Monitoring by Other Agencies with Relevance to the Alaska NWRs

U.S. Forest Service's Forest Inventory and Analysis (FIA) program – The FIA program in Alaska is part of a national program that monitors status and change of all U.S. forest lands (http://www.fia.fs.fed.us; appendix 3). In Southeast and South-central Alaska, the program uses the national design: a spatially-balanced probability sample of field plots across all lands and use of spatially-complete remote sensing data for stratification (appendix 11). Field sample points are randomly divided into 10 panels, with one panel measured each year using a boat/helicopter combination that travels from Ketchikan to Kodiak. The program covers 15 million ha, and the sample contains about 5,620 plots on land (2,200 forested plots). The national FIA program currently operates in all states and territories of the U.S. with the exception of Wyoming and the remainder of Alaska. If funded, the program proposed for the remainder of Alaska will have a reduced sampling intensity, some modifications to the design and indicators, and incorporation of LiDAR data. Indicators monitored by the FIA program are generally reported at the ecoregion, survey unit, state, or national level. Status and change of a variety of forest indicators are reported, as listed in appendix 8. On a 1/16th subsample of plots, additional indicators include suites of variables for down woody debris, vegetation diversity, crown conditions, lichens, and soils.

U.S. National Park Service's Inventory and Monitoring (I&M) program – Five overarching objectives guide the program nationally (appendix 1), and suites of stepped-down objectives analogously guide each of the four I&M networks within Alaska (see http://science.nature.nps.gov/im/units/akro/index.cfm and links). Each network chose, via a carefully orchestrated process, a group of about 20 to 30 'Vital sign' indicators, which are organized under the themes of Air and Climate, Geology and Soils, Water, Biological Integrity, Human Use, and Landscapes. I&M networks consider their constituent park units as their primary clients, but interface with a diversity of other stakeholders and audiences. A summary of the I&M effort at the national level is given in appendix 1. As illustrated in appendix 12, the suites of indicators monitored in each park and network in Alaska represent a balance between comparability across space and acknowledging the unique resources and management priorities of each park.

Bureau of Land Management (BLM) – As with Forest Service lands, BLM lands are administered under a multiple-use mandate. Ecological monitoring in BLM occurs within Fisheries, Wildlife, Cultural, Recreation, and Vegetation programs (appendix 11). Species groups include cliff-nesting raptors; eiders; game mammals; breeding and migrating birds; polar bears; subsistence-use (for example, salmon, northern pike), recreationally important, unique and resident fish. Across Alaska, BLM works through NRCS to collect soils information in a few regions, and data on snow-depth and snow-water equivalent in specific areas that are part of NRCS' regional networks. There is no cultural or paleontological information collected that is not site- or project-specific; it will thus be difficult to organize this information at ecoregional or statewide extents.

Priorities for Baseline Information Needs

One clear message expressed by participants at the Forum on Ecoregional Monitoring was that most USFWS refuges within Alaska lack baseline data on many biotic and (especially) abiotic components. Addressing this deficit would provide managers fundamental information regarding exactly what resources they have to protect. Relative to supporting monitoring this information would: (a) provide a baseline against which to measure refuge-wide and ecoregional-scale change and (b) inform analysis, interpretation, and forecasting of numerous other monitored indicators, and (c) provide a basis for spatial stratification that may be needed to distribute samples.

This message was not new; in fact, by 2004, the National Wildlife Refuge System had already developed "guidelines and core baseline biotic data standards for inventories that include the types of information every unit of the National Wildlife Refuge System should have on its resources." (USFWS Baseline Inventory Team 2004:3). In addition to identifying the minimum inventory data needed for every refuge and determining the spatial scales most appropriate for data collection and presentation, the 2004 document also provided standardizing guidelines for realizing the inventories and suggested standards for reviewing products. The minimum set of inventories included GIS data layers for abiotic (topography, hydrography, soils, boundaries, and manmade features) and, biotic features (vegetation mapping and National Wetland Inventory data), and aerial photography. In contrast to refuges in the contiguous U.S., for which these data layers exist free of cost via other sources, many Alaskan refuges have never had comparable inventories of their resources. Species lists of vertebrate fauna and flora, as well as supplemental data on resources of special interest (for example, Threatened and Endangered species) were among the highest priorities, after the minimum set.

Although some at the Forum on Ecoregional Monitoring for the NWRS and other Public Lands across Alaska have espoused considering these informational products as one-time "baseline" inventories, their value will increase the more times that they are repeated. Furthermore, in the particularly unpredictable environment created by climate dynamics, a 'baseline' may be better defined by a few snapshots or estimates than by a sample at a single point in time. That is, historical range of variability is no longer dependable as a paradigm, because targets will likely shift through time.

To obtain a cross-disciplinary assessment of the value of various pieces of spatially explicit information for inventory and monitoring purposes, Forum participants were randomly distributed into four groups while balancing regional and discipline affiliations to assess and prioritize inventory needs for refuges in Alaska (table 14). The groups identified a number of abiotic (permafrost, landform, bathymetry, climatology, traditional ecological knowledge), and biotic inventories (rapid biodiversity assays) that were not part of the 2004 list but would be particularly valuable for refuges in Alaska. Although not shown in table 14, other needs that were communicated included spatially explicit layers of fire history, future-fire projections, and LANDSAT vegetation mapping. None of these was listed in the 2004 document, although National Vegetation Classification System (NVSC) data were recommended for creating a vegetation map.

Table 14. The top four priorities for inventory needs for National Wildlife Refuges in Alaska, as determined by each of four multi-disciplinary, multi-affiliation groups at the (April 2009) Forum on Ecoregional Monitoring.

[The overall average rank of the four highest-priority inventories appears in the leftmost column]

Rank	Overall	Group 1	Group 2	Group 3	Group 4
1	High-resolution imagery (1,1,1,3)	Abiotic Suite (DEM, soils, etc.)	High-resolution imagery	High-resolution imagery	Topographic and aerial imagery
2	Abiotic Suite (1,2,3,3)	(Rapid) biodiversity assay	(Rapid) biodiversity assay	Abiotic (soils, landform, permafrost, etc.)	Water
3	Water (2,3,4,4)	High-resolution imagery	Abiotic Suite (DEM, bathymetry, climatology)	Hydrology, vegetation maps, and rapid biodiversity assay	Soils
4	Biodiversity Assay (2,2,3,-)	Water quality and quantity	Water quality and quantity	Human component; traditional ecological knowledge	Vegetation

Technical Capabilities/Staffing

Technical capacities that must be brought to bear in ecological monitoring are diverse and varied. In most cases, moving forward without possessing these capacities within the I&M workforce or securing a collaboration to otherwise access these skill sets can create a bottleneck that dramatically slows the productivity of the entire monitoring process. These capacities include expertise in statistical analysis, Geographic Information Systems (GIS) analysis, remote sensing, database management and programming, and the disciplinary expertise required to write, review, and implement protocols (that is, '-ologists') in addition to the fundamental need for administrative support. Disciplinary expertise is especially important for resources (for example, glaciers, insect identification) for which refuges within an ecoregion may not possess specific experience and knowledge. Not all positions need to be filled at all sites, but it is desirable that the capability be available somewhere. Short-term, intensive needs may be met by consultants, especially for statistics, or by other agencies (for example, USGS).

Currently two positions are dedicated to data management and analysis in the Alaska NWRs: a biometrician in the Regional Office and a database programmer at Kenai NWR. In addition, Alaska Maritime NWR is trying to hire an individual who specializes in databases. While there are also individuals using these skill sets in other parts of the refuge system, the current investment in data management is lower than the approximately 30 percent of program funding dedicated by many ongoing monitoring programs (for example, USFS Forest Inventory and Analysis, NPS Inventory and Monitoring programs). These resources are needed because developing an active constituency and sustaining support for monitoring programs involve timely reporting of synthesized and interpreted information, which requires technical resources. Note that the 30 percent budgeted in most programs excludes the initial effort to develop and refine primary objectives, monitoring designs, methods used, and analysis-support tools.

Many of these points are recognized by the leadership of USFWS and were expressed at two breakout sessions held for managers at the Forum on Ecoregional Monitoring for the NWRS and other Public Lands in Alaska (appendix 13).

Chapter 7. Road Map for Developing Monitoring Plan

To aid visualization of the road ahead, we consolidate the process of developing a monitoring plan into a list of steps, both sequential and concurrent, and a rough estimate of the time required for each. We also provide a rough draft of a potential monitoring program in broad terms, based on the legal, environmental, and managerial context of Alaska NWRs and considerations for developing a monitoring program described above.

Steps Required to Implement Monitoring

In practice, most broad-scale monitoring programs at regional, national, and international scales have required about a decade to become fully functional. The many steps or activities required to develop such programs and the estimated amount of time required to complete each of those activities are listed in table 15. It is clear that the process of monitoring program development requires much forethought, and continued vigilance to ensure that deadlines are met and progress develops as envisioned. Each of the listed activities could easily be more fully described by a list of sub-activities

Table 15. A roughly sequential list of activities that are typically accomplished in the development of an integrative, long-term program of monitoring natural resources across broad spatial scales.

Activity	Typical duration
Begin to hire staff for broad-scale Monitoring Center: Coordinator, Data Manager	4-15 mos
Perform inventories of resources present in management areas (especially within target domains)	1-several yrs
Amalgamate information from existing monitoring programs within the sphere of influence of the target domains(s)	6-24 mos
Summarize resources, processes, drivers, and gradients existing within focal area	9-18 mos
Create conceptual models that link prominent resources, processes, structure, and stressors via defined interactions/links	6-12 mos
Develop and refine objectives for the Monitoring Center (and other levels, as appropriate)	1-6 mos
Identify more-comprehensive list of potential indicators	1-4 mos
Decide upon method to prioritize indicators; obtain input on priorities from researchers and managers	3-9 mos
Select initial list of indicators to be monitored in short and longer terms (tiered, to accommodate various funding levels)	2-6 mos
Write comprehensive monitoring plan covering objectives, conceptual models and all decisions regarding indicators	18-36 mos
Hire disciplinary Specialists to lead monitoring program(s) for related indicator(s)	6-15 mos
Develop objectives/questions for each indicator	1-2 mos
Develop sampling design and protocols for each indicator	6-18 mos
Obtain external peer-review of objectives/questions, sampling design, and protocols	6-18 mos
Pilot test methods and protocol and protocol revision	1-4 yrs
Begin full implementation of monitoring	5-7 yrs
Review progress of monitoring for each indicator	Every 3-5 yrs
Produce annual reports for indictors	Annually
Create synthetic report to summarize, interpret and communicate findings of monitoring; multiple formats may be needed to address different audiences	Every 5-7 yrs

that are required as steps to achieving the completion of that activity's overarching objectives. For example, external peer review of many of the most-technical intermediate products in the process, especially without dedicated funding, can require non-trivial amounts of extra time. Although a summing of the duration for each activity could provide a 'ballpark' estimate for the upper and lower bounds of time required for the entire process, two facts complicate estimation of the sum: (a) multiple activities can occur simultaneously, thereby lowering the total estimate; and, more commonly, (b) the estimates for duration assume that work on the monitoring program is both the dominant priority for all staff members and continues without interruption in personnel.

