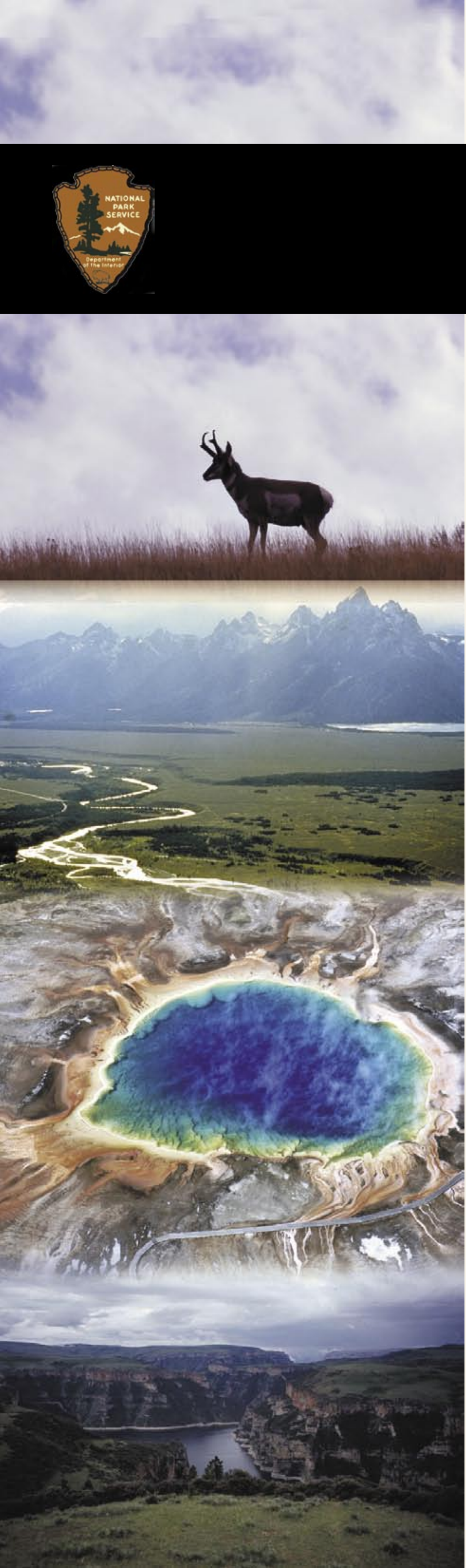


National Park Service
U.S. Department of the Interior

Vital Signs Monitoring Plan for the Greater Yellowstone Network

September 30, 2005

Prepared by C. Jean[1],
A.M. Schrag[2], R.E. Bennetts[1],
R. Daley[1], E.A. Crowe[2] and S. O'Ney[3]

Greater Yellowstone Network
National Park Service
P.O. Box 173492
AJM Johnson Hall, Montana State University
Bozeman, MT 59717

[1] Greater Yellowstone Network, National Park Service
[2] Big Sky Institute, Montana State University
[3] Grand Teton National Park, National Park Service

Suggested citation:
Jean C, Schrag AM, Bennetts RE, Daley R, Crowe EA, O'Ney S. 2005. Vital Signs Monitoring Plan for the Greater Yellowstone Network. National Park Service, Greater Yellowstone Network, Bozeman MT. 107 pp. plus appendices.

EXECUTIVE SUMMARY

The mission of the National Park Service is "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations" (NPS 2000). To uphold this goal, the Director of NPS approved the Natural Resource Challenge to encourage national parks to focus on the preservation of the nation's natural heritage through science, natural resource inventories and expanded resource monitoring (NPS 1999). Through the Challenge, 265 parks in the national park system were placed into seven regions and, subsequently, organized into 32 inventory and monitoring networks. The parks of the Greater Yellowstone Network include Yellowstone National Park, Grand Teton National Park, John D. Rockefeller, Jr. Memorial Parkway and Bighorn Canyon National Recreation Area.

Each network of parks that receives funding for monitoring is required to prepare a vital signs monitoring plan. The purpose of this plan is to establish the vital signs (i.e., indicators of ecosystem health), explain the approach used to develop sampling designs and protocols, and analyze, manage and report on data. In addition, the report includes a data and information management plan that guides the long-term management of data essential to the monitoring program.

The GRYN took a multi-step approach to identifying and selecting vital signs. One essential step involved the use of conceptual ecological models. Conceptual models prepared by the GRYN explain the structure, function and interconnectedness of park ecosystems, enabling the identification of vital signs for assessing ecosystem health. In addition to conceptual modeling, the GRYN used a Delphi survey and a workshop series to further identify and prioritize vital signs. The Delphi survey was an Internet-based questionnaire sent to subject-area experts and park personnel that asked participants to nominate possible vital signs for monitoring and then rank them on a scale of importance. The GRYN then held park-specific workshops to gain further insight from park staff and managers and also hosted a "vital signs monitoring workshop," during which invited subject-area experts and park managers judged dozens of candidate vital signs against 13 selection criteria. These criteria considered the ecological and managerial relevance, response variability, feasibility of implementation and interpretation and utility of the candidate vital sign. The outcome of the workshop was a ranked list of potential vital signs.

Using the workshop list of highly ranked vital signs, the Technical Committee (a steering committee made up of NPS representatives) developed the final list of vital signs for monitoring, including a subset to be monitored primarily using I&M funds. It is impossible for any single monitoring program on a limited budget to develop a complete picture of ecosystem health with its staff and funding alone; thus, the network's subset of 12 vital signs were chosen to fill gaps in current monitoring in the parks and allow I&M resources to be spent on issues that had high management relevance and would create a more complete picture of ecosystem health when synthesized with ongoing monitoring of other vital signs.

The vital signs chosen by the network include a suite of physical, chemical and biological elements and processes that collectively represent the overall health or condition of park resources. These vital signs, as presented within the vital signs framework as developed by the National Park Service vital signs monitoring program, include four related to air and climate, seven related to geology and soils, 11 related to water, 19 related to biological integrity, three related to human use and three related to ecosystem pattern and processes.

The subset of 12 vital signs that will be funded by the GRYN include: climate, water chemistry, aquatic invertebrate assemblages, streamflow, arid seeps and springs, invasive plants, exotic aquatic assemblages, whitebark pine, amphibians, landbirds, soil structure and stability and land use. Following approval by the BOD in August 2003, the network began work on developing specific monitoring objectives, sampling designs and protocols for these vital signs.

Since the selection of the vital signs, the GRYN has begun to focus on the development of the monitoring program, emphasizing three particularly important elements of any monitoring program: 1) applicability; 2) reliability (i.e., scientific defensibility); and 3) feasibility. Sampling design is one of the major means by which the GRYN ensures scientific reliability and defensibility. Sampling design ensures that data collected are representative of the target populations and sufficient to draw defensible conclusions about the resources of interest.

Sampling designs are described in individual monitoring protocols, which are detailed plans that explain how data are to be collected, managed, analyzed and reported. The GRYN is working to prepare and implement 12 monitoring protocols by 2007. In most cases, full implementation of these protocols will be preceded by field testing, except when protocols are well established and substantial refinement is not anticipated. Field testing will be followed by revision of the protocol before full implementation can begin.

As network monitoring protocols are approved and implemented, planning will shift towards helping update and/or revise existing park-sponsored monitoring protocols. The technical expertise of network staff can help to standardize procedures and establish quality control, data management and reporting protocols. This planning step will help promote coordination and communication of monitoring activities and should encourage broad participation in monitoring and use of resulting data.

The management, analysis and reporting of monitoring data become especially important once long-term monitoring has commenced. Data management is an important aspect of the I&M program, as it provides guidelines for all aspects of data handling. Data and information management in the GRYN will attempt to support an adaptive, yet consistent, approach to managing and delivering a useful suite of natural resource inventory and monitoring data and information. This will be achieved by including written data management procedures and responsibilities in each monitoring protocol.

Data analysis and reporting are also essential components to monitoring long-term ecosystem health, due to the importance of communicating information gained through monitoring to various constituents. While analysis techniques will vary depending on the sampling design, all analytical methods will ensure that the program meets the national goals of monitoring. In addition, the GRYN will use a set of reports to target a variety of audiences in order to make this information useful to numerous end users. Another reporting mechanism that will be used by the GRYN is the expansion of its Web-based interface. This Web-based communication mechanism will allow the GRYN to provide background data and information to a large audience with relative ease, due to its widespread accessibility to park managers and the relative simplicity of providing updates when new information is acquired.

The monitoring schedule and staff requirements of the program will be driven by the overall monitoring design and resultant technical needs. Currently, three core NPS staff positions (the program manager, data manager and ecologist) are assigned to the GRYN. In addition, affiliated NPS staff at the network parks and affiliated University staff at Montana State University provide a flexible pool of individuals to plan and implement monitoring protocols. Once the monitoring program is fully operational, a schedule of monitoring frequencies will enable the network to develop permanent staffing plans and allocate funding resources. Changes in available funds for monitoring will be mitigated by one or both of the following opportunities: 1) opportunities for cost-sharing with partner agencies or organizations; and 2) adjustments in the scope of monitoring that can be conducted. A periodic program review will allow for adjustments in budget and staffing to be made on an intermittent basis with approval from oversight committees. In addition, this review will evaluate the efficacy of monitoring by reviewing individual protocols and monitoring plans.

ACKNOWLEDGEMENTS

Many people contributed to the development of this report. Resource management staff at the network parks, as members of the network's Technical Committee, contributed time and effort to laying the groundwork for the monitoring program and providing direction and feedback during planning. We thank Tom Olliff, Ann Rodman, Steve Cain, Sue Consolo-Murphy and Rick Lasko for their countless contributions and dedication as participants of this committee.

We thank the Board of Directors (Frank Walker, Jim Bellamy, Darrell Cook and Bruce Bingham) for their support, advice and advocacy. Because of their involvement, the network will become integrated into park management and relevant to resource-related decisions. Thanks also to departing board members Steve Martin, Mike Britten and Kathy Tonnessen. As the Rocky Mountains Cooperative Ecosystem Studies Unit Research Coordinator, Kathy provided early guidance and oversight for the program, building awareness and support among superintendents, establishing the Science Committee and hiring positions.

Thanks to Bruce Bingham, Intermountain Region Inventory & Monitoring Coordinator, for guiding, facilitating and encouraging the GRYN through the completion of the vital signs monitoring plan. Thanks also to the IMR staff for administrative support provided over the past year. We are indebted to Mike Britten, former IMR I&M Coordinator, for his past supervision and appreciate the technical assistance that he and Billy Schweiger of the Rocky Mountain Network are providing as we develop a sample design for water quality.

Thanks to the members of the GRYN Science Committee: Duncan Patten, Tim Kittel, Joel Berger, Mike Ivie and Lisa Graumlich for their sound advice and contributions to several vital signs meetings and workshops. We extend a special thanks to Lisa Graumlich for her ongoing role in providing affiliated staff positions to the network, along with administrative services and university involvement, through her position as Executive Director of the Big Sky Institute. We thank the USGS Northern Rocky Mountain Science Center—specifically Judy O'Dwyer and Richard Jachowski—for hosting the GRYN and helping establish our presence at Montana State University. A huge thank you to Bridget Ashcraft for the design and layout of this plan and also to Suzi Taylor, Director of Publications and Graphics. Both Bridget and Suzi work in the Office of Communications and Public Affiars at Montana State University.

We would like to thank the many individuals at the network parks who have provided information, participated in meetings and workshops or helped in countless other ways. These individuals include: Mary Maj (GYCC), John Varley, Wayne Brewster, Glenn Plumb, Todd Koel, Mary Hektner, Henry Heasler, Jennifer Whipple, Shannon Savage, Roy Renkin, Kerry Murphy, PJ White, Jeff Arnold, Rick Wallen, Doug Smith, Kerry Gunther, Terry McEneaney, Pat Bigelow, Dan Mahony, Christie Hendrix, Dan Reinhart, Cheryl Jaworowski, Steve Miller, Colleen Watson, Joy Perius, Mark Davidson (all of YELL), Suzanne Morstad, Bill Picket, Yvonne Powers, Cassity Bromley (all of BICA), Sue Consolo Murphy, Steve Haynes, Sue Wolff, Kelly McCloskey, Diane Abendroth, Peter Lindstrom, Richard Easterbrook, Dan Burgette and Thayne O'Brien (all of GRTE). Collectively, the experience and insights of park staff provide an incredible knowledge base for the vital signs monitoring plan.

We thank former staff Lane Cameron, Laura Gianakos, Chad Jacobson, Sarah Stehn and Pat Flaherty and contractor Scott Bischke for their past contributions to the previous phases of this report.

We extend our gratitude to Abby Miller, Gary Williams and Steve Fancy for providing leadership and guidance to the I&M networks and for their continued advocacy of the program at the national level.

TABLE OF CONTENTS

Figures

Tables

Appendices

I. INTRODUCTION AND BACKGROUND

The Greater Yellowstone Network (GRYN) is one of 32 National Park Service (NPS) inventory and monitoring networks that are using ecosystem indicators—also known as "vital signs"—to assess the state of the ecosystems contained within its parks. The GRYN consists of four park units located within and around the Greater Yellowstone Ecosystem, which includes parts of Idaho, Montana and Wyoming. These units include: Bighorn Canyon National Recreation Area (BICA), John D. Rockefeller, Jr. Memorial Parkway (JODR), Grand Teton National Park (GRTE) and Yellowstone National Park (YELL). For the purposes of this report, the John D. Rockefeller, Jr. Memorial Parkway is considered part of Grand Teton National Park. A map of the parks is provided in Figure 1.1. It is the goal of this report to present an overview of the GRYN and provide information related to its strategy for monitoring vital signs.

TABLE 1.1 GRYN parks and associated acronyms.

Park Name	Alpha Code (Acronym)
Bighorn Canyon National Recreation Area	**BICA**
John D. Rockefeller, Jr. Memorial Parkway	**JODR**
Grand Teton National Park	**GRTE**
Yellowstone National Park	**YELL**

INTRODUCTION TO INVENTORY AND MONITORING

The NPS Inventory and Monitoring (I&M) Program provides an avenue for integrating inventory and monitoring activities into the parks, as well as presenting a means through which parks can collaborate and cooperate on ecosystem-wide projects. The I&M networks have the opportunity to use numerous resources to aid in planning prior to beginning on-the-ground monitoring. Thus, the products the networks produce—including protocols, standard operating procedures (SOPs) and data stewardship plans—can serve as a guide for park monitoring projects that are ongoing or funded through other sources. In addition, the I&M program integrates information from many different sources and synthesizes this information into a coherent whole that can be communicated to numerous audiences through a variety of media.

Definition of Inventory and Monitoring

To understand the state of park resources, it is necessary to first conduct an inventory of those resources. An inventory is "a point in time survey to determine the location or condition of a biotic or abiotic resource" (NPS 2004a). The initial focus

FIGURE 1.1 Map of Greater Yellowstone Network parks.

FIGURE 1.2 Map of 32 Inventory and Monitoring networks nationwide.

of the I&M networks was to conduct inventories of vertebrates and vascular plants. An inventory study plan (GRYN 2000) for the GRYN established the scope and schedule of biological inventories that were meant to provide baseline information on species occurrence in the parks.

The goal of monitoring is to detect change over time and to use this information to understand the state of the parks' ecosystems. The definition of monitoring, then, is to "detect changes or trends in the status of a resource" (NPS 2004a). Monitoring in the National Park Service is intended to aid in the development of broadly based, scientifically sound information on the current status and long-term trends in the health, composition, structure and function of park ecosystems.

The "Network" Concept and I&M Funding

The mission of the National Park Service is "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations" (NPS 2001b). To uphold this goal, the Director of NPS approved the Natural Resource Challenge in 2000 to encourage national parks to focus on the preservation of the nation's natural heritage through science, natural resource inventories and expanded resource monitoring (NPS 1999). Through the Challenge, 265 parks in the national park system were placed into seven regions and, subsequently, organized into 32 inventory and monitoring networks, based on geographic and ecological similarities (see Figure 1.2). The NPS Advisory Board suggested the following reason for creating these I&M networks:

> "A sophisticated knowledge of resources and their condition is essential. The Service must gain this knowledge through extensive collaboration with other agencies and academia, and its findings must be communicated to the public. For it is the broader public that will decide the fate of these resources" (NPS Advisory Board 2001).

Legislation

Natural resource monitoring in the national park system is mandated by a variety of laws, acts and enabling legislation. The following paragraphs provide a synopsis of those laws that are intended to guide the I&M program. A complete list of relevant legislation is contained in Appendix II.

Congress established Yellowstone National Park in 1872 as the first national park (Yellowstone National Park Act of 1872) and, in doing so, "dedicated and set apart [nearly 1,000,000 acres of land] as a…pleasuring ground for the benefit and enjoyment of the people." Grand Teton National Park, Bighorn Canyon National Recreation Area and John D. Rockefeller, Jr. Memorial Parkway were established as units in the national park system in 1929, 1966 and 1972, respectively.

The National Park Service Organic Act of 1916 established and defined the mission of NPS to be the following:

> "…to promote and regulate the use of the Federal areas known as national parks, monuments and reservations hereinafter specified…by such means and measures as conform to the fundamental purposes of the said parks, monuments and reservations, 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."

Congress reaffirmed the purpose of the park units stated in the Organic Act by creating a national park system through the General Authorities Act of 1970 in which all parks were united by a common purpose of preservation. Preservation in the park units was thereby enforced even in those units whose original enabling legislation intended for them to be primarily used for recreational purposes. Within the parks of the GRYN, this is especially important in BICA, whose enabling legislation was to:

> "provide for public outdoor recreation use and enjoyment of Yellowtail Reservoir and lands adjacent thereto and for the preservation of the scenic, scientific and historic features contributing to public enjoyment of such lands and waters" (NPS 1994a).

The National Park Service then amended the Organic Act in 1978 to further strengthen the protection of resources by stating:

> "…the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established…"

In 1998 the National Parks Omnibus Management Act stated the intent to create an inventory and monitoring program that may be used "to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources." In 2001, NPS management directed the Service to inventory and monitor natural systems in an effort to provide information for park management decisions:

> "Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions" (NPS 2001a).