The process of developing a monitoring program is well documented by the U.S. NPS I&M program (http://science.nature.nps.gov/im/monitor/). In addition to many reports with useful ideas about all aspects of monitoring, the site provides the monitoring plans from all NPS networks including the four in Alaska (Arctic Network, ARCN; Central Alaska Network, CAKN; Southeast Alaska Network, SEAN; and Southwest Alaska Network, SWAN). Good examples of layout and production also include plans from the Greater Yellowstone Network (GRYN) and the Mojave Network (MOJN) (John Gross, NPS I&M Program, oral commun., 2010.). Good examples of data-management plans include those from the National Capital Network (NCRN), the Southeast Coast Network (SECN), and the Southeast Alaska Network (SEAN) (Margaret Beer, NPS I&M Program written comm.). All can be found fairly easily on the national website.

Outline of Monitoring Plan

Tables 11 and 12 present one possible version of a multifaceted, multi-scale monitoring program for USFWS refuges in Alaska that relies upon a number of key characteristics to increase the likelihood of its long-term success. As stated previously, this is merely illustrative of what may result from an indicator selection process reflecting management information needs. The brief notes regarding potential temporal and spatial monitoring strategy are not meant to underestimate the tremendous amount of work that must be invested in determining these. They are merely meant to suggest a range of possibilities and to illustrate how they may vary with monitoring question.

This plan has several notable features. First, it acknowledges that different ecological resources vary on different spatial and temporal resolutions, and that their dynamics and trend are most logically and efficiently monitored organizationally at different extents. Second, it accommodates and blends with the wealth of monitoring efforts that are already occurring in and adjacent to refuges across Alaska; at least some of these efforts may be best performed only at local (refuge-specific) extents, from biological and analytical standpoints. Third, it allows for collaboration with other entities performing ecological monitoring within Alaska, and helps fill gaps in things that are not already being monitored, thereby creating synergy across entities via a discipline-oriented (rather than spatial) GAP analysis. Fourth, the suite of metrics and attributes reflects the laws and statutes that guide management philosophies and actions on refuges of Alaska. Fifth, the suite of indicators include numerous monitoring targets that numerous constituencies in Alaska and broader publics care about, due to their charisma, elevated conservation status, or ability to effect dramatic changes on the landscape. This interest and ‘investment’ in those species’ status and trends may serve as another impetus to retain support for the monitoring program. Sixth, although the hypothetical plan includes charismatic elements, it also includes metrics such as water quality, invasive species, land cover, and other abiotic measures. Seventh, humans are considered an integral part of the natural landscape, and human needs for sustenance and transportation are explicitly acknowledged. Finally, the plan considers not only contemporary climate change, but a suite of potential drivers of resource condition and trend, in a stressor-based paradigm, as part of analysis and interpretation (Roux and others, 1999; Dubé and Munkittrick, 2001). Although climatic influences will be a pervasive and strong driver of ecological dynamics for many years to come, long-term monitoring must be responsive to all sources that cause variability in the condition of that resource.

It is important to note that although ecosystem function is one of the three fundamental aspects of biological diversity (other than composition and structure; Noss, 1990; Niemi and McDonald, 2004) and will likely increase in importance over time due to its intimate connection with provision of ecosystem services (for example, clean water, flood attenuation, prevention of erosion), it is largely absent from table 11. Because ecosystem function is often poorly linked to biodiversity (Schwartz and others, 2000; Hector and others, 2001), monitoring biological diversity with the assumption that it will be a surrogate for ecosystem functioning is untenable. Thus, although it is comparatively difficult to develop measurable attributes as proxies of ecosystem function, we suggest further consideration of ecosystem-function indicators.

Chapter 8. Conclusions

In this document, we have reviewed multiple broad-scale ecological monitoring programs and shown that careful planning is the foundation of a good monitoring program. Because of the complexity and the number of people necessarily involved, the planning and design processes can take much longer than expected. The refuge system in Alaska has taken major steps in this process through meetings with staff and the creation of refuge-scale and ecoregional conceptual models. Other building blocks include existing monitoring conducted by the refuges, other branches of USFWS, and other agencies. Some program-level decisions are being made at the national level, but many regional, ecoregional, and refuge-scale decisions will have to be made and other steps will be required before protocols for monitoring specific indicators are completed. These steps include selection of indicators, prioritization of alternatives, and developing sampling frames based on design considerations that are appropriate for the desired results. Despite the challenges, Alaska NWRs are on the path to developing an effective ecoregionally based monitoring program that will meet information needs at several spatial scales and organizational levels.

Decisions regarding monitoring must be driven by carefully articulated objectives, and several tiers of objectives must be developed. First, programmatic objectives reflect the audience and purpose of the monitoring data, and state what the program strives to achieve. These objectives may or may not specify particular resources to monitor, but instead guide decisions regarding program strategy and structure, such as types of questions, spatial scale, and allocation of personnel and funds. Monitoring objectives form the second tier of objectives. They derive from the programmatic objectives, and describe what should be monitored in general terms. Finally, measurable objectives (or monitoring questions) specify specific indicators and monitored attributes in sufficient detail to determine a spatial and temporal survey design, as well as sampling methods that will be used. Careful attention to objectives insures that the resources allocated to monitoring will indeed meet the information needs of the agency.

An important conclusion of this report is that the management context of Alaska NWRs, (that is, relevant statutes, logistical constraints, potential threats to resources, etc.) results in both strategic and tactical monitoring needs. Tactical information relates to the effectiveness of active management actions to natural resources within the ecosystem (for example, habitat restoration, harvest limits on game species), whereas strategic information relates to the effectiveness of passive protection of ecosystem integrity. Tactical information needs can be met with the standard adaptive-management approach where indicators are specified by the nature and purpose of a management action. Strategic information needs, which usually require describing ecosystem status and trend, are more difficult to identify and are based on current understanding of ecosystem structure, composition, and function. Because these two needs require different approaches to identifying indicators, and often different temporal and spatial scales for trend detection and inference, it makes sense to address them separately at every stage of program development. Nonetheless, both types of monitoring, as well as inventories, will achieve maximum utility when they are explicitly tied to management decisions and actions, in some way.

We also emphasize the utility of using hierarchical structures throughout the development and implementation of monitoring. Hierarchical structures are especially useful for an agency with vast landholdings that are embedded in a matrix of other federal lands and are facing a variety of threats acting over a range of time frames. The result is a hierarchy of information needs in time (strategic, tactical) and space (international, regional, ecoregional, refuge; table 1). Coarser information is often sufficient to meet information needs at larger spatial scales and longer time frames, while finer detail is more likely required at smaller spatial scales and more immediately. Moreover, protected resources are organized on the landscape according to a hierarchy of ecoregional delineations. The hierarchy of needs and spatial structure can be appropriately met by hierarchical organization of objectives, conceptual models, and program structure.

The management context of Alaska NWRs requires that several challenges be met throughout the development of a monitoring program. Perhaps the most difficult challenge is to maintain enough flexibility to both address strategic and tactical needs, yet also address unforeseen future needs. Flexibility is extremely difficult to sustain, given the rigidity and uncertainty of annual federal budgets. Moreover, monitoring decisions usually require an arduous process of negotiation and compromise among agency staff and are therefore not easy to alter. Another important challenge is to achieve collaboration among refuges and with other agencies to accomplish monitoring goals. Collaboration can be difficult, especially among agencies, because different entities are likely to have different objectives for monitoring the same resource, as a function of different mandates and other factors. Consequently, attributes and sample frames monitored by one agency may be inadequate to meet the information needs of another agency. Nevertheless, the potential savings in staff time and funds means that exploring opportunities for collaboration is worthwhile. A final challenge is to realize that the information needs are so great and the costs of acquiring it so high, that it will not be possible to monitor anything in great detail. It is important to remember that the monitoring program is meant primarily to indicate change and thereby trigger a management action, which might include research efforts to better understand what is happening.

Effective data management is required to produce high-quality data that is appropriately analyzed and effectively communicated. Because data management pervades the monitoring process, planning for and funding these activities are crucial for a successful monitoring program. It is sometimes hard to accept that the costs of monitoring are greater than the costs of simply collecting data, but unless the data are reported and archived for future uses, the effort to collect them was wasted. These costs are not trivial; they can constitute from one-fifth to fully one-third of the entire monitoring budget. However, the rise of ecoregional monitoring represents a landmark opportunity for a sea change in USFWS monitoring efforts across Alaska, wherein the amount of information learned and the number of individuals better informed can be maximized at every opportunity.

Despite the complexity of the process and inevitable challenges, staff members of the Alaska NWRs have an invaluable opportunity to use lessons from the experiences of other agencies to develop a successful monitoring program. The required steps begin with hiring leadership staff and developing programmatic and monitoring objectives. Choosing and prioritizing indicators and attributes with the help of conceptual models are the next steps, followed by developing protocols and the data-management infrastructure to ensure that results are produced and communicated. Along the way, documentation of plans, decisions, and protocols will enable internal and external scientific peer-review and review by Service management staff, thereby ensuring that all scientific and management implications have been considered. The benefits of investing in the careful, thorough development of a monitoring program include creation of an endeavor that persists through time while providing status-and-trends information to support the agency decision-making process. While this process must integrate multiple social and scientific considerations to evaluate the need for and consequences of management actions, adequate information regarding resource condition is indispensible.

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Speakers featured on Day 1 of the Forum, who introduced the essential aspects of existing long-term monitoring programs, included Donald McLennan (Parks Canada Agency), John Gross (NPS), Michael Gill (Circumpolar Biodiversity Monitoring Program, Environment Canada), Tara Barrett (USFS-FIA), John Morton (Kenai NWR, USFWS), Christian Torgersen (USGS Forest and Rangeland Ecosystem Science Center), Tony Olsen (EPA), Terry Chapin (University of Alaska, Fairbanks), Kelly Redmond (Desert Research Institute), Melinda Knutson (USFWS), and WilliamThompson (NPS I&M). Furthermore, Torre Jorgenson (Alaska Ecoscience) provided an overview of effects of contemporary climate change that have been predicted and already evidenced.

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Appendix 1. Summary of National Park Service Inventory and Monitoring Program

(Based on presentation by John Gross at the Forum on Ecoregional Monitoring for the NWRS and other Public Lands across Alaska [*http://Alaska.usgs.gov/science/biology/ecomonitoring*], Fancy and others, 2009, and the program website [*http://science.nature.nps.gov/im/monitor*])

Agency Mission

The mission of the National Park Service is "to promote and regulate the use of national parks … which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." National Park Service Organic Act, 16 U.S.C.1.

Agency Structure

The National Park Service is a nationally distributed collection of fairly autonomous park units, having unique specific purposes stated in the establishing legislation for each.

Objectives for Monitoring

- Determine the status and trends in selected indicators of the condition of park ecosystems to allow managers to make better informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparison with other, altered environments.
- Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress toward performance goals.

Monitoring Program Administrative Structure

The parks with significant natural (as opposed to cultural) resources are grouped into 32 geographically related networks of parks to facilitate collaboration, information sharing and economies of scale. Each network shares core funding and a professional staff to design and implement the monitoring program. Profession staff includes a network coordinator, data manager, quantitative ecologist, and sometimes GIS support. A national staff sets the overall program objectives (quoted above); sets standards for monitoring plan content and the timeline for completion; sets standards for protocol content; and evaluates programs. National program direction is facilitated by regional coordinators. Specific monitoring objectives and decisions about indicators and attributes are set at the park level.

Monitoring Program Approach

The program strives to identify a small set of information-rich attributes that will indicate the 'health' of park resources and to provide early warning of conditions that require management action. These ‘Vital Signs’ are defined as a subset of all physical, chemical and biological elements and processes of park ecosystems and the information obtained from them is expected to have application for management decisions, research, education and promoting public understanding.

Pillars of the I&M effort include: thorough assessment of existing resources and previous monitoring efforts, creation of conceptual models that describe ecosystem dynamics (Gross 2003), creation of protocols that facilitate repeatability of monitoring through time and through staff turnover (Oakley and others, 2003), creation and maintenance of databases that archive collected data that have been carefully quality-checked, rapid and regular availability of monitoring results through various communication avenues (for example, online, annual reports, podcasts, summary briefs for managers), and connection to management (Fancy and others, 2009).

Linkage between Monitoring and Management

National parks are managed to promote visitor enjoyment and to protect natural resources from damage. Consequently, active management to achieve biological outcomes is minimal. Monitoring objectives reflect this situation by aiming to provide understanding of ecosystem function and early warning of changes rather than having an adaptive management role. The goal is to provide managers with the knowledge necessary to respond effectively when needed, and to alert them to the need as early as possible. Predictions of where to expect change, and therefore where to invest monitoring resources, are based on ecosystem conceptual models.

Administrative Location of Decisions

Networks were given a fair amount of autonomy to determine their structure, especially regarding whether network staff would be full time network employees or part time network and part time park employees. The table below describes the most common situation.

	ADMINISTRATIVE LEVEL		
FUNCTION	PARK	NETWORK	NATIONAL
General Guidance			X
Detailed Planning			
Specific Objectives	X		
Attribute Selection		X	
Survey Design		X	
Choice of Methods		X	
Data Management Plan		X	
Program Implementation			
Data Collection	X	X	
Data Management		X	
Data Analysis		X	
Reporting/Dissemination		X	
Program Administration			
Program Revision		X	
Funding Allocation		X	X

Audience for Monitoring Results

The primary audience of monitoring results is at the park level: park managers and planners, natural resource specialists, interpreters and scientists working at the park level. The secondary audience is the public, Congress and the Office of Management and Budget.

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Appendix 2. Summary of Inventory and Monitoring Program of Parks Canada Agency

(Based on presentation by Don McLennan at Ecoregional Monitoring for the NWRS and other Public Lands across Alaska [*http://Alaska.usgs.gov/science/biology/ecomonitoring*] and the program website [*http://www.pc.gc.ca/progs/np-pn/*])

<u>Agency Mission</u>
"On behalf of the people of Canada we protect and present nationally significant examples of Canada's natural and heritage, and foster public understanding, appreciation and enjoyment in ways that ensure the ecological and commemorative integrity of these places for present and future generations."

<u>Agency Structure</u>
Parks Canada Agency consists of 42 national parks and national park reserves, which have been grouped into six bioregions (Pacific, Montane, Interior Plains, Great Lakes, Atlantic-Quebec, and Northern and Arctic groups).

<u>Objectives for Monitoring</u>
The objective of the monitoring program is to measure changes in ecological integrity of parks:

- to assess the effectiveness of management
- to increase the understanding of ecosystem change
- to find areas where future research is needed
- to serve as 'ecological baselines' to which non-protected areas can be compared.

Ecological integrity is a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes.

<u>Monitoring Program Administrative Structure</u>
The National Ecological Integrity Monitoring Committee provides general guidance and evaluates park monitoring plans.

<u>Monitoring Program Approach</u>
Two levels of questions drive the monitoring approach:

What is the state of park ecological integrity?
How do our management actions affect park ecological integrity?

To answer these questions, the program strives to develop core indicators that are relevant to parks but can be summarized regionally and nationally. Indicators of ecological integrity are ecosystems (for example, forest, tundra) within bioregions. Measures (attributes) are grouped by biodiversity, ecosystem functions and stressors, and are collected at the spatial scales of plots and remote sensing. Landscape-scale metrics of ecological integrity in development for arctic national parks in Canada include:

Tundra ecosystems

- Change in area of tundra ecotypes
- Change in tundra vegetation biomass/Leaf Area Index
- Change in tundra growing season length
- Change in tundra snow phenology

Freshwater ecosystems

- Change in lake ice phenology
- Change in river ice phenology
- Change in lake surface area

Wetlands ecosystems

- Change in area of wetland ecotypes
- Change in wetland physiognomy/structure
- Change in wetland vegetation biomass/LAI
- Change in wetland snow phenology

Coastal ecosystems

- Change in area of coastal ecotypes
- Change in biomass/LAI of coastal ecotypes
- Change in sea ice phenology
- Change in rate of shoreline erosion
- Change in sea surface temperatures

Forest ecosystems

- Change in area of forest ecotypes
- Change in forest vegetation biomass/LAI
- Change in forest growing season length
- Change in forest snow phenology

<u>Linkage between Monitoring and Management</u>

Results are communicated with simple graphics that indicate whether a given attribute can be described as having impaired, fair, or good condition. The process of setting thresholds to define levels of condition is also the process of setting management goals and indicating management success. These are used to assess fulfillment of management objectives through park management plans which are reviewed and updated every 5 years.

Administrative Location of Decisions

	ADMINISTRATIVE LEVEL		
FUNCTION	PARK	BIOREGIONAL	NATIONAL
General Guidance			X
Detailed Planning			
Specific Objectives	X	X	X
Attribute Selection	X		
Survey Design	X		
Choice of Methods	X		
Data Management Plan	X		
Program Implementation			
Data Collection	X		
Data Management	X		
Data Analysis	X		
Reporting/Dissemination	X		X
Program Administration			
Program Revision			X
Funding Allocation			X

Audience for Monitoring Results

The audience for monitoring results is park management and the public through State of the Park Reports and visitor education.

Appendix 3. Summary of Forest Inventory and Assessment Program

(Based on presentation by Tara Barrett at the Forum on Ecoregional Monitoring for the NWRS and other Public Lands across Alaska [*http://Alaska.usgs.gov/science/biology/ecomonitoring*], USDA Forest Service (2007), and the program website [*http://fia.fs.fed.us*])

<u>Agency Mission</u>
The mission of the U.S. Forest Service is to "sustain that health, diversity and productivity of the National's forests and grasslands to meet the needs of present and future generations."

<u>Agency Structure</u>
The U.S. Forest Service is composed of nationally distributed national forest units.

<u>Objectives for Monitoring</u>
The fundamental objective of the program is to "make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of the forest and rangelands of the United States." Recent legislation further instructed the FIA program to establish an enhanced program to inventory and analyze public and private forests and their resources including

- an annual inventory of each State every year
- a 5-year report for each State
- national standards and definitions for reporting
- provisions to ensure protection of private-property rights
- a process for employing remote sensing, global positioning systems, and other advanced technologies.

<u>Monitoring Program Administrative Structure</u>
The monitoring is directed and funded nationally but it is implemented operationally at the regional level. Regions are composed of several states. Data are compiled on an annual basis and made available on line within 6 months of collection. Complete State-level analytical reports are completed every 5 years. Experts in various technical areas who develop methods and approaches needed to implement the program form "Technical Bands".

Monitoring Program Approach

The attributes described under monitoring objectives are measured in a rotating panel design of 10 percent, 15 percent or 20 percent of plots per year, depending on region, of a systematic grid of plots (Bechtold and Patterson 2005). Special designs are being developed for interior Alaska, the Caribbean and Pacific Islands. The design for attribute selection is hierarchical with a consistent core set of field measurements collected the same way across all U.S. forested lands, paid for with federal funding. Regions may add additional attributes to be paid for with federal and shared funding. Other attributes may be added locally to address local needs and provide data for special studies, to be paid for by clients. Core attributes measured or derived for every plot include:

- above-ground carbon
- fire effects, post-fire succession
- stand age, species composition, stand structure (height, layering)
- species distribution, size, and health of trees
- total tree growth, regeneration, mortality, and harvest
- tree volume and biomass; wood production and utilization rates by various products
- tree diseases, insects, and other damages
- invasive plants
- soils (O'Neill and others, 2005), understory vegetation (Schulz and others, 2009), tree crown conditions (Zarnoch and others, 2004, Schomaker and others, 2007), coarse woody debris (Woodall and Monleon 2007), and lichen community composition (for example, Jovan and McCune 2005) on a 1/16th subsample of monitoring plots (that is, on all Phase 3 plots).

Summary statistics calculated by state or nationally include:

- forest area and location, by owner, by reserve status, and by forest type

Several other additional indicators exist:

- Harvest and utilization: Mill survey of each state occurs every 5 to 10 years.
- National woodland owner survey: Information collected includes reasons for owning forest, how land is used and managed, concerns and issues, sources of information, future intentions, and demographics.
- Ozone damage: This is a special set of plots across the U.S. used to monitor ozone damage of vegetation – there are only 4 plots in Alaska and no damage has been found in those plots.

Linkage between Monitoring and Management

Most forests of the United States are actively managed to provide a supply of forest products (the major exception being national parks and designated Wilderness). The data from this monitoring program informs public and private forest managers, as well as state and federal policy makers, about the statewide and national condition of forests as a basis for decisions regarding harvest levels, fire management, and other issues.

Administrative Location of Decisions

	ADMINISTRATIVE LEVEL		
FUNCTION	LOCAL	REGIONAL	NATIONAL
General Guidance			X
Detailed Planning			
Specific Objectives	X	X	X
Attribute Selection	X	X	X
Survey Design			X
Choice of Methods			X
Data Management Plan			X
Program Implementation			
Data Collection		X	
Data Management		X	
Data Analysis		X	
Reporting/Dissemination		X	
Program Administration			
Program Revision			X
Funding Allocation			X

Audience for Monitoring Results

The primary audiences for monitoring results are national and state policy makers with responsibility for forest management, and Congress.

References Cited

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Woodall, C.W., and Monleon, V.J., 2007, Sampling protocol, estimation, and analysis procedures for the down woody materials indicator of the FIA program: Washington, D.C., U.S. Department of Agriculture, Forest Service, Northern Research Station, General Technical Report NRS-22.

Zarnoch, S.J., Bechtold, W.A., and Stolte, K.W., 2004, Using crown condition variables as indicators of forest health: Canadian Journal of Forest Research, v. 34, p. 1057–1070.

Appendix 4. Summary of National Aquatic Resources Surveys

(Based on presentation by Tony Olsen at Forum on Ecoregional Monitoring for NWRS and other Public Lands across Alaska [*http://Alaska.usgs.gov/science/biology/ecomonitoring*], and the program website [*http://www.epa.gov/owow/monitoring/nationalsurveys.html*])

Agency Mission

The mission of the Environmental Protection Agency (EPA) is "to protect human health and to safeguard the environment – air, water and land – upon which life depends." EPA leads the nation's environmental science, research, education and assessment efforts.

Agency Structure

The EPA consists of a national office, 10 regional offices, and 12 laboratories.