In addition to Service-wide mandates and enabling legislation, management plans (BICA [NPS 1994], GRTE [NPS 1995]) and business plans (YELL [NPS 2003a]) for each park require inventory and monitoring activities by requiring each park to follow NPS policies.

While additional Executive Orders and legislative acts relevant to the I&M program are described in Appendix II, one legislative act of particular relevance to the I&M program is the 1993 Government Performance and Results Act (GPRA). GPRA sets goals to help federal agencies become more accountable to the public for the money they spend and the results that are achieved. GPRA is required as part of the National Park Omnibus Management Act, which calls for the creation of Strategic Plans and Annual Performance Plans. The National Park Service created a Strategic Plan for 2001-2005 (NPS 2001b), with the Category I goal of "preserving park resources," which includes goals that fit the mission of the I&M program, such as choosing vital signs for assessing the health of park ecosystems. In addition, each park also creates five-year strategic plans and annual performance plans that guide progress toward the Service-wide goals. While a complete list of GPRA Category I goals relating to the GRYN parks can be found in Appendix II, it is important to note that the completion of Phase II of the Vital Signs Monitoring Plan (selection and approval of vital signs) fulfilled GPRA goal Ib.3.

TABLE 1.2 Timeline of funds provided for GRYN activities.

Year (FY=fiscal year [Oct.-Sept.])	Funds Provided For:			
	Inventories	Planning	Water Quality	Implementation
FY2001	X	X	X	
FY2002	X	X (Phase I Report)	X	
FY2003	X	X (Phase II Report)	X	
FY2004	X	X (Draft)	X	
FY2005		X (Peer-Reviewed)	X	X
FY2006			X	X

I&M Goals and Timeline

The National I&M Program has created five major long-term goals that networks must strive to achieve (NPS 2003b). These goals include:

1. Determine 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.
2. Provide early warning of "abnormal" conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other altered environments.
4. Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress toward performance goals.

To fulfill these goals, the networks are divided into groups and placed on staggered schedules to complete inventories, planning, monitoring plans and implementation of monitoring protocols. The timeline for the GRYN is presented in Table 1.2.

TABLE 1.3 Park area and 2002 visitation.

	BICA	GRTE	YELL
2002 visitation (millions)	*0.18*	*2.6*	*3.0*
Land area managed by park (in millions of acres)	*0.12*	*0.31*	*2.2*

INTRODUCTION TO GRYN PARKS AND RESOURCES

Grand Teton and Yellowstone National Parks create the core of the 18 million acre Greater Yellowstone Ecosystem (GYE [GIAC 2003]), one of the largest, relatively intact ecosystems in the contiguous United States. With the addition of Bighorn Canyon National Recreation Area, the network also encompasses the cold desert landscape of the eastern foothills in the northern Rocky Mountains. This section describes significant natural resources within the parks, as well as ecosystem-wide resources and issues, such as air and water quality. Please see Table 1.3 for a synopsis of park area and recent visitation numbers.

Bighorn Canyon National Recreation Area

Bighorn Canyon National Recreation Area (Figure 1.3), located in southeastern Montana and north-central Wyoming, was created in 1966, following the construction of the Yellowtail Dam on the Bighorn River, in large part to provide for recreational use of the dam. Park boundaries also encompass a potrion of the Pryor Mountain Wild Horse Range (managed chiefly by the Bureau of Land Management) and Yellowtail Wildlife Habitat Area (managed cooperatively with the Wyoming Game and Fish Department), which provides habitat for waterfowl, upland game and raptors.

The topography of BICA is characteristic of the Intermountain Semidesert Province (Bailey 1995), which consists of plains surrounded by the foothills of the Bighorn and Pryor Mountains. BICA lies in the rain shadow of the Beartooth Mountains (Nesser et al. 1997), leading to a semiarid environment with an average annual precipitation of 15 inches (38 cm; Western Regional Climate Center 2004). A large gradient of precipitation separates the dry southern end of the park from the less arid northern end. Temperatures can range from over 100°F (38°C) to less than –20°F (-29°C [Western Regional Climate Center 2004]).

Yellowtail Dam is operated by the Bureau of Reclamation and dominates the hydrology of the Bighorn Canyon area. The Bighorn

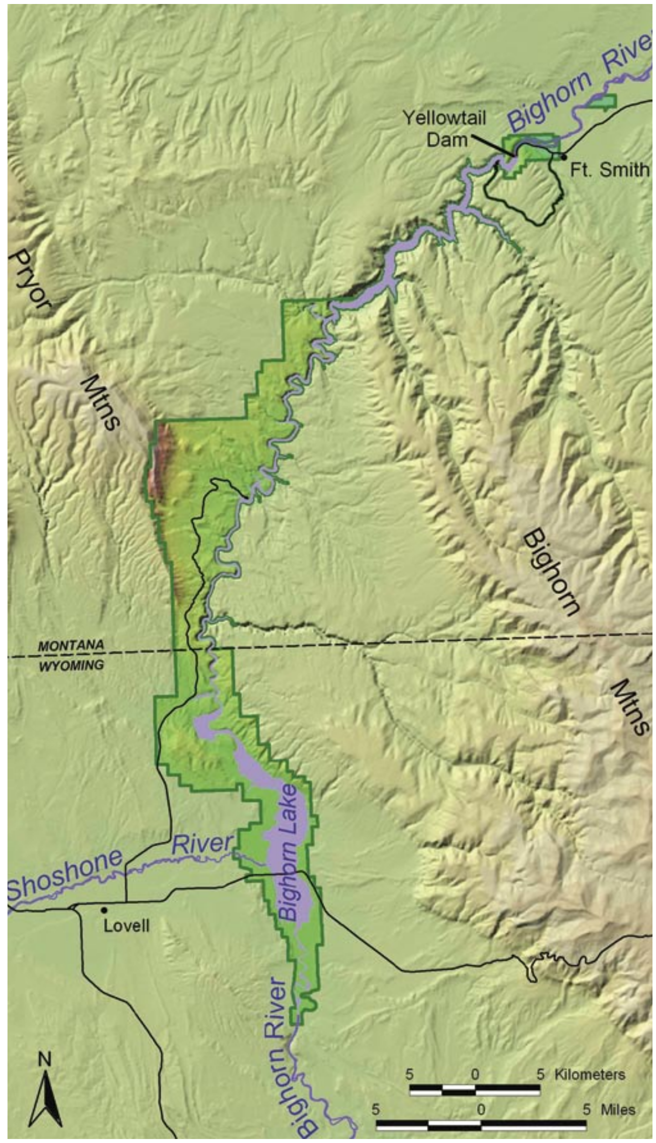


FIGURE 1.3 Bighorn Canyon National Recreation Area.

and Shoshone Rivers, along with other smaller streams that originate in the Bighorn and Pryor Mountains, supply Bighorn Lake and drain into the Yellowstone River. The Shoshone River originates in the Absaroka Mountains (located on the eastern edge of Yellowstone) and meets the Bighorn River in the Yellowtail Wildlife Habitat Area. Both cold and warm water fish species live in Bighorn Lake, which is managed for recreational sport fishing by the Montana Department of Fish, Wildlife and Parks and the Wyoming Game and Fish Department.

The vegetation in BICA is dominated by juniper/mountain mahogany woodlands. Other major vegetative communities include limber pine, desert shrublands, sagebrush steppe, grasslands, riparian habitats and ponderosa pine savannah (Knight et al. 1987). Soils are generally alkaline aridisols, entisols or vertisols and mostly contain lime- or gypsum-enriched subsoils that develop into a caliche hardpan (NPS 2003d).

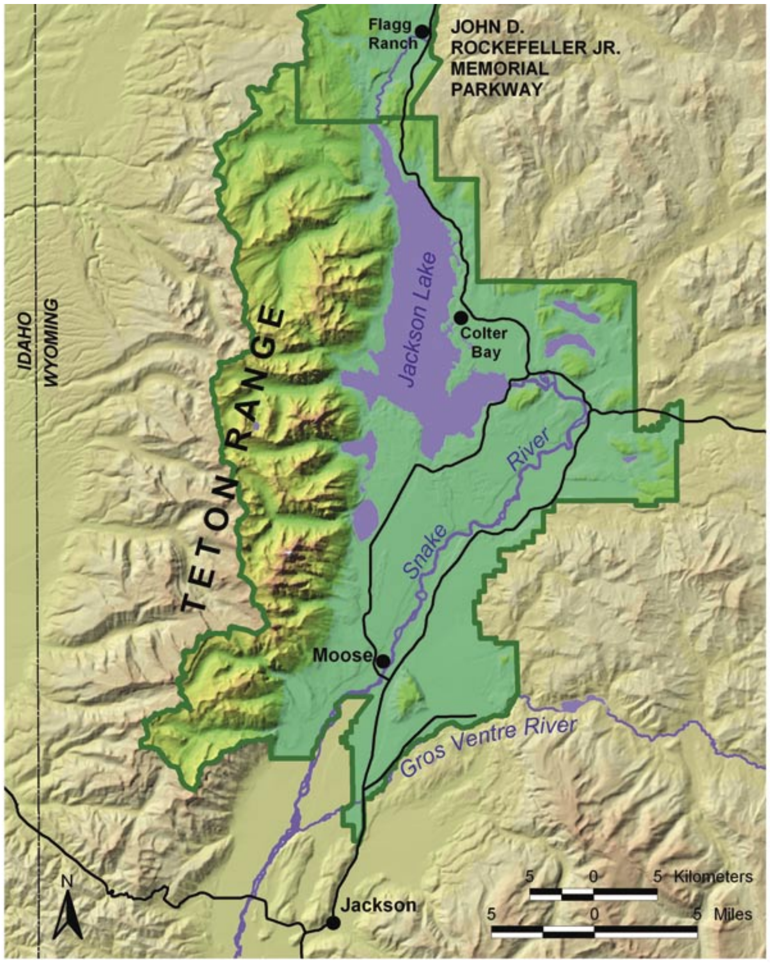


FIGURE 1.4 Map of Grand Teton National Park

Grand Teton National Park

Grand Teton National Park (Figure 1.4), located in western Wyoming, was created in 1929. The purpose of the park, as stated in the Master Plan (NPS 1995), is to "protect the scenic and geological values of the Teton Range and Jackson Hole, and to perpetuate the Park's indigenous plant and animal life." Grand Teton National Park also administers the 23,777-acre John D. Rockefeller, Jr. Memorial Parkway, established in 1972 to honor the contributions of its namesake to the conservation movement.

GRTE is famous for its topography, including 12 peaks above 12,000 feet in elevation, which developed along the north-south Teton Fault. Subsequent glacial activity further sculpted the Teton Range, and perennial glaciers and ice fields occupy some protected recesses within the range. Average snowfall in the park is 191 inches (485 cm), but varies with elevation and location. The park is said to be semiarid, with temperature highs approaching 100°F (38°C) and an extreme recorded low of –46°F (–43°C [NPS 2004b]).

Approximately ten percent of Grand Teton National Park is covered by surface water. The park contains more than 100 alpine lakes, ranging in size from one to 60 acres, many above 9,000 feet in elevation. All surface and groundwater in the park drains into the Snake River. Jackson Lake Reservoir is operated by the Bureau of Reclamation, which retains exclusive control of the flow and utilization of water in the reservoir, except water reserved for Snake River fisheries. The National Park Service and Wyoming Game and Fish Department cooperatively manage fisheries within the park. Several lakes are stocked with fish (including one nonnative species in Jackson Lake) as part of a sport fisheries program.

The Snake River floodplain, which dominates the valley floor of the park, consists of riparian forest (e.g., cottonwood, willow and aspen). Terraces rising above the floodplain, primarily covered by sagebrush and grasses, are occasionally interrupted by glacial moraines and buttes. The forests consist mainly of lodgepole pine, Douglas-fir and aspen at lower elevations, while Engelmann spruce, whitebark pine and subalpine fir inhabit higher elevations.

Yellowstone National Park

In 1872 Yellowstone National Park (Figure 1.5) was created as the world's first national park, due to its vast array of wildlife and geothermal features. The United Nations designated Yellowstone as a Biosphere Reserve on October 26, 1976, stating:

> "Yellowstone National Park is recognized as part of the international network of biosphere reserves. This network of protected samples of the world's major ecosystem types is devoted to conservation of nature and scientific research in the service of man. It provides a standard against which the effect of man's impact on the environment can be measured."

Furthermore, on September 8, 1978, the United Nations, at the request of President Richard Nixon, designated Yellowstone a World Heritage Site, stating:

> "Through the collective recognition of the community of nations . . . Yellowstone National Park has been designated as a World Heritage Site and joins a select list of protected areas around the world whose outstanding natural and cultural resources form the common inheritance of all mankind."

One of the primary reasons for these designations is the plethora of geothermal features found within the park. Almost 500 geysers—

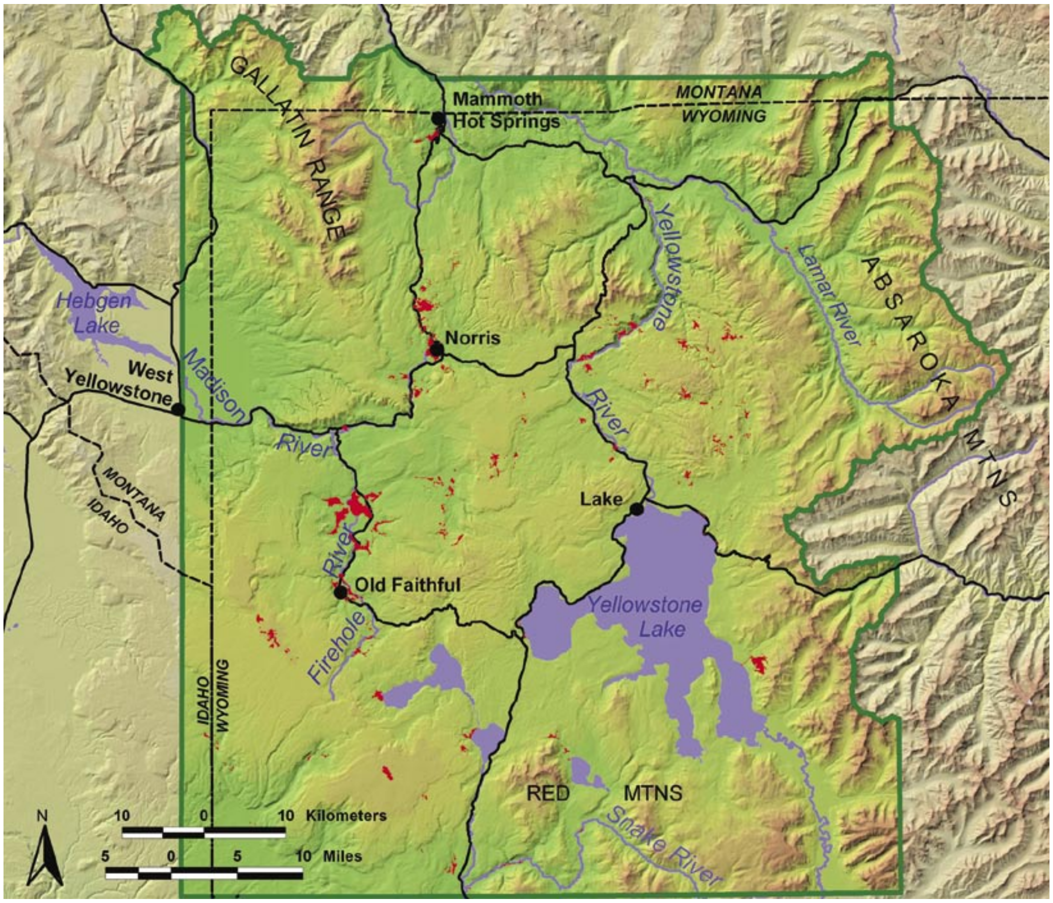


FIGURE 1.5 Map of Yellowstone National Park with thermal areas shown in red.

nearly two-thirds of those on Earth—and more than 10,000 hot springs, fumaroles and mud pots are found within park boundaries (Monteith 2003). Cataclysmic eruptions 2 million, 1.3 million and 630,000 years ago produced the Yellowstone caldera, and magma, located in some places only one to three miles below the Earth's surface, continues to supply heat to the groundwater that creates the features. These features also contain microorganisms, called thermophiles, and one endemic plant species—Ross's bentgrass (*Agrostis rossiae* [YELL 2004a]).

Most of the park is above 7,500 feet in elevation and is dominated by a flat, high-elevation volcanic plateau. The park encompasses part of the Gallatin Mountains to the northwest, the Absaroka Mountains to the east and northeast and the Red Mountains to the south. Due to the variation in topography, it is often stated that Yellowstone has two climates (Despain 1987). Average temperatures at Mammoth Hot Springs range from 9°F (-13°C) in January to 80°F (27°C) in July. The record high temperature in the park was 98°F (37°C; Lamar in 1936), with a record low of -66°F (-54°C; Madison in 1933). Average precipitation also varies, from 10 inches (26 cm) at the north boundary to 80 inches (205 cm) in the southwest corner (YELL 2004b). Snow accumulation provides the primary source of precipitation for the park.

The watersheds in YELL drain into the Yellowstone and Madison Rivers east of the Continental Divide, and into the Snake River to the west. Yellowstone Lake is the most prominent lake in the park with a surface area of 136 miles^2 (352 km^2). More than 634 lakes and ponds comprise approximately 107,000 surface acres (43,301 hectares) in Yellowstone—94 percent constitute Yellowstone, Lewis, Shoshone and Heart Lakes—while 1,000 rivers and streams create approximately 2,463 miles of running water (YELL 2004a).

Yellowstone Lake and Yellowstone River together contain the largest population of native cutthroat trout in the world (YELL 2004a). Four native fish—the fluvial form of Arctic grayling, westslope cutthroat trout, Yellowstone cutthroat trout and Snake River cutthroat trout—that inhabit the waters of Yellowstone are thought to be at risk. Cutthroat trout are of particular concern due to decreases in their population size and their importance as a food source for threatened grizzly bears (YELL 2004a). Lake trout—a nonnative fish that inhabits the waters of Yellowstone—are thought to out-compete cutthroat trout and may be a leading cause of decline in the cutthroat trout population (YELL 2004a).

Four of the five vegetation zones in Yellowstone are underlain by bedrock of volcanic origin and contain forests—interspersed with subalpine meadows and alpine tundra—that are dominated by lodgepole pine, Engelmann spruce, subalpine fir or whitebark pine. The Northern Range, a low-elevation vegetation zone underlain by glacial debris of volcanic and sedimentary composition, is located along the Yellowstone and Lamar River valleys and provides critical winter range for elk, bison and other ungulates. This area is dominated by sagebrush steppe and grasslands.

NATURAL RESOURCE THREATS AND ISSUES

Although the parks of the Greater Yellowstone Network serve as refuges for numerous flora and fauna, natural resources in the parks face a variety of threats from outside and within park boundaries. Following is a synopsis of these threats (which is not meant to be a thorough review of all possible threats) organized under broad topic categories created by the National I&M Program as a "vital signs framework." Thorough, detailed information on threats and issues related to selected GRYN vital signs can be found in the individual monitoring protocols.

The integrity of biological systems is threatened in numerous ways within the parks of the GRYN. Most notably, changes in species composition, including numbers and types of species inhabiting ecosystems in the parks, are a threat to native species viability and trophic cascades. The introduction of nonnative species—both terrestrial and aquatic—can often lead to widespread invasion of habitat for native species. In addition, the introduction of exotic diseases and insect outbreaks can lead to the destruction of native species or their habitat.

Water quality in the parks is threatened by nitrogen deposition, changes in hydrologic regime and exotic species introduction. High-elevation watersheds in the GRYN are thought to be highly impacted by atmospheric deposition (particularly nitrogen), primarily due to their underlying thin soils and resistant bedrock that limit acid-neutralizing capacity (Kashian 2004). Other forms of pollution, including trace elements, mercury and pesticides, may also threaten aquatic resources in the GRYN. In addition, changes in hydrologic regimes can result from climate change, diversions and damming; this can lead to flow alteration, changes in water temperature and shifts in community composition (Kashian 2004). Furthermore, whirling disease, New Zealand mud snails and lake trout have been introduced to the system and have led to the decline of native communities.

With respect to geology and soils, potential geothermal development outside the boundaries of Yellowstone National Park could lead to reductions in the flow of water in the basins, causing disruptions to geothermal features in the park. In addition, loss of biological soil crusts is occurring in Bighorn Canyon due to wild horse, cattle and native ungulate trampling. These crusts contain important organisms that help protect desert soils from erosion.

Ecosystem patterns and processes can be disrupted by changes in land use, another issue around the GRYN parks. Increases in the size of surrounding cities and towns can lead to habitat fragmentation, which may adversely affect species that migrate outside of park boundaries, as their migration routes can be lost and important habitat may be unavailable. These impacts are especially devastating to those species that have large home ranges. Increases in human use inside the parks (i.e., visitation, day use, backcountry day and overnight use) may also impact flora and fauna.

Changes in climate can have wide-ranging impacts on ecosystems, from alterations in species distributions to species extinctions and altered fire regimes. Ozone, nitrogen, sulfur and organochlorine compounds—in the form of atmospheric deposition—can become concentrated in snow pack at high elevations and affect water chemistry.

OUTSTANDING NATURAL RESOURCES: STATUS AND CURRENT MONITORING

The following section is a summary of the status and current monitoring of threatened and endangered species and air and water resources. Further information on current monitoring taking place in the GRYN, along with Web links, can be found in Appendix II.

Threatened and Endangered Species

Four threatened or endangered species inhabit the parks of the Greater Yellowstone Network: gray wolves, bald eagles, Canada lynx and grizzly bears. Following is a summary of current monitoring and status for each species. Further information on current monitoring for these species, along with Web site links, can be found in Appendix II.

4A. GRAY WOLVES

Although listed as a nonessential, experimental species under the final U.S. Fish and Wildlife Service (USFWS 1994) ruling, national parks are directed to manage wolves as a threatened species under Section 10(j) of the Endangered Species Act. In Yellowstone, wolves have been monitored since their reintroduction in 1995 and 1996; this monitoring includes information on population dispersal, distribution, reproduction, mortality and predation of ungulates (Smith et al. 2003).

After their 70-year absence from Jackson Hole, gray wolves returned to Grand Teton National Park in the fall of 1998, when two groups from the Yellowstone reintroduction appeared. Most of the monitoring ongoing outside of Yellowstone National Park is lead by USFWS and USFS staff and consists of censusing, monitoring of reproduction and mortalities, and movement and dispersal patterns (USFWS et al. 2004). Science and Resource Management personnel at Grand Teton locate radio-collared wolves using aerial surveys and conduct ground-based observations of packs in the region from May through September (GRTE 2004). Please see Appendix II for links to reports and further information on monitoring outside the parks.

4b. Bald Eagles

Significant increases in population numbers caused the USFWS to downlist the bald eagle from endangered to threatened in 1995 (McEneaney 2004). When the eagle was originally chosen as the national symbol in 1782, some 100,000 nesting pairs of bald eagles resided in the continental United States. By 1963, their numbers were down to 417 pairs (USFWS 1999). A loss of nesting habitat, coupled with the use of DDT and other organochlorines, which caused thinning of egg shells and decreased nesting success, lead to the decline in bald eagle populations (USFWS 1999). Captive breeding programs, reintroduction efforts, nest site protection and law enforcement helped in the recovery effort (USFWS 1999).

Yellowstone National Park publishes an annual report documenting the population status, territorial occupancy and nest productivity of the bald eagle. Bald eagle monitoring has been ongoing in Grand Teton National Park since the 1970s, including ground surveys for nests and monitoring reproductive status at historical nests (Wolff 2003). Bald eagle nests south of Bighorn Canyon National Recreation Area are currently monitored by Wyoming Game and Fish and the Bureau of Land Management (D. Saville pers. comm.). This monitoring is mostly within the boundaries of the Yellowtail Wildlife Habitat Area, but also extends approximately 0.5 miles into BICA boundaries (B. Pickett pers. comm.). Please see Appendix II for links to reports and information on monitoring by the Greater Yellowstone Coordinating Committee outside the parks.

4c. Canada Lynx

In March 2000, the USFWS listed the Canada lynx as a threatened species (USFWS 2000). Canada lynx were listed as threatened due to the inadequacy of forest plans to provide for protection of the ecological needs of lynx. National forest and park resource management plans have been amended, and a strategy is now in place for the conservation of lynx and their habitat. Threats include loss of connectivity between isolated ecosystems supporting lynx, incidental mortality during otherwise lawful trapping, hunting and snaring of other animals, and human encroachment on wildlands (USFWS 2003).

An inventory of Canada lynx in Yellowstone National Park was completed in 2004. Using a variety of survey methods, Canada lynx adults and kittens were detected in the park, with most detections occurring in an area near Yellowstone Lake that supports forests with dense understory vegetation (Murphy et al. 2004). It was concluded that the Canada lynx suffers from reduced population viability in the park, probably because the park represents the limit of its range (Murphy et al. 2004).

GRTE has completed a three-year study in collaboration with the Wildlife Conservation Society to determine (a) the status of lynx in the park, and (b) the activity of their primary prey, snowshoe hares. Results from these efforts will provide information for the determination of coarse-scale habitat requirements and, ultimately, what role Grand Teton plays in the overall conservation of lynx.

4d. Grizzly Bears

Grizzly bears were listed as threatened under the Endangered Species Act on July 28, 1975 (USFWS 1993). At the time of listing, they occupied only two percent of their original range in the continental United States and numbered 800 to 1,000 individuals in five or six populations (USFWS 1993). After listing, work began on the recovery plan for the species, which was approved on January 29, 1982, with revisions made in 1993 (USFWS 1993). The primary threats to grizzly bear populations are loss of habitat due to fragmentation, and adverse bear-human interactions, which leads to the destruction of "nuisance" bears (USFWS 1993). Human encroachment into grizzly habitat is a major threat because of the bears' very large home ranges that cover 309-537 square miles for females and 813-2,075 square miles for males (YELL 2004a).

In an effort to provide information to assist with long-term management of grizzly bears in the GYE, the Interagency Grizzly Bear Study Team (IGBST) was formed in 1973. This team has representatives from the following agencies: U.S. Geological Survey, National Park Service, U.S. Forest Service, U.S. Fish and Wildlife Service, Idaho Department of Fish and Game, Montana Fish, Wildlife and Parks, and the Wyoming Game and Fish Department. The IGBST is responsible for: "conduct[ing] both short- and long-term research projects addressing information needs for bear management; monitor[ing] the bear population, including status and trend, numbers, reproduction and mortality; monitor[ing] grizzly bear habitats, foods and impacts of humans; and provid[ing] technical support to agencies and other groups responsible for the immediate and long-term management of grizzly bears in the GYE" (Schwartz and Moody 2004). For further information on recovery goals, the IGBST and bear management activities in YELL, please consult Appendix III.

Air Resources within the Greater Yellowstone Network

Grand Teton and Yellowstone National Parks have been designated Class I areas under the Clean Air Act (YELL 2004a). The purpose of the Clean Air Act is to "preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value" (YELL 2004a). Section 169(A) of the Clean Air Act clearly identifies the goals of air quality monitoring in Class I areas:

> "Congress hereby declares as a national goal the prevention of any future, and the remedying of any existing impairment of visibility in mandatory Class I Federal areas which impairment results from any manmade air pollution."

In accordance with its classification as a Class I area, visibility monitoring is ongoing in Yellowstone National Park as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. IMPROVE is composed of members from federal, state and regional agencies and has the common goal of providing information to protect visual environments under the Clean Air Act of 1977 (IMPROVE 2004). The program was initiated in 1985 to protect visibility in Class I airsheds in 156 national parks and wilderness areas.

Passive ozone monitoring was conducted from 1995 through 2004 to determine ozone exposure levels at GRTE. Data collected from this site can be downloaded from: http://www2.nature.nps.gov/air/studies/passives.htm. Passive ozone monitoring is an inexpensive method that involves exposing the passive sampler to ozone on a weekly basis during the "ozone season" from May to September. After exposure, the sampler is retrieved and mailed to a contract lab for analysis. The passive ozone monitoring program was supervised and funded by the NPS-ARD and was discontinued in 2005. Please see Figure 1.6 for a map of current air quality monitoring stations withinn the GRYN.

In addition to visibility monitoring, atmospheric deposition monitoring is ongoing in YELL through two major programs: the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) and the Clean Air Status and Trends Network (CASTNET). NADP is a multi-agency (including federal, state and local) approach to monitoring the chemistry of wet deposition throughout the country at over 200 sites (NADP 2004). NADP/NTN currently operates one station at Tower Falls in Yellowstone National Park that collects information on daily, weekly, seasonal and annual totals and trends for the site (NADP 2004). NADP also operates a Mercury Deposition Network (NADP/MDN) that collects information on weekly total mercury concentrations in precipitation, as well as seasonal and annual mercury flux. An MDN station was started at Yellowstone Lake in February 2002 and moved to Tower Falls in 2005.

CASTNET is a joint venture between the Environmental Protection Agency (EPA) and the National Park Service-Air Resources Division that operates more than 70 dry acidic deposition sites throughout the U.S. (EPA 2004). These sites provide hourly data on ozone levels and weekly information on the concentration of sulfate,

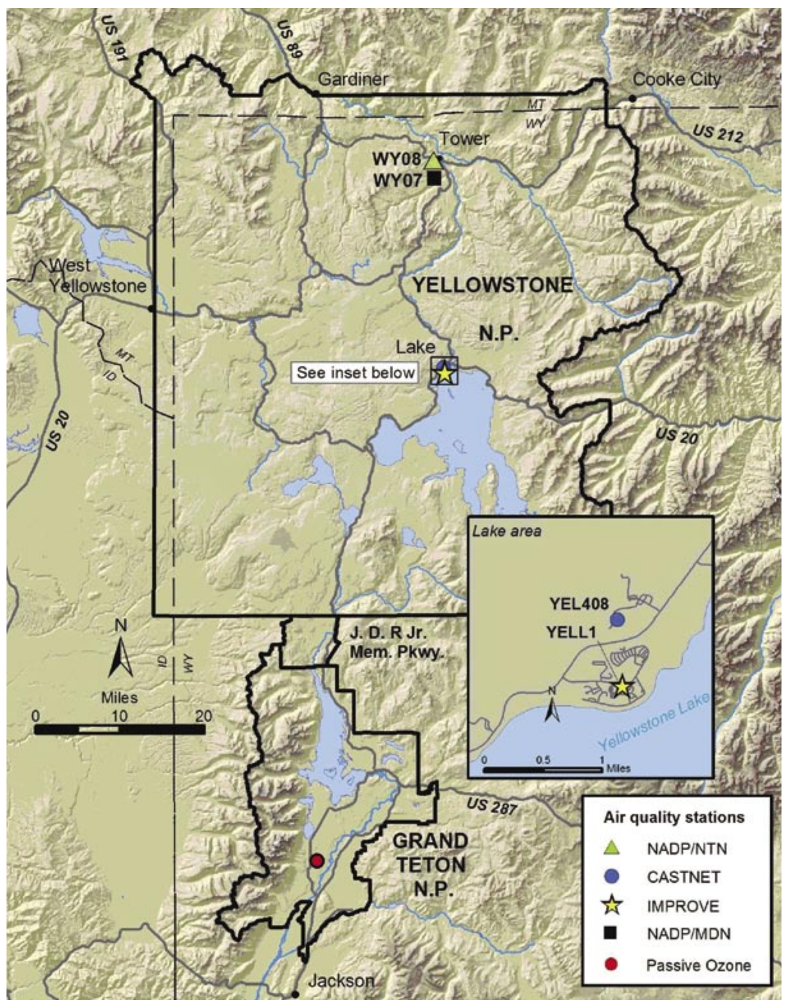


FIGURE 1.6 Map of air quality monitoring stations with new MDN location and added passive ozone site in GRTE (coordinates from GRTE GIS). Source: NPS-Air Resources Division

nitrate, ammonium, sulfur dioxide and nitric acid (EPA 2004). One CASTNET site is currently located near Yellowstone Lake. Please refer to Appendix II for more information on air quality monitoring.

Water Resources within the Greater Yellowstone Network

The state of Wyoming has classified all surface waters located within the boundaries of Yellowstone and Grand Teton National Parks as Class 1 waters. Class 1 waters are defined by the state as "those surface waters in which no further water quality degradation by point source discharges other than from dams will be allowed" (Wyoming DEQ 2001). The classification of these waters corresponds with the EPA Outstanding Natural Resource Waters (ONRWs) designation, giving them the highest level of protection from degradation (EPA 1994).

Section 303(d) of the Clean Water Act requires states to assess their waters to determine which water bodies are impaired or threatened and to develop water quality improvement strategies for these waters. Every other year, a list of these waters is submitted to the EPA. Bighorn and Shoshone Rivers in BICA, Reese Creek in northern Yellowstone and Soda Butte Creek (outside the Yellowstone boundary) are 303(d)-listed streams that will be monitored as part of the regulatory water quality monitoring by the GRYN (Wyoming DEQ 2002; Montana DEQ 2002). See Table 1.4 for locations of 303(d)-listed streams within network parks.

Surface water quality data retrievals from six of the USEPA's national databases served as the basis for the Baseline Water Quality Data Inventory and Analysis Reports completed for YELL, GRTE and BICA by the Servicewide Inventory and Monitoring Program and the Water Resources Division (National Park Service 1994b, 1998, 2001c). These data were later acquired and analyzed for state water quality exceedances by Woods and Corbin (2003a, 2003b, 2003c). Knauf and Williams acquired and analyzed seven data sets for Soda Butte Creek (2005), dating from 1987 to 2001; these data were submitted to EPA for submission to the EPA STORET database. In 2004 the GRYN prepared a phase II Water Quality Monitoring Plan (O'Ney and McCloskey 2004) to address overall water quality goals, background information and conceptual models for water quality monitoring in the GRYN. These reports can be found on the Web at: http://www.nature.nps.gov/im/units/gryn/index.shtml.

In 2005 the GRYN, together with the network parks, began monitoring water bodies identified as water quality impaired following the Regulatory Water Quality Protocol (O'Ney 2005); these streams include Soda Butte Creek, Reese Creek and the Bighorn River in Montana and Shoshone River in Wyoming. The Regulatory Water Quality Monitoring Protocol for the Greater Yellowstone Network (O'Ney 2005) establishes the standing operating procedures for measuring core parameters and discharge plus dissolved and total metals in water, metals in sediment, nutrients, *E. coli* and fecal coliforms and macroinvertebrates. Please see Table 1.4 for a summarization of trends in water bodies to be monitored by the GRYN.

Both Yellowstone and Grand Teton NP's have on-going monitoring water quality within their boundaries. The following section describes water quality monitoring currently being done by the YELL aquatic resource division in YELL and by park staff at GRTE. See also sections on geothermal and streamflow monitoring for more information on water related monitoring.

At the USGS gauging station at Moose (GRTE), there is a real-time, continuous monitor for water temperature, pH, dissolved oxygen and specific conductivity. Also in GRTE, approximately 20 groundwater wells adjacent to sewage ponds and leach fields within park boundaries are presently being monitored once a year for basic water quality parameters, fecals and nutrients to comply with the requirements of Wyoming Department of Environmental Quality. Additionally, Snake River Pit ground water levels are monitored on a biweekly basis from wells installed by the USGS in 1997 (O'Ney and McCloskey 2004). Testing for fecal coliform, including DNA source tracking of *E. coli* to determine the mammalian source of coliforms, began in 1996 in selected backcountry streams, and has continued to date (O'Ney and McCloskey 2004).