Objectives for Monitoring

The National Aquatic Resources Surveys (NARS) is the institutionalized monitoring program resulting from the monitoring tools developed by the Environmental Monitoring and Assessment Program (EMAP). The objectives of the program are to "report on core indicators of water condition using standardized field and laboratory methods." Specific questions include

- What is the extent of waters that support healthy ecosystems, recreation and fish consumption?
- How widespread are water quality problems?
- Is water quality improving?
- Are we investing in restoration and protection wisely?

Monitoring Program Administrative Structure

EPA provides federal funds to states to monitor the condition of waters across the nation. Funding is contingent on states using a statistically valid survey design, that they use at least some of an identified set of core attributes, and that they achieve a minimum level of statistical confidence in the results. States are allowed to use national or state methods, and use any temporal sampling frame as long as the results can be aggregated for a state-scale survey. States report results to EPA; EPA will create a national summary. EPA regional offices provide technical assistance to states. EPA recognizes that the unique nature of the land and waters in Alaska mean that more time may be required to meet program requirements.

Monitoring Program Approach

The EMAP program pioneered the development of General Randomized Tesselation Stratified sampling (GRTS) for establishing spatially balanced random sample frames for monitoring. Monitoring attributes measured at GRTS-selected plots were developed by EMAP to effectively and efficiently describe water quality. Core indicators are expected to be measured at each plot over the long term; supplemental data may be collected short term to meet special needs; research indicator studies may also be conducted to pilot new indicators.

Linkage between Monitoring and Management
Results are presented in simple graphics describing whether individual attributes are good, fair or poor by region. Producing these summaries requires that monitoring objectives for attributes be stated in precise quantitative terms, and thresholds must be established to categorize results into good, fair or poor. Therefore, there is a clear assessment about whether management of the nation's waters is effective in protecting water quality.

Administrative Location of Decisions

	ADMINISTRATIVE LEVEL		
FUNCTION	STATE/TRIBES	REGIONAL	NATIONAL
General Guidance			X
Detailed Planning			
Specific Objectives	X		X
Attribute Selection	X		X
Survey Design			X
Choice of Methods	X		
Data Management Plan	X		
Program Implementation			
Data Collection	X		
Data Management			X
Data Analysis	X		X
Reporting/Dissemination			X
Program Administration			
Program Revision			X
Funding Allocation			X

Audience for Monitoring Results
The primary audiences for monitoring results describing the conditions of the nation's waters are the public and Congress. Results also measure the performance of EPA protection and restoration programs.

Appendix 5. Summary of United Kingdom Countryside Survey

(Based on presentation by Christian Torgersen at Forum on Ecoregional Monitoring for NWRS and other Public Lands across Alaska [*http://Alaska.usgs.gov/science/biology/ecomonitoring*], Kugler and others, (2009), and the program website [*http://www.countrysidesurvey.org.uk*])

Agency Mission

"The Natural Environment Research Council delivers independent research, survey, training and knowledge transfer in the environmental sciences, to advance knowledge of planet Earth as a complex, interacting system. Our vision is to advance knowledge and understanding of the Earth and its environments to help secure a sustainable future for the planet and its people."

Agency Structure

The NERC national office funds research in universities and its own centers. Four centers are owned by NERC and five are collaborative with universities or other institutions.

Objectives for Monitoring

The mission of the Countryside Survey is to provide scientifically reliable evidence about the state or 'health' of the United Kingdom's countryside and to identify change and rate of change in resources. Specific objectives change with every survey and reflect the resources available. In 2007, the objectives included:

- To record and report on the amount and condition of widespread habitats, landscape features, vegetation, land cover, soils and freshwaters.
- To assess changes in the countryside and improve our understanding of the causes and processes of change, by comparison with data from earlier surveys.
- To collect, store and analyze data in ways that optimize the integration of Countryside Survey data through time and make it compatible with other data sources.
- To provide access to data and interpreted results that underpin a range of policy and science needs for major environmental zones and landscape types in the UK, Great Britain, England, Scotland, Wales and Northern Ireland.
- To contribute to the development of an integrated assessment of the drivers and pressures of change and better understand their effects on the UK countryside and their implications for ecosystem goods and services.

Monitoring Program Administrative Structure

The Countryside Survey is conducted by the Natural Environment and Research Council's Center for Ecology and Hydrology with funding from NERC and a partnership of other government agencies, led by the Department for Environment, Food and Rural Affairs. The project is divided into Work Packages, which are managed and undertaken by highly trained teams. Work Packages address such topics as Landcover mapping, soils, reporting, filed surveys, informatics, etc. Surveys have been conducted in 1978, 1984, 1990, 1998, 2000 and 2007.

Monitoring Program Approach

Surveys consist of a national landcover map based on remote sensing plus a random sample of a systematic grid of 1-km squares distributed across all non-urban landscapes and stratified by habitat type. Each 1-km square is mapped according to broadly defined priority habitats, linear, and point features. Multiple subsamples are taken to describe vegetation, streams, pond and soils. Plots are documented with georeferenced photographs.

Linkage between Monitoring and Management

The program reports percentage change from the 1978 baseline for attributes by habitat type as a means to inform government policy-makers and the public regarding biodiversity, natural environment, sustainable agriculture, environmental stewardship, water resources, sustainable forestry, soil protection, urban development, air quality and climate change.

Administrative Location of Decisions

	ADMINSTRATIVE LEVEL		
FUNCTION	LOCAL		NATIONAL
General Guidance			X
Detailed Planning			
Specific Objectives			X
Attribute Selection			X
Survey Design			X
Choice of Methods			X
Data Management Plan			X
Program Implementation			
Data Collection			X
Data Management			X
Data Analysis			X
Reporting/Dissemination			X
Program Administration			
Program Revision			X
Funding Allocation			X

Audience for Monitoring Results

The primary audience is policy makers in the governments of Great Britain, and the public.

Reference Cited

Kugler, T.A., Torgersen, C.E., Benjamin, S.P., Gelfenbaum, G.R., Woodward, A., Torregrosa, A., and Fuentes, T., 2009, Integrated Landscape Monitoring: Lessons Learned from Four National Programs. Unpublished manuscript.

Appendix 6. Summary of Circumpolar Biodiversity Monitoring Program

(Based on presentation by Mike Gill at Forum on Ecoregional Monitoring for NWRS and other Public Lands across Alaska [*http://Alaska.usgs.gov/science/biology/ecomonitoring*], and the program website [*http://cbmp.arcticportal.org/*])

Agency Mission

The Arctic Council was formed by the Ottawa Declaration of 1996 to create a "high level intergovernmental forum to provide a means for promoting cooperation, coordination and interaction among Arctic states, with the involvement of Arctic Indigenous communities and other Arctic inhabitants on common Arctic issues, in particular issues of sustainable development and environmental protection in the Arctic."

Agency Structure

The Arctic Council includes Working Groups on various topics, including Conservation of Arctic Flora and Fauna (CAFF), which are responsible for executing the programs and policies mandated by Arctic Council Ministers. The Working Groups have supporting scientific and technical Expert Groups.

Objectives for Monitoring

The Circumpolar Biodiversity Monitoring Program (CMBP) was initiated by the CAFF working group of the Arctic Council. The mission of CBMP is "to facilitate the conservation of biological diversity in the Arctic and the sustainable use of the region's natural resources by:

- harmonizing and enhancing Arctic monitoring efforts, thereby improving our ability to detect and understand significant trends, and
- reporting to and communicating with both key decision makers and stakeholders, thereby enabling the effective conservation and adaptation responses to changes in Arctic biodiversity.

Fundamentally, the goal is to build a collaborative framework for Arctic biodiversity monitoring.

Monitoring Program Administrative Structure

The program does not administer monitoring.

Monitoring Program Approach

CBMP takes an ecosystem-based approach to aggregating monitoring data by integrating information on land, water and living resources in a geographic region. The CBMP is incorporating the ecosystem-based approach primarily through the establishment of five integrated, cross-disciplinary Expert Monitoring Groups representing the Arctic's major systems: marine, freshwater, coastal, terrestrial fauna and terrestrial vegetation. These monitoring groups are supported by the coordination of a "network of networks", drawing on existing species, habitat and site-based monitoring networks. The CBMP is assuming the role of coordinator for the networks by supporting monitoring standardization across networks and providing value-added services in the areas of data management, communications, reporting and decision-making.

Linkage between Monitoring and Management
The primary linkage with management is through providing information to the Arctic Council.

Administrative Location of Decisions

	ADMINISTRATIVE LEVEL		
FUNCTION	LOCAL	NATIONAL	ARCTIC-WIDE
General Guidance			X
Detailed Planning			
Specific Objectives		X	
Attribute Selection		X	X
Survey Design		X	
Choice of Methods		X	X
Data Management Plan		X	
Program Implementation			
Data Collection		X	
Data Management		X	X
Data Analysis		X	X
Reporting/Dissemination		X	X
Program Administration			
Program Revision			X
Funding Allocation		X	

Audience for Monitoring Results
Audiences include members of Arctic Council governments, Permanent Participants, local Arctic residents, other global and regional shareholders with the goal of enabling policy-making decisions.

Appendix 7. Summary of Environmental Monitoring and Assessment Network

(EMAN; based on presentation by Christian Torgersen at Forum on Ecoregional Monitoring for NWRS and other Public Lands across Alaska [*http://Alaska.usgs.gov/science/biology/ecomonitoring*] and the program website [*http://eman-rese.ca/eman/*])

Agency Mission

The mission of Environment Canada is "to preserve and enhance the quality of the natural environment; conserve Canada's renewable resources' conserve and protect Canada's water resources; forecast weather and environmental changes; enforce rules relating to boundary waters; and coordinate environmental policies and programs for the federal government."

Agency Structure

Environment Canada has a national office and 100 community offices.

Objectives for Monitoring

EMAN's main role is one of coordination, as it does not have the resources to operate its own sites or fund monitoring and research. EMAN must rely on information and cooperation from other agencies, in order to better deliver information to decision-makers, demonstrate the relevance of ecosystem monitoring and maintain a range of long-term integrated monitoring sites.

EMAN was established with the following four objectives:

- to provide a national perspective on how Canadian ecosystem are being affected by multitude of stresses on the environment;
- to provide scientifically defensible rationales for pollution control and resource management policies;
- to evaluate and report to Canadians on the effectiveness of resources management policies; and,
- to identify new environmental issues at the earliest possible stage.

Monitoring Program Administrative Structure

The program consists of a national Coordinating Office and seven regional leaders who are responsible for day-to-day organizational and scientific issues related to EMAN sites in their region.

Monitoring Program Approach

As EMAN is not financially able to provide funding for monitoring and research, it must provide some other benefits for its partners in order to encourage participation in the network. EMAN does this through the development of products, services and programs that aid in ecological monitoring and assessment. These include monitoring protocols, metadata and databases, an annual national science meeting, early warning reporting and the coordination of two community-based monitoring programs.

Linkage between Monitoring and Management
EMAN strives to support effective management decisions and policy by providing coordinated reporting on environmental conditions at the national scale.

Administrative Location of Decisions

	ADMINISTRATIVE LEVEL		
FUNCTION	SITE		NATIONAL
General Guidance			X
Detailed Planning			
Specific Objectives	X		
Attribute Selection	X		X
Survey Design	X		
Choice of Methods	X		
Data Management Plan	X		
Program Implementation			
Data Collection	X		
Data Management	X		
Data Analysis	X		X
Reporting/Dissemination	X		X
Program Administration			
Program Revision			X
Funding Allocation			NA

Audience for Monitoring Results
The primary audiences for program information are the federal Minister of the Environment, the Canadian public and EMAN partners.