A long-term water quality monitoring program was started in YELL in 2002 and includes nineteen fixed sites; twelve of these stations are located on rivers and streams and seven are located on Yellowstone Lake. Field measurements include pH, dissolved oxygen, specific conductance, temperature and turbidity; samples are collected for total suspended solids (TSS) and volatile suspended solids. Sampling takes place at two-week intervals during the spring, summer and fall and monthly during the winter (December, January and February). On Yellowstone Lake, monitoring stations were established at four historic sampling stations (Koel et al. 2004), with sampling taking place between May and October (during ice-free periods). Two additional sampling sites on the southern arms of Yellowstone Lake were added in 2003 for a total of seven stations on the lake.

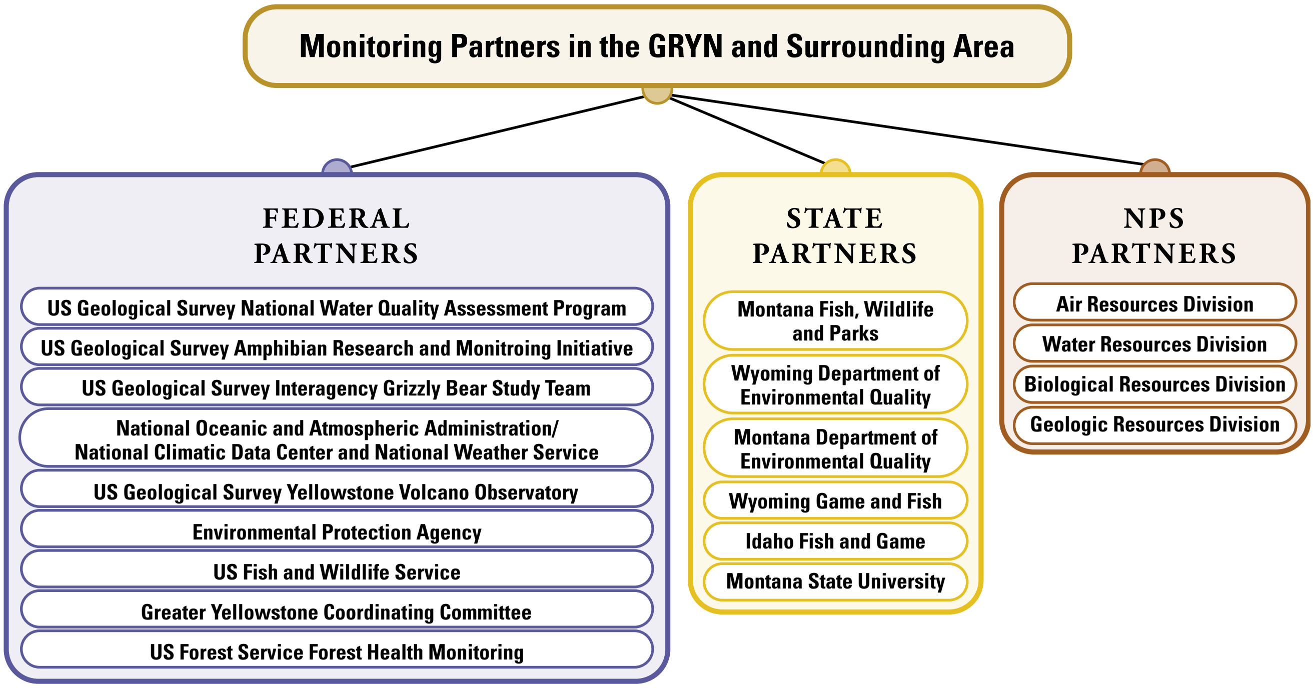


FIGURE 1.7 The National Park Service is involved with many other federal agencies and state agencies to complete monitoring within and around the parks of the GRYN. This figure is meant to illustrate the importance of these monitoring efforts and is not meant to be an exhaustive list of all organizations and agencies monitoring resources within the ecosystem. Appendix II of this report describes current monitoring programs taking place in the GRYN in more detail.

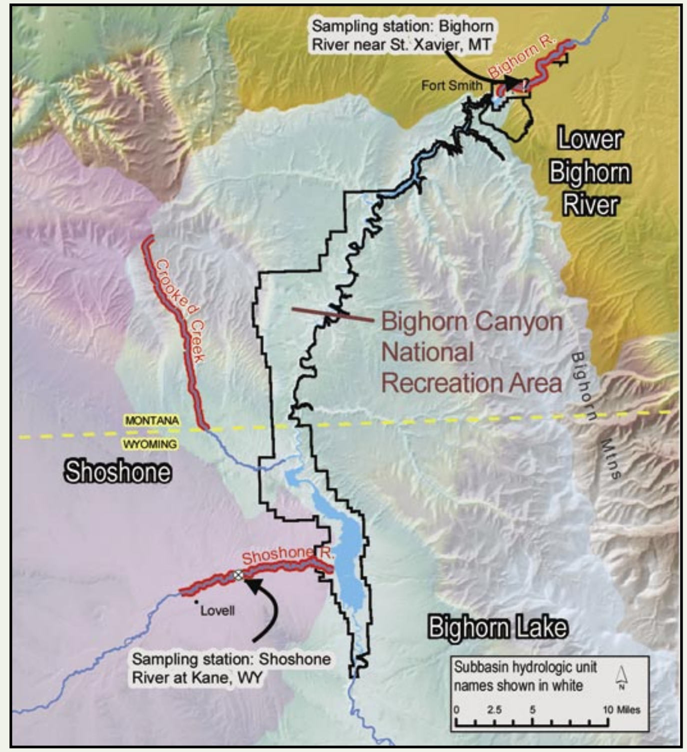
Streamflow (real time discharge and gage height) is being monitored by the USGS at several locations in the GRYN. This monitoring is often in cooperation with other state and federal agencies including YELL geothermal program and other cost share with GRTE. See Appendix II for a table of key streamflow gages in the GRYN. Data can be obtained from http://waterdata.usgs.gov/nwis. These gages are usually located on the mainstem of larger rivers at easily accessible sites. While this network provides invaluable information on regional hydroclimatic variability, the lack of gages in headwaters areas or on smaller tributaries may represent and important data-gap for the GRYN. Smaller streams generally respond more rapidly to variations in climate (NAST 2001; Wagner 2003). Small streams also provide key habitats for species of interest within the Greater Yellowstone Ecosystem (e.g. cutthroat trout).

Other Natural Resource Monitoring

Numerous types of natural resource monitoring are ongoing in the GRYN parks and surrounding landscapes. Understanding the scope of these projects, along with the goals and objectives of the agencies or groups conducting the monitoring, allows the GRYN to integrate with these programs to achieve a more balanced and efficient program. Appendix II contains a detailed explanation of current monitoring in the GRYN parks and surrounding lands. Figure 1.7 presents a brief overview of those federal, state and park partners that are currently involved in monitoring some aspect of one or more GRYN vital signs. This figure is not an exhaustive list, nor does it include those organizations that actively participate in research in the GRYN parks and surrounding landscapes. For the purposes of the I&M program it is most important to understand which groups are currently involved in taking repeat, standardized measurements that can provide information to help assess the state of the ecosystems contained within these parks. Integration with these agencies and groups is essential to the success of the GRYN; the GRYN can take advantage of the ongoing momentum of established programs and increase efficiency and cost-effectiveness by combining efforts. This can lessen redundancy, lead to shared resources and more effectively cross political boundaries. For information regarding integration with other ongoing monitoring programs (with respect to design issues), please consult Chapter 5; for additional information on program integration, please see Chapter 8. Developing Vital Signs and Monitoring Objectives—An Overview of the Program

TABLE 1.4 Exceedances of state water quality standards, potential causes and water quality trends for waters in GRYN sub-basins taken from Woods and Corbin (2003 a,b&c). Many sampling locations were of limited value in determining trends due to either a lack of data for a particular parameter or a lack of sufficient data points. Refer to Woods and Corbin for a more detailed discussion, including information on potential data outliers. See also Montana and Wyoming DEQ water quality assessment reports (WYDEQ 2004, MTDEQ 2004) for additional sub-basin information. Streams segments (within or near the park boundary) that are listed as 303 (d) water quality impaired are show in red.

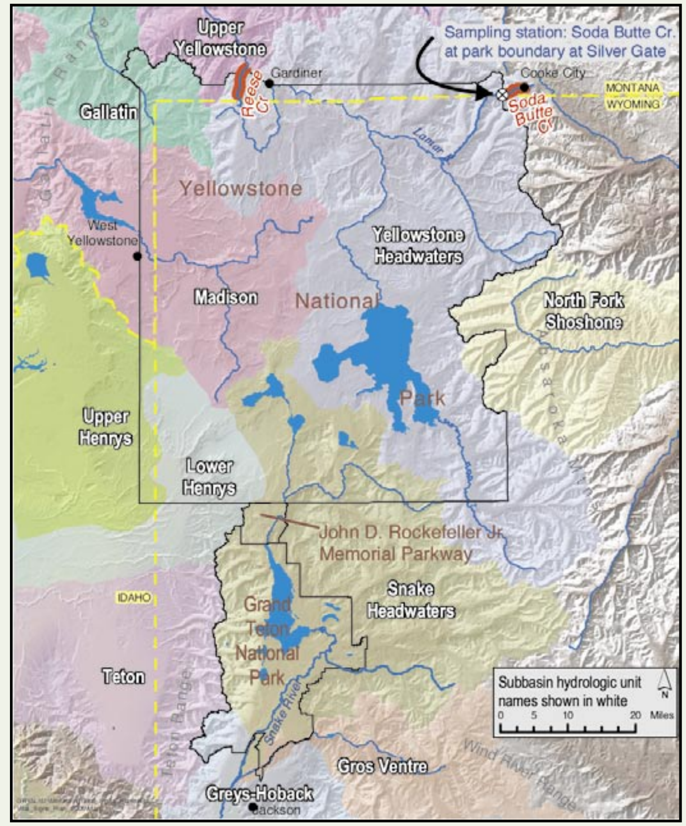
Sub-basin[1]	Documented water quality exceedances (# exceedances/ # records)	Potential causes for exceedances
Bighorn Lake: Trend = 1	Bacteriological (128/1181)	Wastewater discharge from campsites, watercraft and from the presence of cattle in and near streams flowing into the lake
	Turbidity (108/1304)	Sediment accumulation due to high sediment loads from the Shoshone and Bighorn Rivers
	Dissolved oxygen (40/1650)	*
	Nitrate-nitrogen (22/5477)	Runoff from range and cropland and wastewater treatment plants; wastewater discharges from campsites and other recreational areas
	Sulfates (546/3294)	*
	Toxic elements (298/16132)	Runoff and erosion from upstream watersheds, along with discharges from municipal areas and from industry
Shoshone: Trend =1, 2	Bacteriological (57/224)	Wastewater treatment plants upstream from BICA
	Turbidity (69/238)	Suspended sediment from the erosion of irrigated croplands, rangelands and stream banks
	Nitrate-nitrogen (17/2155)	Non-point and point sources as described for Bighorn Lake
	Sulfates (272/2510)	*
	Toxic elements (45/8951)	Runoff and erosion as described for Bighorn Lake
Lower Bighorn: Trend = 1	Sulfates (169/1154)	*
	Toxic elements (130/6061)	Runoff and erosion as described for Bighorn Lake
	Sulfates (1/73)	Geology
	Toxic elements (9/1207)	Geology; geothermal



[1] The Federal Geographic Data Committee's Subcommittee on Spatial Water Data has developed a hierarchical six level system for classifying the United States into discrete hydrologic units. The fourth level of classification is the sub-basin. Sub-basins are identified with an eight-digit Hydrologic Unit Code (HUC).

Potential causes for exceedances
*no cause suggested

Sub-basin[1]	Documented water quality exceedances (# exceedances/ # records)	Potential causes for exceedances
Yellowstone Headwaters: Trend = 5	Dissolved oxygen (18/430)	Natural characteristic of wetland areas
	pH (306/1369)	A natural characteristic of the waters of YELL
	Sulfate (97/1998)	High total sulfate associated with geothermal activity.
	Toxic elements (303/6939)	Arsenic and copper high due to geothermal influences; iron and manganese in Soda Butte Creek are likely high due to the impacts of historical mining activity
Madison: Trend = 6	pH (73/564)	Natural characteristic
	Phosphorus (1/469)	Geothermal influences
	Temperature (2/1020)	Geothermal influences
	Toxic elements (158/2178)	Geothermal influences
Gallatin: Trend = 4	pH (32/83)	Natural characteristic
	Toxic elements (6/325)	*
Upper and Lower Henry's: Trend = 4	pH (38/132)	Natural characteristic
	Toxic elements (21/404)	*
N. Fork Shoshone: Trend = 4	pH (15/32)	*
Snake Headwaters (YELL): Trend = 7	Toxic elements (74/1499)	Geothermal influences on lake water chemistry
Snake Headwaters (GRTE): Trend = 3	Bacteriological (8/704)	Sewage disposal ponds
	Turbidity (11/984)	Park roads and trails, and cattle and elk grazing.
	Dissolved oxygen (30/1717)	Natural characteristic of wetland areas
	Nitrate –nitrogen (1/2036)	Wastewater effluent, grazing of native and domestic ungulates
	pH (205/2604)	A natural characteristic of the waters of GRTE
	Sulfates (3/8951)	Geology
	Toxic elements (159/9056)	Geology; geothermal
Gros Ventre: Trend = 4	pH (11/76)	A natural characteristic of the waters of GRTE
	Toxic elements (9/1207)	Geology; geothermal



Trend

1 Increase in pH; decrease in conductivity

2 Decrease in dissolved nitrate

3 Seasonal trends only

4 Data have limited value for determining trends

5 Insufficient data to determine trends in the Yellowstone and Lamar Rivers; the Gardner River and Lake Yellowstone exhibit strong geothermal influences; Soda Butte Creek has likely been impacted by historical mining

6 Temperatures at downstream sites are lower than upstream; there is a downstream decrease in the means of dissolved sulfate, dissolved calcium and dissolved sodium

7 Weak temporal trend towards increasing total Kjeldahl nitrogen in Heart and Shoshone Lakes

IDENTIFICATION AND SELECTION OF VITAL SIGNS

The GRYN used a multistep process to identify and select candidate vital signs. One essential step involved the use of conceptual ecological models. Conceptual models provide an understanding of the structure, function and interconnectedness of park ecosystems, enabling the identification of vital signs for assessing ecosystem health. Nine terrestrial models, two aquatic models, and one geothermal model were developed. The models identified the drivers, stressors, response variables, outcomes and metrics of the ecosystem modeled, and highlighted the position of the proposed candidate vital signs within the modeled systems. Please see Chapter 2 of this report for additional information on the conceptual modeling process undertaken by the GRYN.

In addition to conceptual modeling, the GRYN used the Delphi survey process and a workshop series to further identify and prioritize vital signs. The Delphi survey was an Internet-based questionnaire sent to subject-area experts and park personnel that allowed participants to nominate possible vital signs for monitoring and then rank them on a scale of importance. The GRYN also held park-specific workshops to gain insight from park managers on the value of the conceptual modeling and Delphi results, as well as the process used to rank vital signs by their relevance. This ranking process consisted of 13 yes/no questions pertaining to the ecological relevance, response variability, managerial relevance, feasibility of implementation, and interpretation and utility of the candidate vital signs. After peer review by park staff and contributing scientists, the GRYN hosted a "vital signs monitoring workshop," during which invited subject-area experts and park managers judged the candidate vital signs using the selection criteria.

The Technical Committee then held final responsibility for selecting vital signs for approval by the Board of Directors. The selection process represented a synthesis of the information collected in the previously described exercises, as well as park-specific expertise that helped to guide the selection of vital signs that would best fulfill the needs and goals of the GRYN parks. After the selection process, the Board of Directors approved the vital signs and work began to develop specific, measurable monitoring objectives for the selected subset of vital signs that the Technical Committee ranked as top priorities. A complete list of vital signs can be found in Chapter 3 of this report along with additional information related to the selection of vital signs.

GENERAL PROCESS FOR DEVELOPING MONITORING OBJECTIVES

To guide the development of specific monitoring objectives for each vital sign selected, the GRYN chose to follow and modify the process described in Caughlan and Oakley (2001), which is represented in Figure 1.8. While most changes to the process were minor, the GRYN eliminated the use of budgetary constraints in the formation of monitoring objectives. Although cost will always be a consideration in the development of a monitoring program, the GRYN chose to eliminate costs as an initial constraint and, instead, focus on the development of specific monitoring objectives and identify tradeoffs that must be made to meet budgetary limitations.

Broad Monitoring Questions

The process used to select vital signs incorporated the ability of the prospective vital signs to fulfill the five Service-wide I&M goals, stated in section I.A.4, while also satisfying local monitoring needs and questions. Using the process depicted in Figure 1.8, the GRYN adopted three broad monitoring goals to aid in selection of vital signs and in the development of specific measurable monitoring objectives. These goals, now stated as monitoring questions, are meant to be answered by synthesizing the information gained through the specific, measurable monitoring objectives described in the vital signs protocols and also in chapter 5.

- What is the status and trend of selected ecosystem drivers and stressors currently or potentially affecting park resources?
- What is the status and trend of selected species and communities (both plant and animal) and how are they changing as ecosystem stressors and drivers change?
- What knowledge of drivers, stressors and resources of concern will affect sound management decisions and help to protect key resources or provide scientific evaluation and interpretation of ecosystem change?

Answers to these broad questions, achieved through answering specific monitoring objectives, along with information from other programs monitoring natural resources within the parks of the GRYN, present an integrated examination of the state of the parks' ecosystems.