Appendix 8. Example Criteria and Weights for Ranking Indicators and Attributes (from Fancy and others, 2009)

Criterion 1: Management Significance (Weight – 40 percent)

A useful ecological indicator must produce results that are clearly understood and accepted by park managers, other policy makers, research scientists, and the general public, all of whom are able to recognize the implications of the indicator's results for protecting and managing the park's natural resources. Ultimately, an indicator is useful only if it can provide information to support a management decision (including decisions by other agencies and organizations that benefit park resources) or to quantify the success of past decisions, For example, this may happen if:

- there is an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management decisions
- the measurements will produce results that are clearly understood and accepted by park managers, other policy makers, research scientists, and the general public, all of whom should be able to recognize the implications of the results for protecting and managing the park's natural resources
- monitoring results are likely to provide early warning of resource impairment, and will save park resources and money if a problem is discovered early
- in cases where data will be used primarily to influence external decisions, the decisions will affect key resources in the park, and there is a great potential for the park to influence the external decisions
- data are of high interest to the public
- for species-level monitoring, involves species that are harvested, endemic, alien, species of special interest, or are threatened or endangered
- there is an obvious, direct application of the data to performance goals
- contributes to increased understanding that ultimately leads to better management

Criterion 2: Ecological Significance (Weight – 40 percent)

- there is a strong, defensible linkage between the indicator and the ecological function or critical resource it is intended to represent
- the resource being represented by the indicator has high ecological importance based on the conceptual model of the system and the supporting ecological literature
- the indicator characterizes the state of unmeasured structural and compositional resources and system processes
- the indicator provides early warning of undesirable changes to important resources. It can signify an impending change in the ecological system
- the indicator reflects the functional status of one or more key ecosystem processes or the status of ecosystem properties that are clearly related to these ecosystem processes. [Note: replace the term ecosystem with landscape or population, as appropriate.]
- the indicator reflects the capacity of key ecosystem processes to resist or recover from change induced by exposure to natural disturbances and/or anthropogenic stressors

Criterion 3: Legal/Policy Mandate (Weight – 20 percent)

This criterion provides additional weight to a potential vital sign if a park is directed to monitor specific resources because of some binding legal or Congressional mandate, such as specific legislation and executive orders, or park enabling legislation.

Reference Cited

Fancy, S.G., Gross, J.E., and Carter, S.L., 2009, Monitoring the condition of natural resources in U.S. national parks: Environmental Monitoring and Assessment, v. 151, p. 161–174.

Appendix 9. Ecological Monitoring Across Refuges

Alaska Department of Fish & Game

Much of the monitoring of large-bodied mammals occurring in Alaskan NWRs is performed by, or in close collaboration with, the Alaska Department of Fish and Game (ADF&G). Principles that drive the ideal monitoring designs and implementation, statewide, are (1) explicit estimation of detectability ("sightability") except in caribou monitoring, and (2) quantification of uncertainty in population-size estimates. Mark-resign and mark-recapture techniques are commonly used to assess detectability, but their accuracy and precision are vulnerable to unmodeled heterogeneity in recapture probabilities (Borchers and others, 2004).

Caribou (*Rangifer tarandus* L.) monitoring is implemented in the most-consistent manner, across the state. It involves composition counts, to estimate sex and age-class ratios, as well as summer photo censuses, when animals are highly aggregated into groups. The latter method involves taking aerial photos of naturally occurring aggregations then counting individuals. Moose (*Alces alces* L.) monitoring most commonly takes one of two forms: surveys using Gasaway (1986) methods, or the VerHoef (2001, 2002) GSPE (GeoSpatial Population Estimator) approach. The latter method uses flights immediately before the planned survey to stratify sampled grid cells into high- and low-density grid cells. Both methods account for variable detectability, and are used in various places to better understand trend via annual re-visits. The GSPE approach appears robust to some violations of model assumptions, and delineation of survey-area boundaries with GPS coordinates (rather than landmarks, which were previously used to delineate boundaries of Gasaway surveys) allows for more-rapid navigation to and within survey units. As a disadvantage, gridded cells typically encompass a heterogeneous mix of habitat elements important for the focal mammal species. GSPE is model-based and thus can accommodate more restrictions on sample composition, such as inclusion of index sites or other patterns that would compromise assumptions of simple random sampling. GSPE provides kriging of count data across the entire study area.

ADF&G also monitors numerous terrestrial carnivore species. Black bears (*Ursus americanus* Pallas) and grizzly bears (*Ursus arctos* L.) are typically surveyed using aerial line transects (Becker and Quang 2009), and analyzed to account for assumptions about survey conditions that are normally violated. Mark-resight approaches are not commonly used for bears in Alaska, due to the high survey costs associated with their typically low densities and large number of replicate trials to accurately model heterogeneity. Wolves (*Canis lupus* L.) and wolverines (*Gulo gulo* L.) have been monitored using TIPS (transect-intercept probability sampling) or SUPE (sample-unit probability estimation) designs, although much less frequently than for ungulates. For example, the last extensive survey for wolves by ADF&G in an NWR occurred in 2002. Becker and others, (2004) describe the assumptions, implementation, analysis, variations, and advantages and disadvantages of the TIPS and SUPE methods. Re-visit strategies for carnivore surveys have not yet been systematically addressed, because few areas have been sampled twice using the same methods.

Breeding Bird Survey (BBS) *http://www.pwrc.usgs.gov/BBS*

Although most monitoring within USFWS refuges of Alaska occurs independently of other refuges, there are several monitoring efforts that span broader extents and encompass several refuges. For example, many refuges have one or more Breeding Bird Survey (BBS) routes on or nearby refuge lands for which sampling is completed at least in part by USFWS biologists. The North American BBS is a continent-wide program designed to monitor the status and population trends of North America’s breeding birds at large spatial scales – from states and provinces, to the entire continent. The BBS is the most comprehensive avian survey in the continent; trends are estimated for over 420 bird species, including most landbirds breeding in the U.S. and Canada (Sauer and others, 2005). The program is based on a network of volunteer observers who conduct nearly 3,000 road-side surveys each year along predetermined routes in the United States and Canada (Figure A9.1). The program has been in existence since 1966, and is administered by the USGS in the United States and by the Canadian Wildlife Service in Canada.

Each roadside route is randomly assigned and consists of a 24.5-mi (39.2-km) stretch of secondary road with 50 stops spaced 0.5 mi (0.8 km) apart. At each of the 50 stops, the observer records the number of individuals of all bird species, either heard or seen, within 0.25 mi (0.4 km) of the stop during a 3-min period. Routes are surveyed once a year (10-30 June in Alaska) by an observer that has good hearing and eyesight, can identify all birds in the region by sight and sound, and has completed the BBS on-line training program. The Alaska BBS has been most effective since 1993 when the number and consistency of routes surveyed annually was dramatically increased. As of 2009, ~70 routes are run each year, covering most of the appropriate road system in the state. The BBS is currently the only widely implemented monitoring program for landbirds in Alaska, and has a total of 142 routes that have been sampled for various lengths of time since 1968. Significant modifications to the program in Alaska include the collection of habitat data along most routes (Cotter and Andres 2000), the establishment of routes on rivers run by motorboat in areas without roads (Harwood 2002), and the non-random location of routes due to the limited number of appropriate roads in many portions of the state. The Alaska BBS does not cover the long-term sampling frame analyzed for trends (1966–present), so data are not currently included in the estimation of continent-wide trends (J.R. Sauer, U.S. Geological Survey, oral commun., 2009). Nonetheless, 15 years of consistent effort in Alaska has allowed for habitat relationships for 48 landbirds (Cotter and Andres 2000), and estimates of trends are available for >100 species across the state.

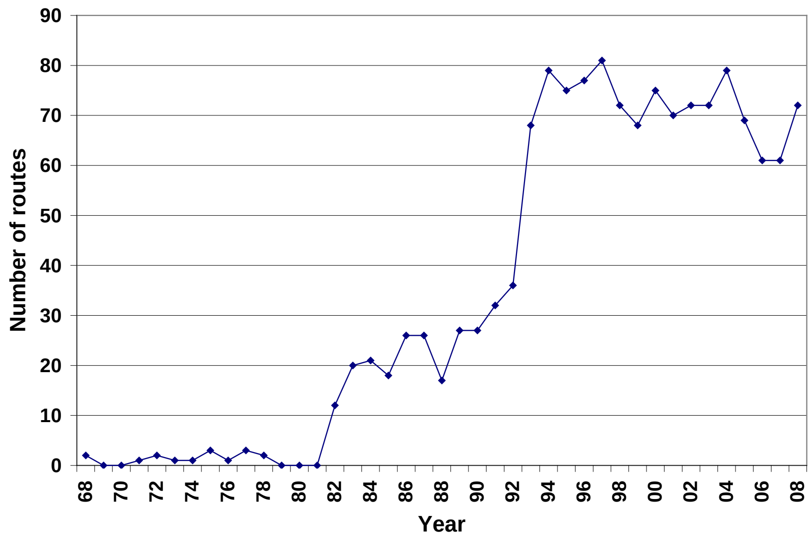

Figure A9.1. Breeding Bird Survey (BBS) routes performed annually in Alaska, during 1968–2008.

Alaska Landbird Monitoring Survey (ALMS)
alaska.usgs.gov/science/biology/bpif/monitor/alms.php

Developed by Boreal Partners in Flight, ALMS is designed primarily to: (1) monitor population trends of landbirds across the vast roadless areas of Alaska and (2) model the distribution and abundance of birds relative to habitat, physiography, and other factors across the landscape. The program has been designed to complement the North American Breeding Bird Survey, which, by virtue of its restriction to roadsides, is greatly biased in Alaska and inadequate to estimate population trends because of the sparse road system in the state. Field protocols were developed and tested for ALMS over a 10-year period with the help of volunteer and agency biologists across Alaska. The program has been designed primarily to monitor passerines and other small landbirds during the breeding season; however, these surveys also gather valuable data for other groups of birds. Officially launched in 2003, ALMS is a statewide program in which cooperators conduct surveys on their own lands using a standardized methodology and a unified sampling design and pool their data for regional and statewide analyses. The sampling frame consists of a grid of 10-km by 10-km sampling blocks across mainland Alaska whose eastern boundary is aligned with the Alaska-Canada border (141° W). Within each sampling block is a mini-grid of 25 points (5 by 5) whose southwestern-most point is offset from the corner of the block by a randomly selected set vector. Sample points within each mini-grid are separated by 250 m in the Northern Pacific Rainforest and by 500 m in the other four Bird Conservation Regions (BCRs) in Alaska. These distances were selected to minimize travel distance between points while also minimizing the potential for double-counting the same individual birds at adjacent survey points. Within each sampling block, a minimum of 15 of the 25 points must be available for surveying birds (that is, not in lakes, on glaciers, on terrain too unsafe to survey, etc.).