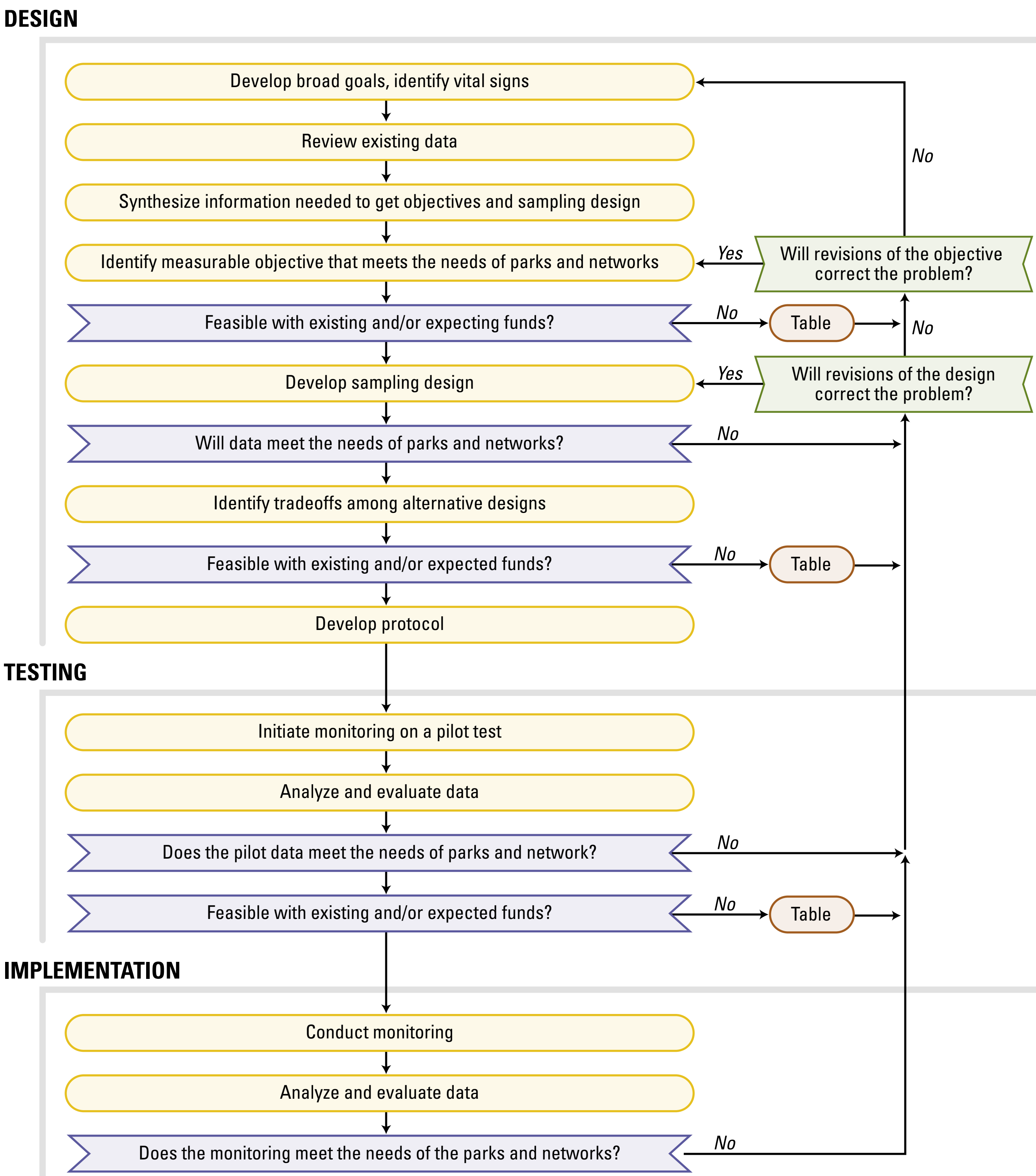


FIGURE 1.8 Diagram depicting the process used to conduct monitoring in the GRYN. This diagram is adapted from Caughlan and Oakley (2001).

2. CONCEPTUAL MODELS

A conceptual model is a visual or narrative summary that describes the important components of an ecosystem and the interactions among those components (NPS 2003c). Conceptual models also help identify the impacts of major drivers and stressors on ecosystem components (Barber 1994), and can aid in the identification of possible indicators for monitoring long-term ecosystem health. This chapter describes the conceptual modeling process undertaken by the GRYN to aid in the development of vital signs.

USING CONCEPTUAL MODELS

Conceptual models are beneficial to a monitoring program by providing the following (taken from Plumb 2002):

- An understanding of ecosystem structure, function and interconnectedness at varying temporal and/or spatial scales that enables identification of vital sign indicators for assessing ecosystem health in parks.
- An understanding of the range of natural and human-induced ecosystem variability, which helps park managers plan adaptive management programs, determine at what threshold variances these programs should be instituted, and then measure the results of the management programs to assess their value.

The GRYN used conceptual models at different points in the planning process. During Phase I, Patten and Schmitz developed a series of nested ecosystem conceptual models for each of the three network parks (see Appendix III). These models started with a simple overview model followed by a park ecosystem model. Nested submodels prepared for specific resources such as upland vegetation, water, riverine-wetlands and birds, provided a greater level of detail. These models, especially as they were being developed, were useful in communicating relevant ecological themes within the network parks during vital signs scoping meetings. These park ecosystem conceptual models were followed by a deliberate process for model development based on an over-arching template for information organization and vital signs selection discussed below.

DEVELOPING CONCEPTUAL MODELS

Conceptual models should demonstrate the strength and direction of connections among ecosystem components and the indicator chosen for monitoring (Olsen et al. 1992), as well as providing the anticipated response of the system to stressors (USDA 1999). Three general types of conceptual models can be used to depict these connections. These types include:

- Narrative conceptual models: models that describe an ecosystem through word description, mathematical or representational formula, or a combination of both.
- Tabular conceptual models: models that describe an ecosystem by presenting a two-dimensional array of related ecosystem components.
- Schematic conceptual models, which take one of the following forms:
  - Picture models, which show ecosystem function either in plot form or through diagrams
  - Box-and-arrow models, which represent ecosystems by focusing on key components and the relationships among them.
  - Input/output matrix models, which are a subset of box-and-arrow models that explicitly indicate mass and/or energy flow between ecosystem components.

After examination of the strengths and weaknesses of each type of model, the GRYN chose to prepare a literature review and narrative coupled with hierarchical box-and-arrow models to aid in vital signs selection due to the models ability to demonstrate how large-scale constraints (e.g., climate) can cascade down to small-scale, measurable endpoints (e.g., soil moisture [Allen and Hoekstra 1992; Allen and Starr 1982]) and their intuitive nature. This decision was also based on the ability of the models to provide information related to the 35 desirable vital sign characteristics, as described in Plumb (2002).

The GRYN then chose appropriate spatial and temporal scales as an overarching ecological framework on which the conceptual models could be developed. For the temporal aspect of the conceptual models, the GRYN chose to include 100 years before and after present because the majority of reliable historic data and knowledge developed for the ecosystems would be included. In addition, this time period represents the period of immediate utility for the vital signs selected. To choose the spatial scale for the models, the GRYN evaluated three methods that might server as an over arching template and allow for partitioning ecosystems into manageable components for model development. These methods included:

- Ecoregion classification (Bailey 1995, Omernick 1987), which yielded spatial scales that were too large for examining fine details associated with ecosystem monitoring.
- Fourth-level Hydrologic Units, which resulted in appropriate spatial resolution and sections that also closely aligned with existing land management boundaries.
- National Vegetation Classification Standards (NVCS) (Federal Geographic Data Committee 1997), which describes terrestrial vegetation by physiognomic classification and closely parallels terrestrial vegetation described in existing classifications.

Of these possibilities, the GRYN chose to use classes of terrestrial vegetation and created nine conceptual model themes, many of which included aggregations of closely related vegetation types (i.e., mixed conifer forests). In addition, two aquatic systems, one geothermal system and wetlands and riparian systems were chosen. Please see Table 2.1 for a list of conceptual models developed during Phase II and Appendix III for the complete collection of conceptual models developed for the GRYN parks.

TABLE 2.1 Ecosystem conceptual models developed during phase II vital signs planning.

Ecosystem Conceptual Model
Aquatic Ecosystem
Alpine-Timberline Ecosystem
Aspen Ecosystem
Dry Woodland Ecosystem
Geothermal Ecosystem
Grassland Ecosystem
Shrubland Ecosystem
Lodgepole Pine Ecosystem
Mixed Conifer Ecosystem
Ponderosa Pine Ecosystem
Whitebark Pine Ecosystem
Riparian/Riverine Ecosystem
Wetland Ecosystem

During development of the conceptual models, the GRYN proposed the following methods for maintaining uniformity:

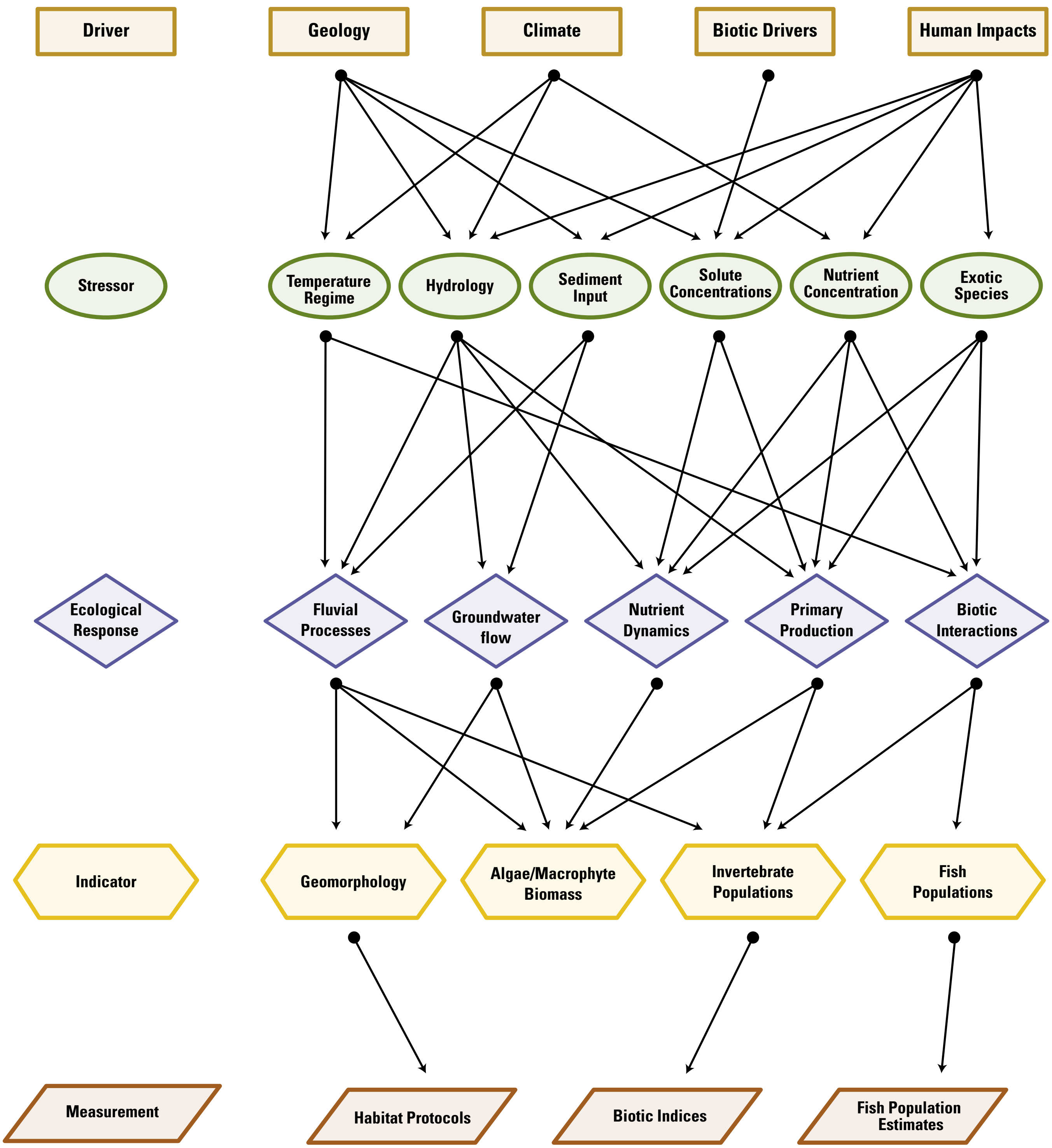
- The model should be based on a review of the relevant literature in the subject area.
- The model should identify specific resources that are vulnerable to natural and anthropogenic disturbances, primary drivers and stressors on ecosystem integrity, and ecosystem response to the drivers and stressors.
- The model should identify potential indicators for assessing ecosystem health and possible measurements of these indicators.

An example of an aquatic conceptual ecological model developed for the GRYN is shown in Figure 2.1. This model depicts drivers in the riverine ecosystem, which include abiotic processes, such as climate, as well as biotic functions, such as human impacts. The model then shows the connection between these drivers and stressors, such as exotic species. From this point, the model shows how the ecosystem responds to these stressors and how that response can lead to the identification of indicators and their measures (such as the indicator invertebrate populations and the biotic index measurement). Thus, the conceptual models can identify drivers, stressors, response variables, indicators and measurements of these indicators. Table 2.2 lists seven stressor and response variables that were recommended as vital sign indicators in the aquatic ecosystem model. Definitions of model components are described in Figure 2.1. For more information, refer to Appendix III which includes the complete conceptual model chapter which has 32 individual ecosystem models and ecosystem submodels. The use of conceptual models increases understanding of the interconnectedness of ecosystem components and helped the GRYN identify information-rich indicators. These indicators were later evaluated and ranked against a set of criteria; this planning step and outcome are described in Chapter 3.

CONCEPTUAL MODELING AMONG VITAL SIGNS

While the conceptual modeling method was first introduced in the I&M program as a method for selecting vital signs that provide a wealth of information on the state of the ecosystem, the GRYN has continued to use conceptual models to demonstrate the ecological connections among its chosen vital signs. These conceptual models help to tie sometimes disparate vital signs together and to demonstrate the way in which information from many vital signs may be tied together to give a complete picture of the state of the ecosystems encompassed by the GRYN parks.

Figure 2.2 shows a conceptual model that relates whitebark pine to other



assessing ecosystem health (refer to Appendix III). Drivers are major, naturally occurring, forces of change (can be anthropogenic) and operate on national or regional levels. Stressors are physical, chemical, or biological perturbations to a system that operate on more localized levels than drivers. Ecological effects are the physical, chemical, biological or functional responses of ecosystem attributes to drivers and stressors. Indicators are an information-rich subset of attributes providing insight into the quality, health or integrity of the larger ecological system to which they belong (Noon 2002). Measurements are the specific variables used to quality the condition or state of an attribute or indicator.

TABLE 2.2 Aquatic indicators recommended by the riverine conceptual model author (adapted from Plumb et al. 2003). See Appendix III for the riverine and lake ecosystem conceptual models and recommended aquatic indicators. After the conceptual models were complete, these indicators or candidate vital signs were evaluated and ranked by a panel of experts at the GRYN Vital Signs Workshop. The workshop is described in Chapter 3 and in detail in Appendix V.

Candidate Vital Sign	Justification
Geomorphology	Riparian vegetation not only responds to changing channel geomorphology but plays a role in its formation. Any change in channel geomorphology will consequently alter the amount and distribution of the riparian community. Thus, channel geomorphological metrics may be a useful indicator of the condition of riverine and riparian systems.
Invertebrate Populations	Stream invertebrate assemblages may change in response to exotic species, sedimentation, nutrient load or predator population change. Stream invertebrates are often used as measures of water quality (Karr 1999) and are the current approach used by the state of Wyoming for water quality analyses (King 1993). They are sensitive indicators of change and they can integrate physical stressors that might otherwise be difficult to measure, and these changes can relate to changes in ecosystem function (Wallace et al. 1996). Long term monitoring of invertebrates may be able to detect change in response to exotic mud snails, and new, unforeseen invasions.
Fish Populations	Exotic lake trout and whirling disease can potentially lower densities of native Yellowstone cutthroat trout in Yellowstone Lake; these effects may cascade to streams and predators outside of the lake (Stapp and Hayward 2002).
Algae/Macrophyte Biomass	Increased nutrients or changes to the food web (e.g. Carpenter et al. 1985) may change algal biomass, water clarity and species composition. Research in Yellowstone Lakes has shown that diatom species compositions predictably respond to slight changes nutrients according to their physiology (Interlandi et al. 1999), and these changes in assemblages may be sensitive indicators to nutrient inputs and associated climate change (Kilham et al. 1996). Algal species in high-elevation lakes can also signal changes in nutrient concentrations (Wolfe et al. 2001).
Temperature Regime	Global climate change may increase temperatures of lakes and streams which may alter animal habitat and interactions. Additionally, geologic change (e.g earthquake in Firehole River basin) may alter groundwater inputs with corresponding temperature changes in rivers. Measurement of temperature may be able to detect these changes which can be linked to any biological changes.
Hydrology	Hydrology of lakes and rivers in the GRYN can change from direct human modification (e.g. impoundments, water abstraction) or via changes in climate (Meyer et al. 1999). This monitoring is already occurring for several of the rivers in GRYN, e.g. Snake, Bighorn, Madison, Yellowstone and two of the lakes, Jackson and Bighorn.
Nutrient Concentration	Nitrogen concentrations lead to eutrophication thus increasing primary production, changing biotic assemblages and lowering water clarity (Smith 1998). Stream monitoring can detect long-term trends in deposition (Likens et al. 1996) and may provide a means to detect watershed-level response to N additions (Williams et al. 1996).

relevant vital signs chosen for monitoring by the Greater Yellowstone Network. This model is not meant to be a complete picture of all influences on the whitebark pine community; rather, its purpose is to highlight how whitebark pine fits into the larger picture of the vital signs program and how other vital signs may be connected to the whitebark pine community, thus influencing the monitoring of those vital signs. These types of models can be helpful in identifying important partnerships with cooperating agencies that are already involved in monitoring in the GRYN parks, as discussed in Chapter 1. Complete, detailed information on the ecological connections among the vital signs, such as those contained in this conceptual model, are included in the individual vital signs monitoring protocols.

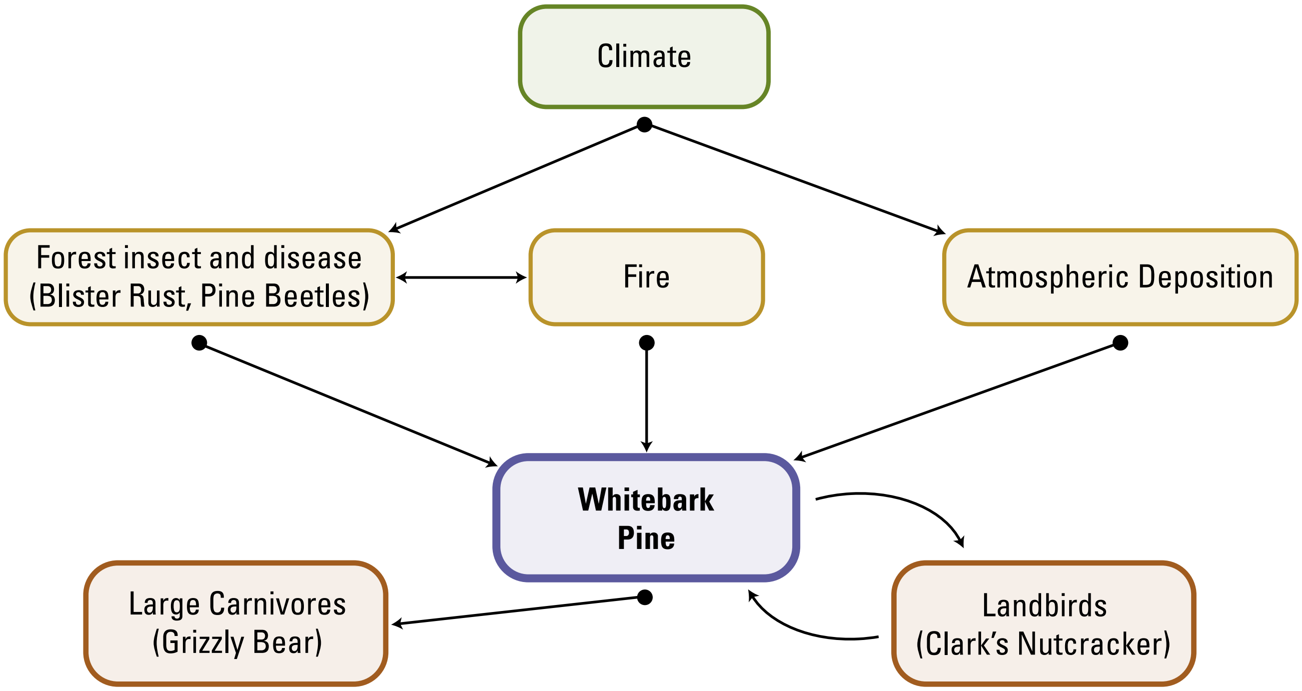


FIGURE 2.2 Whitebark pine vital signs conceptual model.

3. VITAL SIGNS

Vital Signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. (http://science.nature.nps.gov/im/monitor/). Due to the large number of potential vital signs that can be used to monitor the state of an ecosystem, it was imperative for the GRYN to identify and prioritize potential indicators and then select a subset that best represents the parks' ecosystems. This chapter describes the process used by the GRYN to select and prioritize potential indicators as vital signs for the network.

IDENTIFYING POTENTIAL VITAL SIGNS

In addition to the conceptual modeling process (described in Chapter 2), the GRYN used a Delphi survey and workshops at the parks to identify potential vital signs and the attributes that make these vital signs high-quality indicators of ecosystem health.

Delphi Survey

In 2001 the GRYN, in cooperation with the University of Idaho—College of Natural Resources, conducted an Internet-based Delphi survey to aid in the identification and prioritization of ecosystem components, conditions and processes. Over 100 scientists and resource managers familiar with the GRYN parks participated in the survey.

The Delphi process consisted of three rounds of questioning, starting with general resource issues and culminating at specific monitoring needs. Phases I and II of the Delphi process were used to solicit input, while the third phase of the Delphi process solicited rankings from the experts on the importance of ecosystem indicators derived from the resource components, conditions and processes identified in the first and second phases. This process resulted in a list of 188 possible indicators that are ranked within subject areas. Please see Appendix IV for the list of indicators resulting from Delphi III.

The Delphi survey approach to nominating potential indicators had advantages, including:

- the opportunity to obtain ideas from a large audience
- convenience—participants can respond when and where they choose
- cost effectiveness—no travel time or costs involved.

However, the Delphi process used by the GRYN had disadvantages, as well, including:

- that participants can nominate any vital sign they choose, with no peer-reviewed evaluation as to merit or relevance of ideas
- since the survey is voluntary, results will be skewed to the interests and expertise of those who chose to reply
- the results are not repeatable and therefore less defensible.

Park Workshops and Meetings

In conjunction with the Delphi survey process and conceptual modeling efforts, the GRYN held workshops with park staff at Grand Teton and Yellowstone. The purpose of these workshops and meetings was to provide updates and receive input on the following:

- the two methods used to identify candidate vital signs: conceptual modeling and the Delphi on-line survey
- the proposed criteria and process to rank and select vital signs from the list of candidate vital signs.

Conceptual modeling efforts were reviewed with respect to validity of spatial and temporal scale and unit of ecosystem organization. At Yellowstone, the results of the final Delphi questionnaire were reviewed and critiqued. Because some participants were uncomfortable with the Delphi scoring process, and a number of newly nominated vital signs had yet to be scored, a decision was made to prioritize candidate vital signs through a highly structured workshop setting by using a set of selection criteria based on scientific literature and I&M guidance.

SELECTING VITAL SIGNS

Vital Signs Monitoring Workshop

After completing the conceptual modeling and Delphi survey processes, the GRYN hosted a vital signs monitoring workshop to gain expert input into the selection of vital signs. The GRYN invited 56 subject-area experts to convene in Bozeman, Montana, for a three-day workshop with the goal of prioritizing a long list of potential vital signs and, through a scoring process, highlighting valuable indicators for monitoring long-term ecosystem health in the parks.

Prior to the workshop, GRYN staff cross-walked potential vital signs nominated through the Delphi survey and conceptual modeling exercises. The resulting list was then given to workshop participants to prioritize using a set of selection criteria. The selection criteria consisted of 13 yes/no questions based on I&M guidance and literature that identified the qualities of a good indicator. The five categories of selection criteria (and weighting) were as follows:

(1) Ecological relevance (25%)—Does the vital sign help us understand long-term ecosystem health?

(2) Response variability (25%)—Is the vital sign tightly coupled to, and preferably anticipatory of, the change(s) occurring?

(3) Managerial relevance (20%)—Does the vital sign address current or foreseeable management issues?

(4) Feasibility of implementation (15%)—Can the vital sign be measured at a reasonable cost, and can sampling protocols be designed to eliminate personnel-induced variability?

(5) Interpretation and utility (15%)—Can the vital sign differentiate between natural and anthropogenic change and identify the cause of ecosystem change?

A scoring system, essentially as follows, was then devised to quantify the group's expert knowledge regarding the ability of a potential indicator to address the 13 desirable vital signs criteria. For a more complete description of the scoring method, see Appendix V.

$$\text{vital sign ranking} = \sum_{n=1}^{5} \left\{\frac{\text{(\# ``yes'' answers per category)}}{\text{(\# questions per category)}}\right\} \times \text{(category weight)}$$

The selection criteria are presented in Table 3.1. The binary nature of these questions was meant to attach a quantitative value to the qualitative process of choosing vital signs. After the breakout ses-

TABLE 3.1 Vital sign selection criteria.

Category	Criteria (yes or no?)
Ecological Relevance	1. The candidate vital sign has high ecological importance with a demonstrated linkage between the vital sign and the ecological structure or function that it is supposed to represent, based on a conceptual model and/or supporting ecological literature. 2. The candidate vital sign provides relevant information that is applicable to multiple scales of ecological organization.
Response Variability	3. The candidate vital sign responds to ecosystem stressors in a predictable manner with known statistical power. 4. The candidate vital sign is anticipatory and is sensitive enough to stressors to provide an early warning of change. 5. The candidate vital sign has low natural variability and has high signal-to-noise ratio (e.g. low error) and/or supporting ecological literature.
Management Relevance	6. The candidate vital sign is stated in specific park management goals, GPRA goals or business plan standards. 7. There is a demonstrated, direct application of candidate vital sign measurement data to current key management decisions or for evaluating past management decisions.
Feasibility of Implementation	8. The candidate vital sign's cost of measurement is not prohibitive. 9. Impacts of measuring the candidate vital sign meet NPS standards. 10. The candidate vital sign is relatively easy to measure and has measurable results that are repeatable with different personnel.
Interpretation and Utility	11. The response of the candidate vital sign can be distinguished between natural variation and anthropogenic impact-induced variation. 12. The candidate vital sign is helpful in identifying the causal mechanism of an ecological response. 13. Historic databases and baseline conditions for the candidate vital sign are already known.

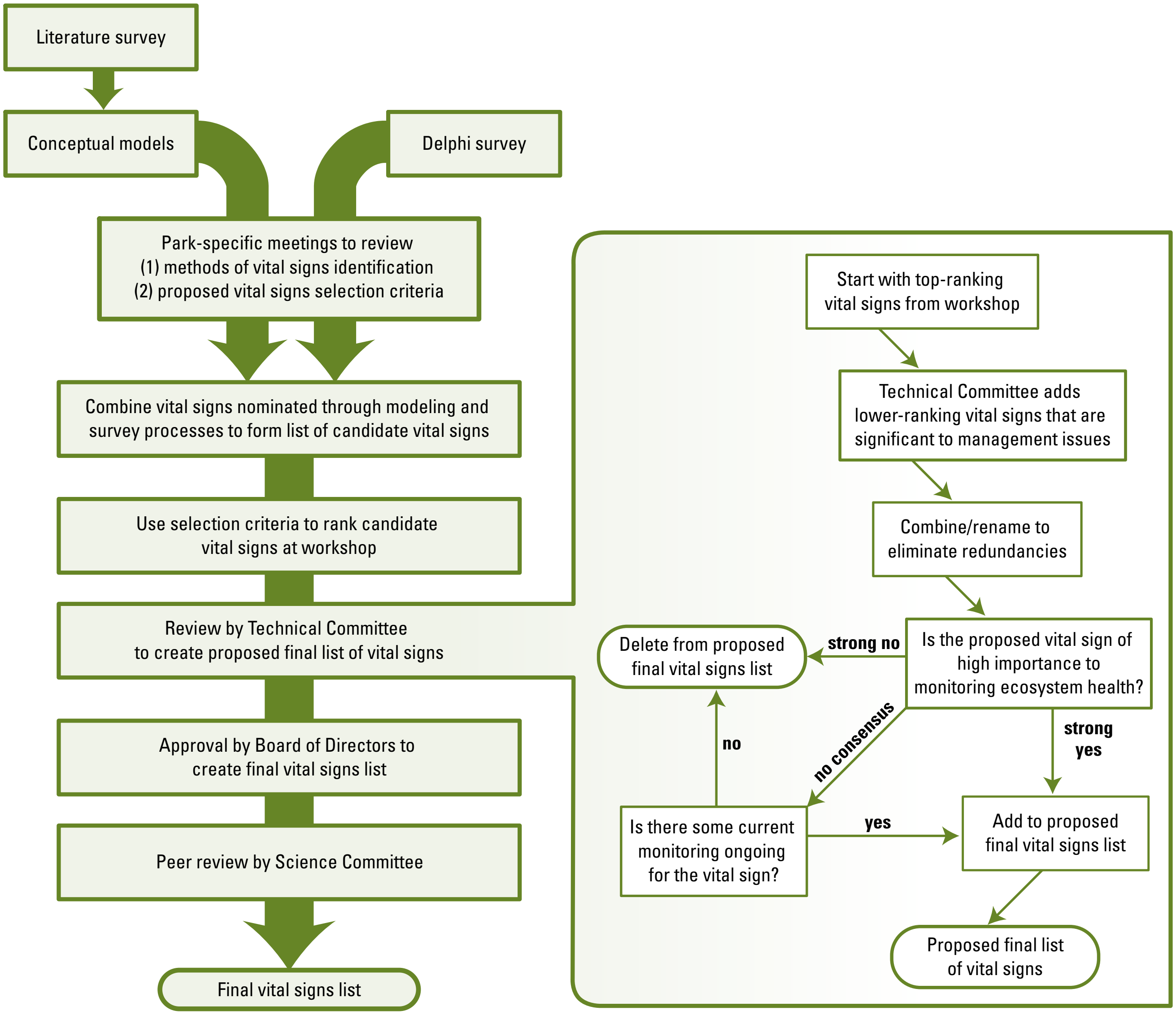


FIGURE 3.1 Vital signs selection process.

sions were complete, GRYN staff entered the responses into a database and presented the ranked list of potential indicators to workshop participants the following day for review and comments. Please consult Figure 3.1 for a diagram of the vital sign selection process. A report detailing the results of the workshop, along with the ranked list of vital signs and a list of participants, can be found in Appendix V.

The vital signs workshop provided an excellent venue for incorporating expert opinion and knowledge into the GRYN planning and decision process. This was the only workshop, except the park meetings, held to identify and prioritize candidate vital signs. Participants were enthusiastic and answered all the criteria for every vital sign and the resulting scores were instrumental in building the final vital signs selected by the GRYN.

TECHNICAL COMMITTEE VITAL SIGNS SELECTION MEETING

With a ranked list of potential indicators in hand, GRYN staff met with Technical Committee (TC) members to develop the final list of vital signs to be monitored in the network. GRYN staff believed that the park-specific management knowledge the TC members brought to the network was an extremely important component in the development of a list of vital signs. This involvement was also important due to concerns expressed by workshop participants that they could not address the management relevance of many potential vital signs.

To begin the process, the TC was provided with the ranked list of potential vital signs from the workshop. TC members were then told

TABLE 3.2 List of vital signs for the Greater Yellowstone Network of parks.

Level 1	Level 2	Vital Sign	BICA	GRTE	YELL
Air and Climate	Air Quality	Atmospheric deposition	✧	✧	•
		Oversnow emissions	–	✧	•
		Visibility	–	✧	•
	Weather	**Climate**	✚	✚	✚
Geology and Soils	Geomorphology	Glaciers	–	✧	–
		Stream sediment transport	✧	✧	✧
	Subsurface Geologic Processes	Geothermal features	–	✧	•
		Geothermal water chemistry	–	✧	•
		Seismic activity	✧	•	•
	Soil Quality	**Soil structure and stability**	✚	✧	✧
		Soil biota	✧	✧	✧
Water	Hydrology	Ground water quantity	✧	✧	✧
		Arid seeps and springs	✚	–	–
		Reservoir and lake elevation	•	•	•
		Streamflow	✚	✚	✚
	Water Quality	Biogeochemical flux	✧	✧	✧
		Water chemistry	✚	✚	✚
		Ground water quality	✧	•	•
		E. coli	•	✧	✧
		Algae	✧	✧	✧
		Aquatic invertebrate assemblages	✚	✚	✚
		Water temperature	✧	•	•
Biological Integrity	Invasive Species	**Invasive plants**	✚	✚	✚
		Exotic aquatic assemblages	✚	✚	✚
	Infestations and Disease	Forest insects and disease	✧	•	•
		Whitebark pine	–	✚	✚
		Vertebrate disease	✧	•	•
	Focal Species or Communities	Aspen	–	✧	•
		Riparian/riverine	✧	✧	•
		Shrub-steppe	✧	✧	✧
		Insects	✧	✧	✧
		Beaver	✧	✧	•
		Meso-carnivores	•	•	•
		Amphibians	✚	✚	✚
		Landbirds	✚	✚	✚
		Native aquatic assemblages	•	•	•
		Alpine	–	✧	✧
		Cushion plants	✧	✧	–
		Ungulates	•	•	•
	At-risk Biota	Birds of concern	•	•	•
		Large carnivores	✧	•	•

Level 1	Level 2	Vital Sign	BICA	GRTE	YELL
Human use	Visitor and Recreation Use	Backcountry day use	–	•	✧
		Backcountry overnight use	–	•	•
		Visitor use	•	•	•
Ecosystem Pattern and Processes	Fire	Fire	•	•	•
	Land Use and Cover	**Land use**	✚	✚	✚
		Land cover	•	•	•
	Soundscape	Soundscapes	✧	•	•

✚ This symbol shows vital signs that the GRYN is working to develop monitoring plans and protocols (also noted with green shading)
● This symbol shows vital signs that are monitored, to some degree, by a network park or another federal or state agency
✧ This symbol shows vital signs with no known current or planned monitoring
– This symbol indicates that the vital sign does not apply to the park

to consider those vital signs that ranked 0.9 (out of 1.0) or higher as a possible list of vital signs to monitor. This served as a starting point for discussion and highlighted those indicators that should be added or deleted. The TC members then proceeded to add vital signs that had scored below 0.9, given their belief in the importance of the vital sign to monitoring long-term ecosystem health and/or to management policies. This step allowed for the addition of candidate vital signs that may have ranked lower during the workshop due to lack of information or knowledge on their management relevance. For instance, E. coli was added to the vital sign list because the Shoshone River (in Bighorn Canyon) is listed as 303(d), impaired for contact recreation, by the Wyoming Department of Environmental Quality (WYDEQ 2004) because levels of fecal coliform exceed state standards.

The next step in selecting vital signs was to combine or rename those vital signs that had similar meanings, as many proposed candidate vital signs nominated by the Delphi process and the conceptual models had similar meanings but were written in slightly different vernacular, depending upon the background and expertise of the nominator. An important outcome of this exercise was the nomination of invasive plants as a vital sign. Prior to this, invasive plants were scattered throughout different habitat-specific vital signs (e.g. mixed conifer plant community composition and exotic species). Following this process, the TC members addressed each vital sign individually, considering the importance of the vital sign to monitoring ecosystem health and/or its management relevance.