The sampling design is a stratified random design. Broad strata are based on the 32 Unified Ecoregions of Alaska (Nowacki and others, 2001), which in turn are substrata of the five BCRs (U. S. NABCI Committee 2000). Except in BCR1 (the Aleutian/Bering Sea Islands), the sampling frame subset selected for initial efforts consists of all blocks within federal and state resource lands. This subset has been divided into “readily accessible” and “less-accessible” strata based on time, cost, regulations, and safety to access, with the accessible stratum being the initial focus of the program. A sample of 200 blocks has been allocated proportional to the area of ecoregions and land management units. The initial statewide goal was to have an active sample of 100 blocks (50 per year) by year 2010, with efforts concentrated in BCR 4 (Interior) and BCR 5 (North Pacific Rainforest) because of the high diversity of landbirds within those regions. Half of the blocks have been allocated to National Wildlife Refuges because of the large land mass they encompass relative to other federal and state resource lands. As of 2009, 65 of the targeted 100 blocks statewide are being regularly surveyed. Among National Wildlife Refuges, however, only 13 of the allocated 50 blocks are being surveyed, although Tetlin NWR is surveying 6 more blocks than its allocated sample (table A9.1).

Detailed protocols and data forms are provided in Handel and Cady (2004). Briefly, surveys consist of 10-minute point-transects during early morning at each of the points in the mini-grid; surveys can require 2–3 days to complete, depending on terrain. Trained observers record all birds seen or heard along with data on distance from the observer, behavior, time interval, weather, and habitat. Each survey is designed to be replicated every two years, with half of the samples surveyed in any given year. The sampling design and survey protocols have been selected to allow much flexibility in choice of analytical methods. Population trends from

ALMS data will be analyzed jointly with data from the roadside Breeding Bird Survey using hierarchical models (for example, Link and Sauer 2007). Distribution and abundance across the landscape can be modeled using designed-based approaches (for example, Handel and others, 2009) or spatial hierarchical models (for example, Gorresen and others, 2009). Estimated total costs are $25–30K per crew per initial year, and $20K per crew in subsequent years. Total for entire program statewide is $250K for initial set-up, and $150K per subsequent year.

Table A9.1. Number of sampling blocks targeted for ALMS program per refuge compared with number currently active and number still needed to meet statewide monitoring goals. Annual effort required is half of this level, since surveys are replicated every other year.

National Wildlife Refuge	Initial Target	Active	Still Needed
		4	
Alaska Maritime NWR	7		3
Alaska Peninsula/Becharof NWR	4	1	3
Arctic NWR	6	2	4
Innoko NWR	4	2	2
Izembek NWR	1	0	1
Kanuti NWR	2	2	0
Kenai NWR	2	1	1
Kodiak NWR	1	0	1
Koyukuk NWR	3	0	3
Nowitna NWR	2	0	2
Selawik NWR	2	0	2
Tetlin NWR	1	7	0
Togiak NWR	3	0	3
Yukon Delta NWR	6	0	6
Yukon Flats NWR	6	0	6
Total	50	19	37

Eelgrass monitoring in southwest Alaska

USGS, in cooperation USFWS refuges, initiated a program to inventory and monitor eelgrass (*Zostera marina* L.) and macro-seaweeds in Alaska in 2009. Eelgrass plays an essential role in the health of estuarine and coastal ecosystems in the southern portion of Alaska (<65^{o} N latitude), where it is a dominant marine plant species, a key primary producer, and a critical food resource and habitat for a rich diversity of plant and animal species. The monitoring program is focused on embayments in or adjacent to the four National Wildlife Refuges of southwestern Alaska: Izembek, Togiak, Alaska Peninsula-Becharof and Yukon Delta NWRs.

The monitoring program uses a hierarchical framework to characterize ecosystem status and trends while diagnosing causes of environmental change (NSTC 1997). The framework involves three levels of monitoring activity, integrated across spatial scales and sampling intensities. Level 1 consists of large-scale mapping and inventory of embayments using satellite and airborne remote-sensing capabilities to develop baseline maps of eelgrass distribution. Given that much of the eelgrass habitat has yet to be inventoried, Level 1 activities comprise a large portion of the initial effort. Level 2 consists of broad-scale boat surveys of the eelgrass and seaweed abundance and health by sampling a subset of points within each embayment, using a systematic sampling design with a random start (Lohr 1999). These surveys collect spatially explicit measurements of eelgrass health (for example, shoot morphometrics, density, abundance, epiphyte loads) during its peak biomass (mid-June to early August). Finally, Level 3 involves more-intensive monitoring of potential environmental parameters (for example, water temperature, turbidity, salinity, irradiance) at a few locations to assess how potential drivers influence eelgrass productivity and survival. Since the program's inception, inventory and monitoring efforts have occurred in three embayments on two refuges (Izembek and Togiak), and are poised to expand to three more embayments on the other two refuges (Yukon Delta and Alaska Peninsula-Becharof) in summer 2010.

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Appendix 10. Monitoring Efforts by USFWS Programs Other than NWRS

Marine Mammals Management

The USFWS Marine Mammals Management (MMM) Office in Alaska is responsible for conservation and management of polar bear, Northern sea otter, and Pacific walrus populations in all Alaska marine habitats, including in and near the eight National Wildlife Refuges in the state with a maritime border. Management of three sea otter, one walrus, and two polar bear stocks occurs at roughly ecoregional scales. Management mandates are largely specified by the Marine Mammals Protection Act of 1972 and the Endangered Species Act of 1973. MMM partners with the refuges, USGS, and others to assess status and trend of stocks using best-science survey techniques and biological monitoring efforts. The Office is also committed to co-management practices that incorporate both western-science and traditional-ecological-knowledge perspectives in monitoring and managing these stocks.

For the last 20 years, MMM has operated a Marking, Tagging, and Reporting Program (MTRP), which is intended to census subsistence harvest of all three species in Alaska and to forestall illegal trade of marine-mammal body parts. The MMM Office maintains a permanent network of about 150 ‘harvest taggers’ in 100 maritime communities and currently holds over 47,000 harvest records across all three species. Taggers are local residents that work for MMM on a contractual basis to collect harvest information, which is used to satisfy the regulatory requirement that each harvested animal be reported within 30 days. Although the MTRP consistently under-reports actual subsistence harvest, it is a reliable harvest indexing system. The Office employs both formal and informal correction factors to estimate true harvest impacts. Two MMM biologists operate MTRP full-time with substantial support from part-time staff. In 2009, MMM also began developing a Polar Bear-Human Information Management System (PBHIMS), which seeks to track and analyze polar bear/human conflicts for all circumpolar nations. There are over 80 variables in this database. One biologist in MMM has been assigned to operate the PBHIMS system for all jurisdictions in the geographic range of the polar bear, including Alaska.

Fisheries

Many of Alaska’s fish species have life histories that involve extensive migrations that range from hundreds to thousands of miles. As a consequence, effective fisheries management requires consistent and strategic population monitoring across these large geographic extents. Having sufficient baseline and time-series data is fundamental to conserving and managing Alaska’s fish species. The USFWS Fisheries Program in Alaska invests the majority of its human and fiscal resources in monitoring and assessing key fish populations in close collaboration with ADF&G, USFWS Refuges, and other natural-resource agencies. However, a persistent problem is that too few baseline and time-series (that is, trend) data exist for most aquatic resources in Alaska. The State’s large size, coupled with the logistical and budgetary constraints associated with conducting monitoring and assessment studies in remote areas, contribute to the paucity of baseline information necessary for making informed decisions. A major challenge is deciding where to use limited funding to monitor stock-specific and broad-scale trends to support the conservation and management of Alaska’s fish populations. Another challenge is ensuring that existing fisheries data and expertise are incorporated into the development of USFWS and external aquatic-resource conservation and management plans. In many cases, data are not readily available or easily accessible to those that need to use them for making decisions.

The USFWS Fisheries Program in Alaska is highly mindful of the need to collect fisheries and aquatic habitat data in a consistent manner that will maximize its utility for management purposes. All fisheries monitoring projects are coordinated closely with ADF&G to insure data collection is standardized across jurisdictions. As a Fisheries Program policy, all projects must complete an Investigation Plan (IP) prior to conducting any field work. The IP must be approved by the Program's regional Fisheries biometrician to insure appropriate sample sizes are considered, appropriate statistical methods have been outlined, and methods of data collection are consistent with primary fisheries and habitat databases. All approved fisheries projects are required to publish results in either professional journals or in the USFWS Alaska Fisheries Publication Series (*http://alaska.fws.gov/fisheries/fish/reports.htm*).

Migratory Birds

The Migratory Birds Management Division consists of two branches: Waterfowl and Non-Game. The Waterfowl group has biologists in field offices throughout the State. Within the Non-Game branch, there are lead biologists for Raptor, Waterfowl, Shorebird, Landbird, and Seabird groups.

The **Waterfowl** Branch conducts surveys around Alaska to monitor abundance, trend, and distribution of waterbirds. Most surveys occur annually in springtime, to coincide with the breeding season. Other surveys are conducted on staging, molting, and wintering areas. Breeding-ground surveys follow a standard protocol (USFWS and Canadian Wildlife Service 1987). Most survey areas are not stratified; however, where long-term distribution information is available, it is used to create designs stratified by bird density. Sampling effort is then optimally allocated within strata. Survey areas are typically sampled with systematically spaced strip transects. Multi-year surveys are designed with a rotating panel of transects with a different set flown annually (over a period of 4 years, for example). This allows pooling of multi-year data for finer-scale mapping of waterbird distribution. Most surveys do not incorporate correction for imperfect detectability; however, an independent-observer double-count technique (Seber, 1973; Magnussen and others, 1978; Pollock and Kendall, 1987; Graham and Bell, 1989) is used for some surveys, to correct for sightability.

For **seabirds**, monitoring began in 1976 by Alaska Maritime NWR, and expanded in the 1980s. Monitoring at colonies is achieved by repeat visits to a collection of index sites, which were originally established by selecting one large seabird colony within each ~500 miles of Alaska Maritime coastline. At each large colony, numerous count plots were non-randomly selected for establishment, and numbers of individuals in those plots are estimated by ground-based observers with binoculars during each survey. Additionally, censuses of kittiwake colonies in Prince William Sound were added after the Exxon Valdez oil spill in 1989. Seabird monitoring in Alaska: occurs during June-August; measures population trends, phenology, productivity, diets, and survival; and averages over 1,000 field person-days per year (for example, see Dragoo and others, 2009).

Raptor monitoring has involved tracking trends of bald eagles (*Haliaeetus leucocephalus* L.) across Alaska since 1967. The state is subdivided into five survey regions: Southeast Alaska, the North Gulf Coast, the Alaska Peninsula (including Kodiak), the Aleutian Islands, and the Interior; the intent is that one of these areas is surveyed each year, on a rotating basis. Most monitoring has focused on the south coast of the state (from Dixon Entrance to the tip of the Alaska Peninsula), where most bald eagles in Alaska occur. The vast Interior region has only been partially sampled once (along segments of some larger rivers), in 2006. The Aleutians have never been comprehensively surveyed due to costs (estimated at >$100,000.), but Byrd and Williams (1991) estimated ~400 pairs for the Aleutians in 1991. The other 3 areas have been surveyed more consistently. Data available from past surveys indicate that eagle numbers are stable in Alaska. There may be interest in increasing survey intensity in light of the new eagle permit program initiated in Nov. 2009 that will allow the take of eagles nationwide, due to the species' delisting from the Endangered Species Act.