Those vital signs that met with strong approval were added to the prioritized list; similarly, those that had strong disapproval were dropped. For vital signs in which a consensus could not be reached, the TC members selected those vital signs that had ongoing monitoring programs, with the thought that the information derived from these programs would add value to the overall program. Thus, the GRYN selected several dozen vital signs important for monitoring ecosystem health.

The TC then selected a subset of vital signs that would be monitored primarily using I&M funds. This was accomplished by giving each TC participant an opportunity to nominate what they believed was an important vital sign for the I&M program to monitor. This selection of vital signs was based on one or more of the following factors: 1) the information gained from the monitoring program would aid in making management decisions; 2) no standardized monitoring was taking place, thus leaving gaps in monitoring information, 3) the information gained from the monitoring program would help explain changes in ecosystem structure and function; and 4) opportunities exist to augment network funds through partnerships and agreements. Please consult Figure 3.1 for a diagram of the vital sign selection process.

Of the twelve vital signs selected for initial planning and implementation, some are currently being funded from other sources but will benefit from new funds provided through the I&M program. Two of these--streamflow and climate—are currently monitored by other agencies and are, therefore, of minimal additional cost to the I&M program, although these long-term programs could benefit from I&M support. Similarly, several of the metrics of the land use vital sign are gathered by county governments and the cost of compiling this data is relatively minimal. Aridland seeps and springs, in addition to soil function and stability, are specific to Bighorn Canyon, where there is currently little repeat, standardized monitoring taking place. These vital signs therefore represent new additions to monitoring in the ecosystem. The amphibian, landbird and whitebark pine vital signs provide important information on species and communities of concern and facilitate partnerships with the USGS Amphibian Research and Monitoring Initiative (ARMI) program, the Interagency Grizzly Bear Study Team (IGBST) and the Greater Yellowstone Coordinating Committee (GYCC), each of which may help augment monitoring costs for these vital signs. Monitoring of invasive plants, including early detection monitoring, will help warn park managers interested in treating populations before they become a significant resource threat. Additionally, the initial subset of vital signs include a suite of water quality indicators (water chemistry, aquatic invertebrate assemblages and exotic aquatic assemblages) that build a water quality program at Bighorn Canyon and integrate with ongoing monitoring at Yellowstone and Grand Teton.

A complete list of vital signs can be found in Table 3.2. Nearly all selected vital signs can be directly tied to one or more conceptual models; the majority of these also were directly nominated as vital signs through the modeling exercises. Figure 2.1 and Table 2.2 in Chapter 2 illustrate an aquatic ecosystem conceptual model with several candidate vital signs that were subsequently cross-walked with the Delphi-nominated candidate vital signs, ranked at the vital signs workshop and later selected by the Technical Committee.

None of the vital signs under the "air and climate" section of the framework were directly nominated by the modeling process because there were no models that directly addressed atmospheric concerns. This weakened the ability of the models to identify indicators from this area. Thus, although there were a number of vital signs whose origins cannot be directly tied to the conceptual models, it was generally due to an oversight in the creation of the model categories, rather than on the modeling process itself. Conversely, many of the potential vital signs in other framework categories were nominated through both the Delphi survey and conceptual modeling processes.

APPROVAL AND PEER REVIEW

Following selection of the vital signs, the Board of Directors approved the Technical Committee members' recommendations with the understanding that available funding through the Natural Resource Challenge was likely insufficient to monitor all 12 vital signs and, therefore, some deletions or reductions in monitoring objectives are to be expected. During the protocol development phase, costs can be more accurately estimated and tradeoffs can be assessed because the monitoring objectives are more specific and the sampling design has been considered.

Peer review of the Phase III Vital Signs Monitoring Plan took place in early 2005. Peer reviewers included members of the NPS National Water and Air Resource Divisions, Regional and Washington office I&M staff and an academic reviewer. Following the peer review, the GRYN Technical Committee provided input and direction on vital sign budget priorities.

RELATIONSHIP BETWEEN THE NETWORK AND PARK-BASED MONITORING ACTIVITIES

It is impossible for any monitoring program on a limited budget to develop a complete picture of ecosystem health with its staff and funding alone; thus, many of the network's subset of 12 vital signs were chosen to "fill the gaps" in current monitoring in the parks and allow time and money to be spent on issues that had high management relevance and would create a more complete picture of ecosystem health when synthesized with ongoing monitoring of other vital signs.

It is essential that the network integrate with ongoing park monitoring programs to maximize the amount of information available to make informed management decisions. To successfully synthesize and report on the state of the parks' ecosystems, the network will work with the parks to update and revise existing protocols, as well as provide direct assistance with data management. The network will collaborate with park staff to develop mutually accepted minimum requirements for existing and future protocols for monitoring in the parks. This process will allow for shared involvement in the construction of protocols for monitoring that is funded mainly by the parks, instead of the I&M program, and will lead to consistency among projects. While the amount of change to the protocols necessitated by these guidelines will vary, the network will attempt to provide technical resources when possible to facilitate this process.

In addition to updating and revising protocols, the network will work with park staff to create models for database and information management, with the goal of increasing the usefulness of collected data. This process will involve building aquatic and terrestrial database models through a user requirements and systems analysis for aquatic and terrestrial information management. The purpose of this exercise is to outline the information needs of both the park and monitoring program before designing the database model. The network will also relay information to numerous end-users by using a Web-based interface.

4. SAMPLING DESIGN

Sampling design is one of the major means by which the GRYN ensures scientific reliability and defensibility of our program. However, the details of the individual sampling designs are beyond the scope of this chapter, and are provided within individual monitoring protocols. Rather, this chapter will identify the major themes and concepts behind our sampling designs that have guided our choices for particular vital signs or protocols.

THE PURPOSE OF A SAMPLING DESIGN

The NPS I&M Program provides information on the status and trends of our natural resources that is essential for the National Park Service to uphold its mission of preserving the national parks unimpaired for the enjoyment of future generations. The information used to determine the state of park resources must be made using reliable scientific information. Thus, the primary purpose of a sampling design is to ensure that the data collected are representative of the target populations and sufficient to draw defensible conclusions about the resources of interest (EPA 2002).

BASIC DESIGN CONSIDERATIONS

General Sampling

1. PROBABILITY-BASED SAMPLING

Because a sample is used to draw valid conclusions about some larger population, it is imperative that the sample is representative of the population of interest (Lohr 1999). Three broad approaches to obtaining samples that are representative of the population include: probability-based sampling; judgment sampling; and convenience sampling. The GRYN considers probability sampling to be the most defensible because it applies sampling theory and some form of randomization in the selection of sample units (EPA 2002). This randomization ensures a reduction in potential bias from judgment or convenience sampling, thus increasing the validity of extending inference from a sample to the population of interest.

Common alternatives to probability-based sampling are judgment and convenience sampling. Judgment sampling employs expert knowledge in the selection of sampling units. Studies have shown that selection bias is common when judgment sampling is used (Edwards 1998, Stoddard et al. 1998, Olsen et al. 1999), although there remains some disagreement among ecologists and statisticians about the validity of using judgment sampling in some contexts (e.g., sentinel sites) (Edward 1998). Convenience sampling is generally based on factors such as ease of access and, thus, there is no assurance that samples collected in this manner will be representative of the target population. While convenience sampling is not considered a valid approach for the GRYN monitoring program, factors that improve efficiency of sampling (e.g., access) will be considered within the context of a probability-based sampling through stratification (see below).

2. SAMPLING FRAME, SAMPLING UNITS

There are subtle differences in how some references define terms associated with sampling. There are probably even greater differences in how these terms are interpreted and applied on different projects. Figure 4.1 illustrates the use of these terms by the GRYN in the context of this report.

Target Population— The target population is a set of all of the units or elements for which inference is intended and should directly reflect the monitoring objectives.

Sampling Frame— The sample frame or sampling frame is a complete collection of the possible sample units (see below) from which the sample can be drawn. There are two types of sample frames commonly recognized: a list frame and an area frame. A list frame is a list of the potential sampling units along with their descriptive attributes. An area frame is typically designated by geographical boundaries within which the sampling

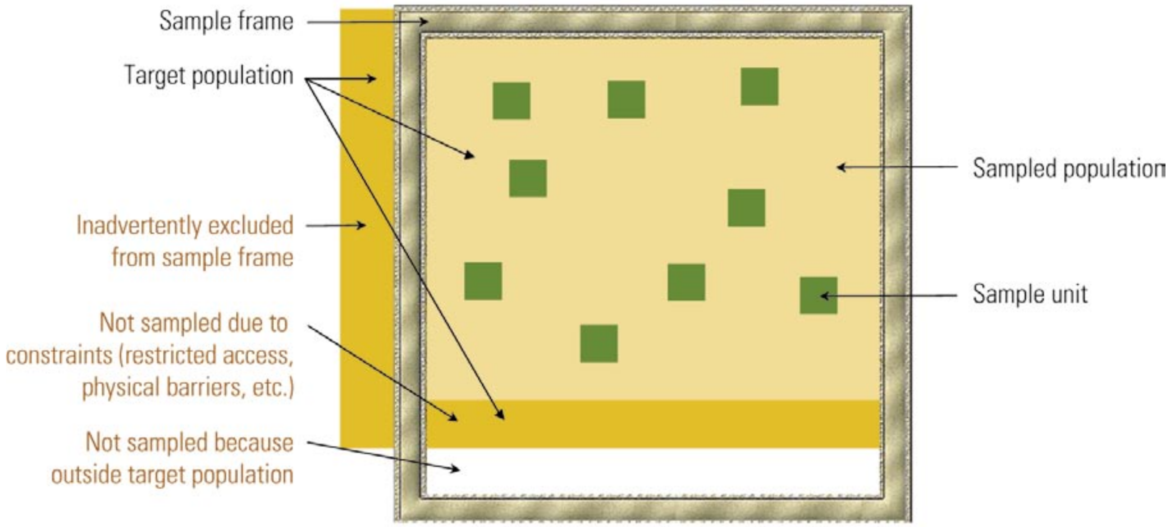


FIGURE 4.1 Conceptual illustration of terms used to describe different units associated with entities being sampled (adapted from A.R. Olson [unpublished presentation] and Lohr 1999).

units are defined as subareas. Some designs (e.g., dual-frame designs, described below) use both frame types.

Sampled Population— The sampled population represents the actual population from which a given sample is drawn. As discussed below, ideally the sampled population would coincide with the target population and the sample frame, but a perfect overlap of these is rarely possible in environmental settings.

Sample Units— The sample units include all of the individual units contained within the frame that are actually sampled. Frequently, this concept appears to be more easily understood than it actually is under certain circumstances. For example, if the objective is to estimate the size of fish in a pond, then individual fish are the sample units. If, however, the objective is to estimate the proportion of native to exotic fish in a collection of ponds, then the sample units would be the ponds.

Elements— In some cases measurements may be taken on individual items within a sample unit. Thus, an element, sometimes referred to as an observational unit, consists of any item for which measurement is made or information is recorded (Schaeffer et al. 1990, Lohr 1999). These are typically individual plants or animals within a sample unit such as a transect, plot or grid cell.

Note: It is important to distinguish the sampling units from elements within a sampling unit because it is not uncommon for the number of elements to be incorrectly treated as if they represented independent replicate samples. This is a form of "pseudo replication" (Hurlbert 1984) and is a common source of statistical error in testing environmental effects.

Ideally, the sampled population and the sample frame would be equivalent to the target population for which inference is to be drawn. Unfortunately, numerous constraints exist that may preclude this from occurring (Figure 4.1), and, therefore, in some situations units within the sample frame and target population are not included in the sampled population.

GRYN Example

In the GRYN, constraints may result from safety concerns (e.g., bear closures), physical barriers or access limitations. It is also possible that part of the sample frame may inadvertently include units that are not within our target population. For example, our sample frame for monitoring whitebark pine is based on a map of whitebark pine generated from satellite imagery. If sites were erroneously classified as whitebark pine that actually did not contain whitebark pine trees, these would be included in our initial sample frame, but not sampled. It should be noted that when the sampled population does not coincide with the target population, that valid inference is limited to the sampled population.

Spatial Allocation of Samples

There are a multitude of potential sampling designs for selecting a sample over space, although most are variations on a few basic themes. Following is a description of the major design themes and the specific variations on these themes will be discussed within individual monitoring protocols (see also Figure 4.2).

Complete Census— One special case of spatial sampling is a complete census, in which measurement is taken on all of the sample units within the population. As such, there is no sampling error that results from taking a sample (because all units are

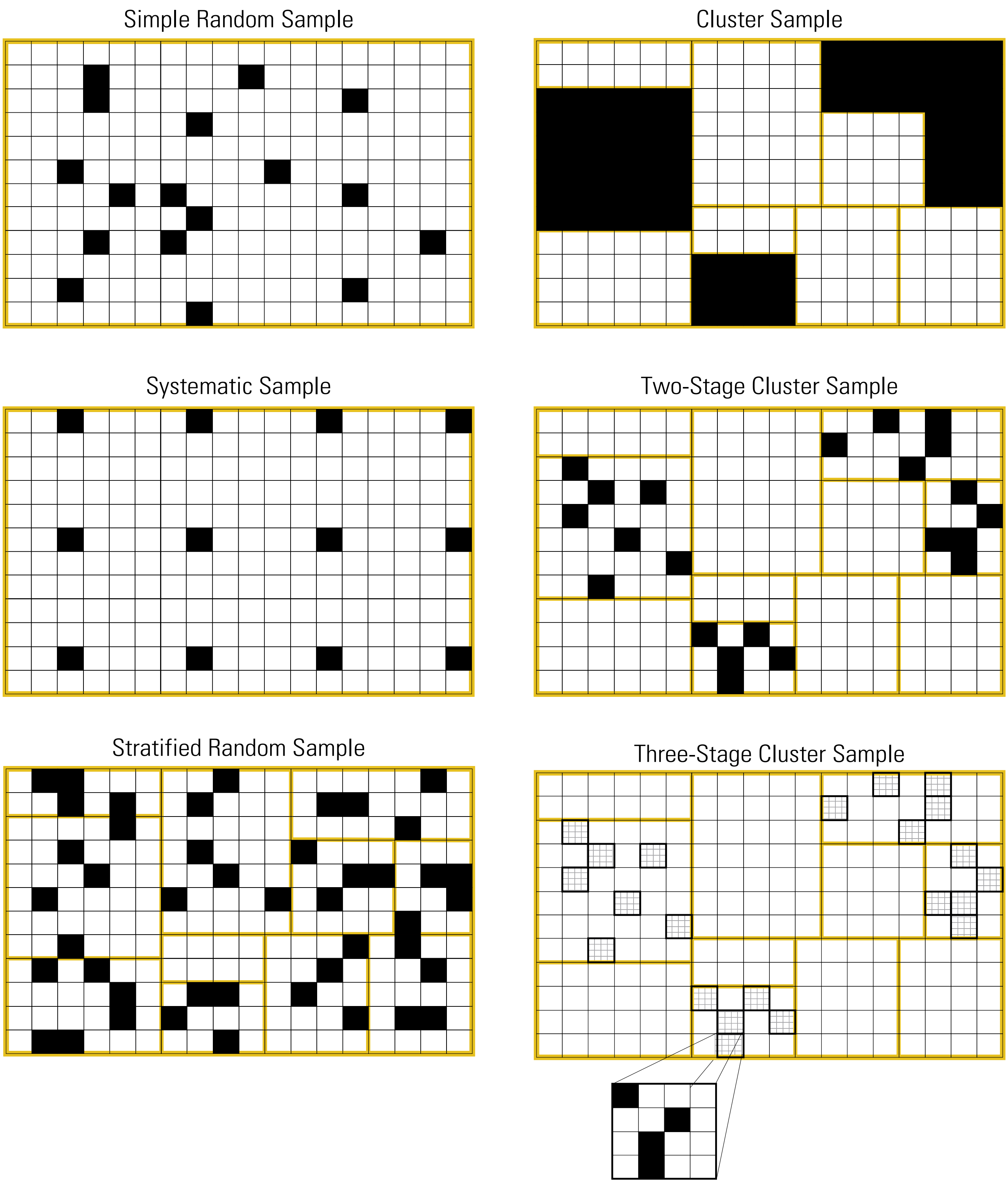


FIGURE 4.2 Conceptual illustration of major spatial designs (adapted from Thompson [2002] and Lohr [1999]).

sampled) which is then applied to estimates for the entire population. However, a complete census may include measurement error associated with the measurement of each sample unit.

Simple Random Sample— In simple random sampling, (n) units are selected from a population of size (N) via a random process, such that every sample unit has the same probability of being included in the sample.

Systematic Sample— A sampling method in which one sample unit is typically selected at random and subsequent units are selected according to a systematic pattern. A common form of systematic sampling is randomly selecting one unit from the first k units in the sampling frame and every k^{th} unit thereafter (Mendenhall et al. 1971).

Stratified Random Sample— In a stratified random sample the sampling frame is divided into mutually exclusive and exhaustive subpopulations called strata, from which n samples are randomly selected from each strata (Levy and Lemeshow 1999). There are several reasons for using stratified sampling design, including increased precision, increased efficiency and greater information about a particular subpopulation(s) (Cochran 1977, Lohr 1999). For increased precision, strata are typically selected such that the variation among units from the same strata is less than the variation among units from different strata (Thompson 2002). Increased efficiency may be based on such things as ease of access or administrative boundaries (Cochran 1977).

TABLE 4.1 Advantages and disadvantages of major spatial design themes.