USFWS Migratory Birds' monitoring of **shorebirds** depends heavily on availability of soft funding, thus effort varies dramatically across years. Monitoring of population status and trends occurs via a double-sample method, to quantify detectability (Bart and Earnst, 2002) and falls within the general hemispheric program designed to monitor shorebirds (Program for Regional and International Shorebird Monitoring, PRISM; Bart 2005, Skagen and others, 2004). Monitoring has been performed primarily along the North Slope of Alaska. Methods include a limited number of "intensive" plots (4 to 8 400-m × 400-m plots around established base camps) where intensive survey efforts (1 to 1 ½ months) are conducted during June and July. A separate team performs rapid (1.25-hr) ground-based searches at many "rapid" plots located randomly over a much larger pre-set area of Arctic breeding habitat. There, the team records bird presence and abundance between 7-21 June, when shorebirds are most detectable. Base camps are not established randomly, due to financial constraints. PRISM was developed in 1998, and fully implemented starting in 2002. Separate and much more intensive demographic monitoring has also been conducted at Barrow during 2003-2009. At ground camps, focused monitoring obtains estimates of nest success, site fidelity, and adult survival. This program is poised to expand to a five-year effort at four Alaskan and three Canadian sites by collaborating with a whole host of NGOs and other federal agencies.

Office of Subsistence Management (OSM) – alaska.fws.gov/asm/fis.cfm

The Fisheries Resource Monitoring Program (hereafter, Program) was established in 2000 and is administered by the OSM. The Program employs a collaborative interagency, interdisciplinary approach to collect and apply information needed for subsistence fisheries management on Federal public lands in Alaska. To date, 325 projects have been funded that address research priorities identified by Regional Advisory Councils, management agencies, and local users. Annual budget is approximately $6.25 million dollars. Monitoring projects are developed through a biennial competitive request for proposals, and evaluated via an interagency technical peer-review process. Projects include investigations of stock status and trends, subsistence harvest and use patterns, and collection and analysis of traditional ecological knowledge. Project designs vary to address specific biological and social-science study objectives, ranging from basic census techniques to survey and sampling designs of varying complexity. Methods have included use of weirs, counting towers, sonar, mark-recapture, and telemetry to assess fish abundance and migration, sampling for genetic stock identification and other biological data, and surveys to obtain harvest, use, and traditional knowledge information. Although most projects address monitoring or research needs associated with salmon management, a significant commitment of funds also has been directed at resident (non-salmonid) fish species (for example, whitefish species on the Yukon and Kuskokwim Rivers). All investigators are now being asked to consider examining or discussing climate-change effects as part of their proposals. Investigators conducting long-term projects are encouraged to participate in a standardized air and water temperature monitoring program for which the OSM will provide calibrated temperature loggers and associated equipment, analysis and reporting services, and access to a temperature database.

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Appendix 11. Monitoring in Alaska by Agencies Other than USFWS

Forest Inventory and Analysis

The FIA program in Alaska is part of a national program that monitors status and change of all U.S. forest lands (*http://www.fia.fs.fed.us*; appendix 4). In southeast and south-central Alaska, the program uses the national design: a spatially balanced probability sample of field plots across all lands and use of spatially complete remote sensing data for stratification. Field sample points are randomly divided into 10 panels, with one panel measured each year using a boat/helicopter combination that travels from Ketchikan to Kodiak. Approximately 18 crew people work in rotating shifts through the field season, which lasts from mid-May through mid-August. Data collection costs are approximately US$ 1.8 million yr^{-1}, the land area within the southeast/south-central survey unit is 15 million ha, and the sample contains about 5620 plots on land (2200 forested plots). The national FIA program currently operates in all states and territories of the U.S. with the exception of Wyoming and the remainder of Alaska. If funded, the program proposed for the remainder of Alaska will have a reduced sampling intensity, some modifications to the design and indicators, and incorporation of LiDAR data. Indicators monitored by the FIA program are generally reported at the ecoregion, survey unit, state, or national level. Status and change of a variety of forest indicators are reported, as listed in appendix 8. On a 1/16th subsample of plots, additional indicators include suites of variables for down woody debris, vegetation diversity, crown conditions, lichens, and soils. Field-collected data and documentation are available from *http://199.128.173.17/fiadb4-downloads/datamart.html*.

U.S. National Park Service's Inventory and Monitoring (I&M) program

Five overarching objectives guide the program nationally (appendix 6), and suites of stepped-down objectives analogously guide each of the four I&M networks within Alaska (see *http://science.nature.nps.gov/im/units/akro/index.cfm* and links). Each network has settled on a group of about 20 to 30 'Vital sign' indicators, which are organized under the themes of Air and Climate, Geology and Soils, Water, Biological Integrity, Human Use, and Landscapes. I&M networks consider their constituent park units as their primary clients, but interface with a diversity of other stakeholders and audiences. Pillars of the I&M effort in Alaska and at the national level are described in appendix 1. As illustrated in appendix 14, the suites of indicators monitored in each park and network represent a balance between comparability across space and acknowledging the unique resources and management priorities of each park.

Bureau of Land Management (BLM)

In contrast to other federal jurisdictions, BLM lands are administered under a multiple-use mandate. Ecological monitoring in BLM occurs within Fisheries, Wildlife, Cultural, Recreation, and Vegetation programs. Across Alaska, BLM works through NRCS to collect soils information in a few regions, and data on snow-depth and snow-water equivalent in specific areas that are part of NRCS' regional networks. There is no cultural or paleontological information collected that is not site- or project-specific; it will thus be difficult to organize this information at ecoregional or statewide extents.

The Wildlife program monitors the following resources: a) occupancy and productivity of cliff-nesting raptors (Peregrine Falcon, Gyrfalcon, Rough-legged Hawk, Golden Eagle); b) population size, nesting, and distribution of Steller's and Spectacled eiders; c) population trends, distribution, habitat use, and subsistence harvest levels of game mammals (moose, caribou, Dall sheep, muskox); d) breeding birds (for example, BBS and ALMS routes); e) migrating birds (for example, banding stations); f) caribou habitat; g) snow depth; and h) polar bear summer on-shore habitat use (starting in 2010). These are mostly partnership projects (for example, with ADF&G, USFWS, USGS, etc). They use a variety of protocols and monitoring techniques, depending on the exact resource monitored, partners involved, and geographic location.

The BLM Fisheries program is driven primarily by agency requirements under FLPMA (the goal of which is to understand the condition of public lands) and ANILCA (which mandates BLM to conduct research and monitoring of subsistence resources). Fulfilling these requirements is critical to insure that managers have the information necessary to make sound land-management decisions. Basic inventories utilize commonly accepted methods and techniques outlined in USFS and BLM manuals. Specifically, the Fisheries program utilizes basin-wide and representative-reach-based habitat surveys to quantify habitat conditions for baseline and monitoring studies. Population monitoring is based on electrofishing techniques, which range from cursory "spot shocking" for inventories to block-netted, triple-pass depletion techniques for more-quantitative assessments of fish community status. BLM also supports salmon escapement monitoring, involving the use of towers, weirs, and DIDSON (Dual-frequency IDentification SONar), and performs habitat use and delineation efforts for resident and anadromous species using radio telemetry. Study designs are variable and depend on the particular question being asked by managers. Less than half of the program’s work involves repeated monitoring at the same locations annually, given BLM's management responsibility over 277,000 km of streams and 4.14 million acres of lakes in Alaska. As such, much of the work involves first-time inventories that may not be re-sampled for >25 years. Repeated sites are generally associated with a specific project, such as the evaluation or monitoring of placer mining activities in certain areas. Increased emphasis is given to subsistence species, such as salmon and northern pike, in addition to recreationally important species. Other focal species include unique fish species or populations, such as the Kigluaik Mountain char and the Gulkana steelhead. In the future, the program expects an increasing emphasis on resident fish management, as a result of the Western Native Trout Initiative under the National Fish Habitat Action Plan. Specifically, the program strives to: a) determine the fish community composition on BLM-managed lands; b) determine the extent of anadromy on BLM-managed lands; c) determine the habitat quality (in-stream and riparian) for priority species (for salmonids, mostly); e) delineate critical habitats (spawning, overwintering, etc.) for priority species; f) quantify the effects of authorized land-use activities on fish populations and habitats; g) determine the effectiveness of mitigation and reclamation for BLM-authorized activities.

Appendix 12. List of ecosystem components and processes monitored on U.S. National Park Service lands, within each of four Inventory and Monitoring Networks in Alaska.

Using a medical analogy, NPS I&M tracks "Vital Signs" as indicators of ecosystem health. These vital signs are organized and listed under six broad "monitoring frameworks" in the far-left column. The Vital Signs and "Parks Where Monitored" columns are visually distinguished by row into one of three categories, as indicated in the legend (that is, **bold ●** for current I&M-led indicators, regular-font ○ for current monitoring led by other sources, and *grey italic* + for most-likely future I&M monitoring). Parks in which the Vital-sign indicator is or will be monitored appear in the right-most columns; abbreviations for each park appear in the corresponding table header.

Table A12.1. Vital signs of the Arctic Network. Park names given by column abbreviations: BELA = Bering Land Bridge National Preserve; CAKR = Cape Krusenstern National Monument; GAAR = Gates of the Arctic National Park and Preserve; KOVA = Kobuk Valley National Park; NOAT = Noatak National Preserve.

Legend:
● Vital signs for which the network will develop protocols and implement monitoring with funding from the vital signs or water quality monitoring program.
○ Vital signs that are currently being monitored long-term by a network park, another NPS program, or by another federal or state agency. The network will collaborate with these other monitoring efforts where appropriate but will not use vital signs or water quality monitoring program funds.
+ Vital signs for which monitoring will likely be done in the future but which cannot currently be implemented due to limited staff and funding.

Level-1 Category	Level-2 Category	Vital Sign	Parks Where Monitored				
			BELA	CAKR	GAAR	KOVA	NOAT
Air and Climate	Air Quality	**Airborne Contaminants**			●		
	Weather and Climate	**Climate**	●	●	●	●	●
		Snowpack	●	●	●	●	●
Geology and Soils	Geomorphology	**Coastal Erosion**	●	●			
		Sea Ice	○	○			
		Permafrost	●	●	●	●	●
Water	Hydrology	*Surface Water Dynamics*	+	+	+	+	+
	Water Quality	**Lake Communities and Ecosystems**	●	●	●	●	●
		Lagoon Communities and Ecosystems		●			
		Stream Communities and Ecosystems	●	●	●	●	●
Biological Integrity	Invasive Species	*Invasive/Exotic Species*	+	+	+	+	+

	Focal Species or Communities	**Land Birds**	●	●	●	●	●
		Yellow-billed Loons	●	●			
		Brown Bears	●	●	●		●
		Dall's Sheep			●	●	●
		Muskox	●	●			
		Caribou	○	○	○	○	○
		Moose	○	○	○	○	○
		Fish Assemblages	+	+	+	+	+
		Small Mammal Assemblages	+	+	+	+	+
		Terrestrial Vegetation and Soils	●	●	●	●	●
Human Use	Consumptive Use	Subsistence/Harvest	○	○	○	○	○
	Point Source Human Effects	*Point Source Human Effects*		+	+		+
Landscapes	Fire and Fuel Dynamics	Fire Extent and Severity	○	○	○	○	○
	Landscape Dynamics	**Landscape Patterns and Dynamics**	●	●	●	●	●

Table A12.2. Vital signs of the Central Alaska Network. Park names given by column abbreviations: DENA = Denali National Park and Preserve, WRST = Wrangell-St. Elias National Park and Preserve, and YUCH = Yukon-Charley Rivers National Preserve.

Level-1 Category	**Level-2 Category**	**Vital Sign**	**Parks where Monitored**		
			DENA	**WRST**	**YUCH**
Air and Climate	Air Quality	Air quality	○		
	Weather and Climate	**Climate**	●	●	●
		Snow pack	●	●	●
Geology and Soils	Geomorphology	**Glaciers**	●	●	
		Permafrost	●	●	●
	Subsurface Geologic Processes	*Disturbance - volcanoes and tectonics*	+	+	+
Water	Hydrology	**Disturbance - Stream flooding**	●	●	●
		River/stream flow	●	●	●
	Water Quality	**Water Quality**	●	●	●
Biological Integrity	Invasive Species	*Disturbance - Exotic species*	+	+	+
	Infestations and Disease	*Insect Damage*	+	+	+
	Focal Species or Communities	**Freshwater fish**	●	●	●
		Passerines	●	●	●
		Bald Eagle		●	
		Golden Eagle	●		

		Peregrine Falcon			●
		Ptarmigan	+	+	+
		Moose	●	●	●
		Sheep	○	●	○
		Small mammals	●	+	+
		Caribou	●	●	○
		Snowshoe hare	●	●	●
		Arctic ground squirrel	+	+	+
		Wolf	●	+	●
		Brown Bear	+	+	+
		Vegetation structure and composition	●	●	●
		Subarctic steppe			+
Human Use	Consumptive use	Consumptive use	○	○	○
	Point-Source Human Effects	*Human populations*	+	+	+
		Human presence/use	+	+	+
	Visitor and Recreation Use	*Trails*	+	+	+
Landscapes	Fire and Fuel Dynamics	Disturbance - Fire occurrence and extent	○	○	○
	Landscape Dynamics	**Land Cover**	●	●	●
		Plant phenology	○	○	○
	Soundscape	Soundscape	○	+	+

Table A12.3. Vital signs of the Southwest Alaska Network. Park names given by column abbreviations: ALAG = Alagnak Wild River; ANIA = Aniakchak National Monument and Preserve; KATM = Katmai National Park & Preserve; KEFJ = Kenai Fjords National Park; LACL = Lake Clark National Park & Preserve.

Level-1 Category	**Level-2 Category**	**Vital Sign**	**Parks where Monitored**				
			ALAG	**ANIA**	**KATM**	**KEFJ**	**LACL**
Air and Climate	Air Quality	**Visibility and Particulate Matter**		○	●		○
	Weather and Climate	**Weather and Climate**			●	●	●
Geology and Soils	Geomorphology	**Glacier Extent**			●	●	●
		Geomorphic Coastal Change		+	+	●	●
	Subsurface Geologic Processes	Volcanic and Earthquake Activity	○	○	○	○	○
Water	Hydrology	**Surface Water Hydrology**	●	●	●	●	●
	Water Quality	**Freshwater Chemistry**	●	●	●	●	●
		Marine Water Chemistry			●	●	●

Biological Integrity	Invasive Species	Invasive/Exotic Species	○	○	○	○	○
	Infestations and Disease	Insect Outbreaks	○		○	○	○
	Focal Species or Communities	**Kelp and Seagrasses**			●	●	
		Marine Intertidal Invertebrates			●	●	●
		Resident Lake Fish	●		●		●
		Salmon	○		○		○
		Black Oystercatcher			●	●	
		Marine Birds			●	●	●
		Bald Eagle	+	+	●	●	●
		Brown Bear	+	+	●		●
		Wolf	+		+		+
		Moose			●		●
		Sea Otter			●	●	
		Caribou			○		○
		Harbor Seal			○	○	○
		Vegetation Composition and Structure	●	●	●	●	●
		Sensitive Vegetation Communities			●	●	●
Human Use	Consumptive use	Consumptive use	○	○	○		○
	Visitor and Recreation Use	Visitor Use	○	○	○	○	○
Landscapes	Landscape Dynamics	**Land Cover**	●	●	●	●	●
		Landscape Processes	●	●	●	●	●

Table A12.4. Vital signs of the Southeast Alaska Network. Park names given by column abbreviations: GLBA = Glacier Bay National Park and Preserve; KLGO = Klondike Gold Rush National Historical Park; and SITK = Sitka National Historical Park.

Level-1 Category	Level-2 Category	Vital Sign	Parks where Monitored		
			GLBA	KLGO	SITK
Air and Climate	Air Quality	**Airborne Contaminants**	●	●	●
		Visibility and Particulate Matter	+	+	+
	Weather and Climate	**Weather and Climate**	●	●	+
Geology and Soils	Geomorphology	**Glacier Dynamics**	●	●	
Water	Hydrology	**Streamflow**	●	●	●
		Oceanography	●		
	Water Quality	**Freshwater Benthic Macroinvertebrates and Algae**	+	+	●
		Freshwater Water Quality	●	●	●
		Freshwater Contaminants	●	●	●

		Marine Contaminants	●	○	●
Biological Integrity	Invasive Species	*Invasive/Exotic Animals*	+	+	+
		Invasive/Exotic Plants	○	○	○
	Infestations and Disease	*Pests and Diseases*	+	+	+
	Focal Species or Communities	*Bald Eagles*	+	+	+
		Bears	+	+	+
		Biodiversity of Select Groups	+	+	+
		Breeding Land Birds Assemblages	+	+	+
		Forage Fishes	+	+	
		Harbor Seals	+		
		Intertidal Communities	+	+	●
		Killer Whales	+		
		Marine Predators	●		
		Salmonids	+	+	+
		Ungulates	+		
		Western Toads	+	○	
		Wetland Communities	+	+	+
		Humpback Whales	○		
		Steller Sea Lions	+		
	At-risk Biota	**Kittlitz's Murrelets**	●		
Human Use	Consumptive Use	*Consumptive Uses*	+	+	+
Landscapes (Ecosystem Pattern and Processes)	Non-point-source Human Effects	Human Uses and Modes of Access	○	○	○
	Landscape Dynamics	**Landform and Landcover**	●	●	●
		Phenology	+	+	+
		Plant Communities	+	+	+
	Soundscape	*Airborne Sounds*	+	+	+
		Underwater Sound	○		

Appendix 13. Notes from Manager's Breakout Group at Forum on Ecoregional Monitoring for the NWRS and Other Public Lands across Alaska

The Manager Breakout Sessions

On Days 2 and 3 of the Forum, breakout sessions were held for managers. Managers were self-elected for this session based on a definition of 'manager' as a higher level supervisor responsible for the general direction of a larger work unit or land management area. Participants in the breakout session included the Alaska refuge chief, refuge and deputy managers, land managers for other agencies, regional or national office unit leaders (specifically invited because of their involvement with I & M programs), and regional office leaders of non-governmental organizations. Representatives included Canadians as well as Americans. Approximately 25 managers attended the first session on Day 2 and about 15 on Day 2. Danielle Jerry was the facilitator for the manager breakout session.

Issues Posed to the Managers

Three programmatic issues concerning ecoregional/statewide monitoring were posed to the managers and their recommendations sought on these issues. The facilitator listed the issues on a flip chart and started the session by briefly describing each of the issues. The listed issues focused an otherwise rather freewheeling conversation, which was cut short by time constraints on both days.

- *Agency cultural issues* – recommendations for dealing with inherent USFWS/NWRS agency cultural issues when creating a new I&M program at the ecoregional and regional scales.

- *Accountability* – recommendations for where and how to invest accountability for an I&M program when the work of the program is done at the refuge level, but the I & M questions and design may be largely focused at the ecoregional/regional level. The concern is that funding for the program could compete directly with other refuge programs in low-budget years.

- *Science credibility* – in 1993, DOI Secretary Bruce Babbitt administratively transferred the biological research arm of the USFWS from the agency to, at first, an independent agency and then ultimately to USGS, where it resides today. Although research by both USGS, universities, and the USFWS, itself, continues on refuge lands, the close interaction of research scientists and agency scientists and the science-based culture of the agency was affected in largely undetermined ways. The NWRS is largely a land management organization and managers within the agency often entering the management series early in their careers, rather than rising in the biological series.

Manager Recommendations, Day 2 - Build and sell the vision of an I&M Program.
At the time of the Forum, organizers had no anticipation of receiving funding in the near future to establish an ecoregional I & M program on refuge lands. As a result, managers first wanted to address the issue of building and selling the programmatic vision of why the NWRS needs an I&M program above the refuge-level. Recommendations from the managers on this issue follow.

(1) All non-USFWS managers emphasized partnering as the first and most important step in building and selling the vision. The Forum and its organizers were praised for the conference and for inviting participants widely across agency, and international boundaries.

(2) Cultivate I & M champions at all levels of the organization, but particularly at the highest level and in the budget arena. The NWRS needs an I&M marketing strategy. Ecoregional I&M means telling a different story that what we have been telling.

(3) To sell a vision locally, NWRS needs to translate performance measures into something that is actually meaningful to the agency.

(4) To sell a vision nationally, NWRS needs to use GPRA (Government Performance Results Act) effectively and tie new requests to agency performance measures.

(5) Be careful of the word ‘monitoring.’ It is has a long history of not being viewed well in our immediate-results based world. ‘Risk-based management’ is a better description.

Manager Recommendations, Day 3 - agency culture, accountability, and scientific credibility.
(6) Agency culture and mission is important. The NPS recognized their culture of strong and independent leadership at the Park level as an up-front obstacle in establishing an I&M program. As a result a decision was made early that at some organizational and administrative level of the Vital Signs program, the Parks managers would be told what to do or they would not be given funds. At the same time, it was also recognized that some levels (ecological indicators) needed regional or local control.
(7) The USFWS has a broader, more complex mission than NPS which will make initiating an I&M program more difficult. The USFWS mission includes a land management program, the NWRS, as well as nationwide responsibility for migratory birds, endangered species, and inter-jurisdictional fisheries. The USFWS will have to address refuge and agency cultures in establishing a program.
(8) USFWS management seemed very aware of agency cultural obstacles and the difficulty in overcoming them. Upon hearing this, a Parks Canada Agency representative suggested that USFWS refuges has a management vision and challenged the agency to examine if climate change alters this vision and if so how.
(9) Personnel administratively dedicated to the I&M program are essential to move the program forward. A network coordinator and a database manager are the two key positions to be filled first.
(10) Monitoring needs to be in addition to rather than in place of existing workloads.
(11) A data base structure should be in place before monitoring begins.
(12) At least one-third of the I&M budget should be dedicated to data management, analysis, and reporting.

(13) If possible, tie monitoring to management decisions. These locally important monitoring targets must be translated into performance measures recognized at the national level.
(14) If data is not readily available to managers, it is irrelevant whether or not it is well-managed.
(15) Collaborate with partners and start by reviewing databases, protocols, and programs from other agencies for use by the USFWS.
(16) And finally, managers really liked the NPS wedding cake model, where the lowest level represented data collected and analysis conducted at the refuge level. Each higher level of the cake represented a synthesis of data analysis for the ecoregional, regional, and national levels.

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