Sampling Design	Major Advantages	Major Disadvantages
Complete Census	• No sampling error	• Seldom logistically or economically feasible • Usually requires greater effort than is needed
Simple Random Sample	• Simple and straightforward analysis • Doesn't require prior knowledge regarding sampling units.	• Can result in poor spatial distribution, particularly with small samples. • Can be inefficient for rare or highly clumped resources
Systematic Sample	• Good spatial coverage • Simple and straightforward • Requires little or no prior knowledge regarding sampling units. • Facilitates co-location of samples	• May not be as efficient as alternative designs if prior information about units is available. • If properties of interest are aligned or there are periodicities with grid, then biased estimates are possible. • A single systematic sample may not produce valid estimates of the standard error under some circumstances
Stratified Random Sample	• Can reduce costs and sample sizes • Can increase precision	• Requires prior knowledge regarding sampling units. • May reduce precision if criteria for strata assignment are uncorrelated.
Cluster Sample	• Can be cost efficient (i.e., it is often cheaper to sample all of the elements within a unit than to sample an equal number of elements at random) • Can be feasible to construct a sampling frame, even when lists are difficult to obtain	• All of the elements within a cluster must be sampled • Appropriate analyses are less straightforward. • Lower precision than simple random or stratified sampling
Two-stage Cluster Sample	• Can be more efficient than single stage when clusters are too large or list units are homogeneous within clusters.	• Analyses more complex
Generalized Random-Tessellation Stratified (GRTS)	• Samples are spatially balanced • Nested subsamples easily accomodated • Good variance properties	• The underlying sampling process is less intuitive to understand than alternative sampling schemes. • Software to use GRTS has only recently been made available to the public

> *GRYN Example*
>
> In the GRYN, many resources are very difficult to access, which can greatly increase the cost and effort required for sampling. Stratification by access can be accomplished by treating areas within a different distance class from access points as different strata (e.g., close, moderate and far from access). Sites that are difficult to access can be sampled at lower frequencies but still be included within the sample. This enables a more efficient sampling effort and reduced cost without sacrificing the original scope of inference.

Panel— Refers to the group of sample units that are sampled during the same sample occasion (time block). For example, if sampling were conducted annually, then all of the units sampled in a given year would comprise the panel for that year. If all of the sample units were sampled every year, then there would only be a single panel for the design (Figure 4.3). During any given sampling occasion, either all of the sample units comprising a panel are sampled or none are sampled.

Revisit design— Refers to the plan or strategy for re-sampling panels over time.

Cluster Sample— Cluster sampling is an approach whereby selection is made of groups or clusters of units, called primary units, within which all of the secondary units are sampled (Levy and Lemeshow 1999). This approach is often used when it is difficult or impossible to enumerate all of the individual units within a sampling frame. Thus, enumeration of units is only necessary for the selected clusters.

Multi-stage Cluster Sample— Multi-stage cluster sampling is an extension of cluster sampling where a subset of the units within the primary units are sampled. For a two-stage cluster design, a sample of secondary units is selected, typically by a random process, from within the primary units. For a three-stage design, a sample of units is taken from the secondary units, and so on.

Generalized Random-Tessellation Stratified (GRTS)— The GRTS design uses a hierarchical randomization process to achieve spatial balance across regions and resources. GRTS samples also easily accommodate nested designs and allow units to be added efficiently after an initial sample has been drawn. Because GRTS samples achieve spatial balance without being evenly spaced, problems associated with correlations between systematic sampling and environmental gradients are reduced.

Temporal Allocation of Samples

Following is a list of defined terms that pertain to temporal allocation of samples (terms have been adapted from McDonald 2003).

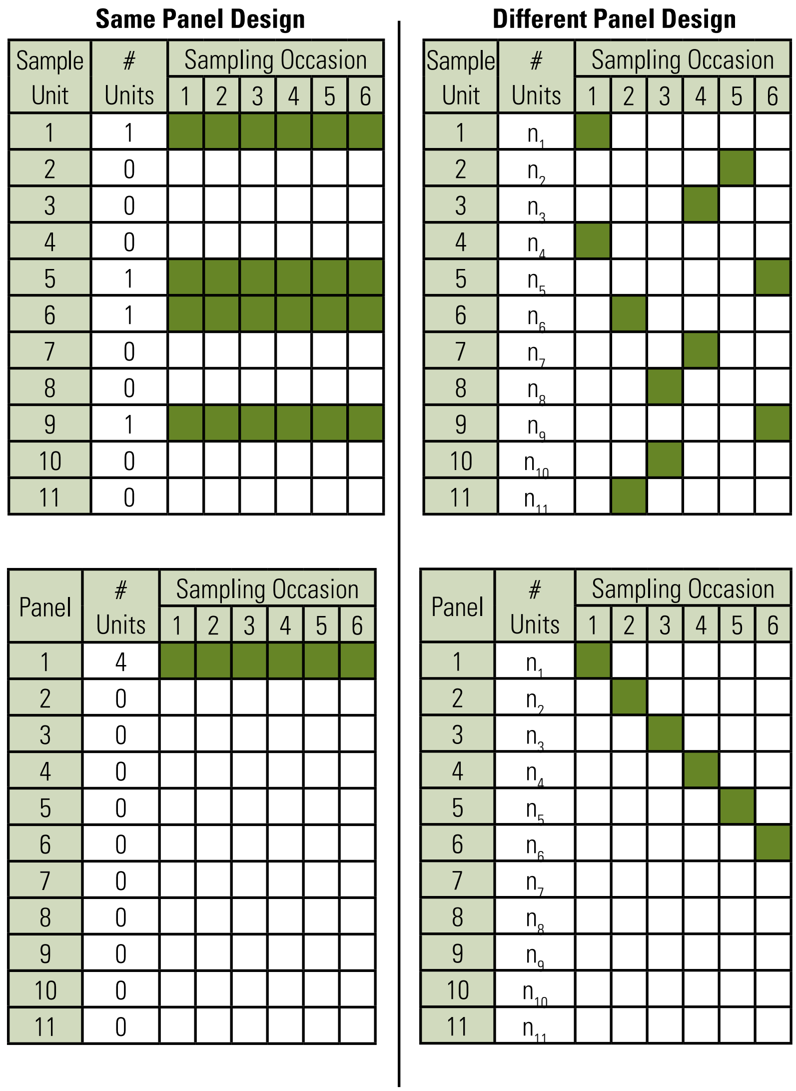


FIGURE 4.3 Graphical illustration of the relationship between spatial and temporal sampling. The Y axis of the upper diagrams represent revisit designs based on sample units, which can become quite cluttered when illustrating complex revisit designs. The lower diagrams represent revisit design-based panels, which are more efficient for illustration, but mask the spatial representation by condensing all of the sample units sampled at a given time into a single panel. To see this relationship, the number of sample units are shown for both graph types.

I. Major Temporal (Revisit) Design Themes

As with spatial designs, numerous temporal sampling (revisit) designs exist, with most being variations on a few basic themes. Following is a description of the major design themes for resampling over time that form the basis of our designs. These have also been illustrated in Figure 4.4. Specific variations on these themes for a given vital sign will be discussed within individual monitoring protocols.

Complete Revisit Design— Under this design, each sampling unit is revisited on each occasion (McDonald 2003). If the primary objective is to detect a linear trend over time, then this design is probably the most powerful (see discussion of power below) (Urquhart and Kincaid 1999). A primary disadvantage of this approach is that it is also probably the poorest for estimating the overall status, because the same sites are repeatedly visited rather than increasing the spatial representation by sampling sites at different locations. Other pieces of the design that must be taken into consideration include: whether or not repeatedly visiting a site can alter its response (e.g., habituation of animals, trampling, etc.); and replacement of units that are no longer usable (e.g., animals that have died, habitats that have changed types, etc.).

Never Revisit Design— Under this design, a different sampling unit is visited on a given sampling occasion and never visited again (McDonald 2003). Such designs are commonly used during inventories, where the primary objective is to estimate status. For that

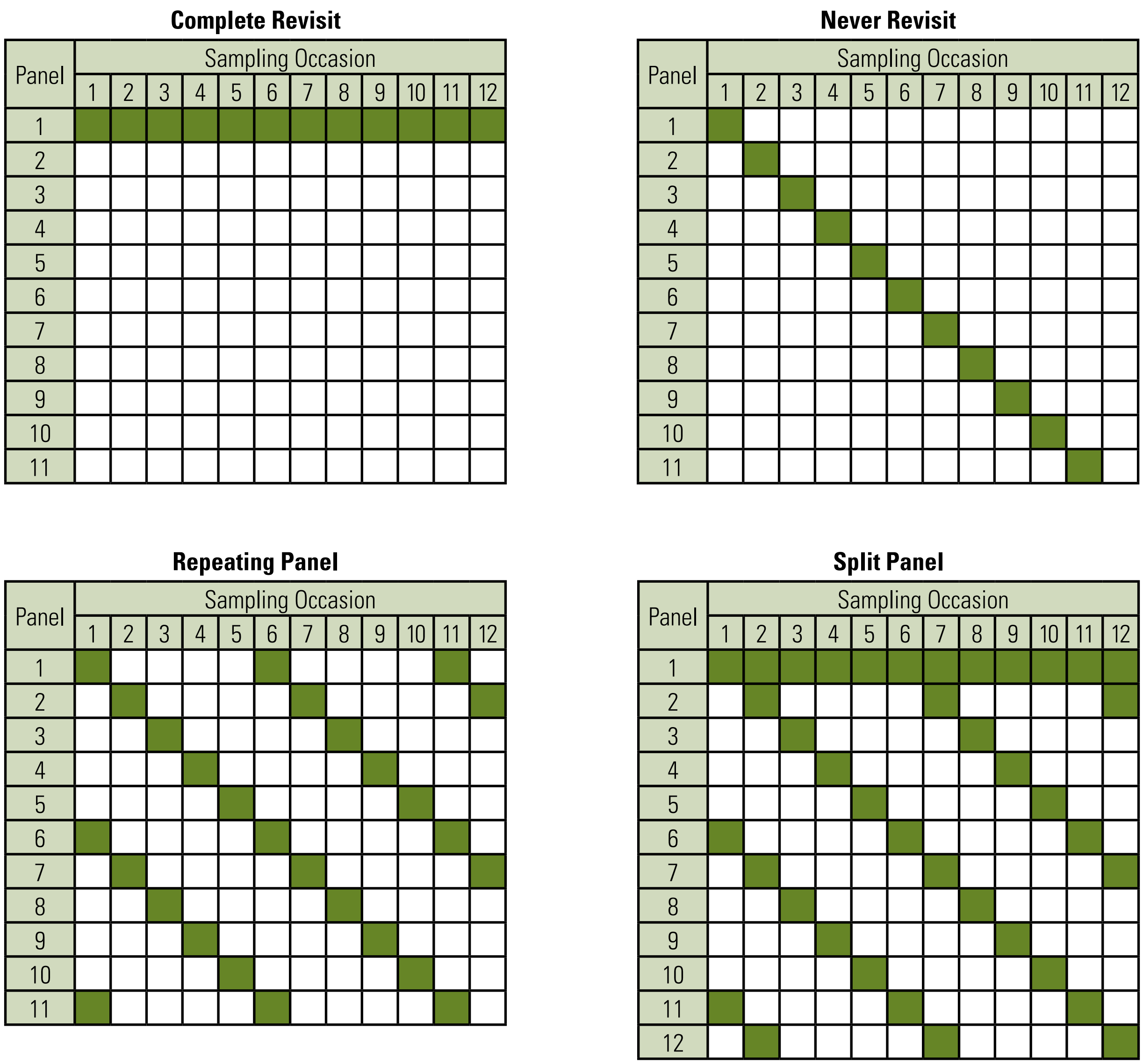


FIGURE 4.4 Graphical representation of major revisit designs.

purpose, this design is efficient because it includes the greatest number of sites (Urquhart and Kincaid 1999). However, for monitoring change over time, it will likely be of limited value.

Repeating Panel Designs— These are designs in which a given survey panel is measured repeatedly over time. For the general case, the number of consecutive sampling occasions that a panel can be surveyed and the interval between consecutive samples can be varied and will depend on the specific monitoring objectives and time scales appropriate to meet those objectives.

Split Panel Designs— This is a design that partitions (splits) the panels into two or more revisit designs. This type of design enables different types of change to be detected (e.g., individual change and gross change). Such an approach also constitutes a compromise between emphasis on spatial and temporal variation. Typically, split panels entail an always visit design in combination with some other revisit design (e.g., repeating panel). The "always visit" design is the strongest for detecting temporal variation, but is weak for detecting spatial variation since the same panels are visited on each occasion. Combining this with an alternative panel can strengthen detection of spatial variation.

Sample Size Considerations

1. Magnitude of Change

Populations in the real world are dynamic, and change over time is to be expected. Even in the absence of some anthropogenic stressor it would be extremely unlikely for a given population to remain constant over time. Thus, to design a monitoring program whose primary purpose is to identify whether there has been a change over time can be rather trivial. What is more important is whether or not there has been a meaningful change (to the public and/or park managers), what has caused that change, and whether or not the resource is expected to change further.

To understand what constitutes meaningful change, it is essential to realize the difference between statistical significance and biological significance. Statistical significance relies on probability and is influenced by sample size. Thus, even minor changes (from a biological perspective) will be statistically significant if the sample size is large enough. Regardless of statistical significance, we would consider something biologically significant if it facilitates a major shift in the ecosystem structure or function such as a loss of one or more species, the addition of non-native species, changes in ecosystem processes, etc.

	True	False
Reject H_o	Type I Error (α)	No Error
Do Not Reject H_o	No Error	Type II Error (β)

FIGURE 4.5 Possible outcomes for null hypothesis test of no effect. Type I error occurs when the test indicates an effect (i.e., null hypothesis rejected) when there was no effect. Similarly, a Type II error occurs when an effect is not detected (failure to reject the null hypothesis) when there really was one.

From a monitoring standpoint, we are concerned with both statistical and biological significance in the sense that we want to know whether or not we are likely to detect a change statistically that we would consider biologically meaningful. To answer this, we need information about what level of statistical significance to we want to attain (i.e., our Type I error rate or α) (see below), what level of change do we consider biologically meaningful that we hope to detect, and how variable is the resource that we are trying to estimate. With this information we can better determine the likelihood of detecting a change (statistically) that we would consider biologically meaningful.

2. Type I and Type II Error, and Statistical Power

In statistical terms, Type I and Type II error refer to erroneously rejecting (Type I error) or failing to reject (Type II error) a null hypothesis (Figure 4.5). With respect to monitoring, a Type I error indicates that there is a trend (the "null" hypothesis is that there is no trend) when none exists, while a type II error occurs when a trend is undetected. The "P value" (or α level) is the probability of making a type I error, while β is a type II error rate. Statistical power refers to the probability of not making a type II error (or $1 - \beta$). It is important to note that statistical power depends on what level of Type I error is acceptable, what level of change (i.e., departure from zero trend) you are trying to detect, and the relationship between variation of the resource you are measuring and the sample size used to detect the trend. Estimating power enables us to determine the sample size needed in order to detect a trend of a given magnitude with reasonable confidence.

Sampling Rare Resources or Resources of Special Interest

Sampling rare resources is often problematic because most major design frameworks are inefficient for sampling rare resources. Increasing overall sample sizes to increase the likelihood that rare resources are included in a given sample can be effective but quite costly. Targeting specific resources in a list sampling frame can certainly improve the efficiency, but will greatly limit the scope of inference to those specific units that were targeted (i.e., the results cannot be generalized to the rare resource as a whole). Following are some design considerations that are considered for those vital signs that represent rare resources.

1. STRATIFIED SAMPLING WITH DISPROPORTIONAL ALLOCATION

One approach to ensuring that rare resource are adequately sampled is to partition the sample frame into strata such that one or more strata includes a high probability of containing the rare resource. This stratum can then be intentionally sampled with sufficient intensity so as to increase the likelihood of encountering the rare resource. This enables a more adequate characterization of the rare resource, but assumes prior knowledge about the distribution of the rare resource.

2. DUAL FRAME DESIGNS

A dual frame design is one that incorporates more than one sample frame (Groves and Lepkowski 1985). A common approach to dual frame sampling is to combine a list frame and an area frame. The list frame contains known information about the targeted resources, such as known nest sites, specific geothermal features, etc. Sampling these known units can provide valuable information about changes in those specific resources over time, but will not allow inferences to be generalized to the rare resource as a whole. Yet by adding in an area frame, a probabilistic design (that would be inefficient on its own) is then combined with the list frame allowing some inferences to be extended beyond the specific targeted resources (Haines and Pollock 1998).

GRYN Example

One of the specific monitoring objectives identified for the amphibian vital sign was to monitor changes in occupancy of boreal toad breeding sites. Boreal toads are quite rare in the GRYN, and existing data indicate that a probabilistic sample to monitor potential changes would be insufficient to estimate changes in the primary parameter of interest (proportion of catchments occupied). Given that there are a limited number of known breeding sites for this species, meaningful estimates of change over time necessitate targeting known sites. While this approach should provide reasonable estimates of the change in occupancy of these sites over time, a disadvantage is that the inference would be limited to these sites. However, for other objectives, a cluster sampling design of an area sampling frame will be used for some of the other amphibian objectives. Including both frames in the design will allow for inference about occupancy of toads at sites that are currently unknown and, thus, not part of our list frame.

3. ADAPTIVE SAMPLING

In most traditional sampling designs, the selection of sampling units is not influenced by what is observed during the sampling. In contrast, adaptive sampling entails the selection of units that may be influenced by the value or type of unit selected (Thompson and Seber 1996). Typically, a decision rule is established a priori that triggers a change in the sampling as it occurs. (Figure 4.6). Thus, adaptive sampling can be an effective design for rare resources, particularly if prior information about the distribution of that resource is poorly known.

Adaptive sampling can be incorporated into a wide variety of traditional designs (e.g., simple random samples, systematic samples or cluster samples). However, it can also introduce bias, which needs to be accounted for with estimators developed for adaptive designs (Thompson 2002). Although none of the vital signs currently have adaptive sampling included in their protocols, it remains a possible sampling design that could be used.

INTEGRATION

The Need for Integration

1. INTEGRATION ACROSS NETWORKS

The I&M Program was intended from the outset to focus on information needed by park managers for understanding and managing our network parks. However, it was also intended from the outset that some subset of the selected vital signs would provide information at scales larger then the GRYN (e.g., water quality). Thus, an additional design consideration has been whether or not there is a need, value or expectation for implementing designs that can be scaled up to levels beyond the GRYN.

GRYN Example

Water quality is an example intended from the outset to provide information for local park managers, while at the same time providing infor-

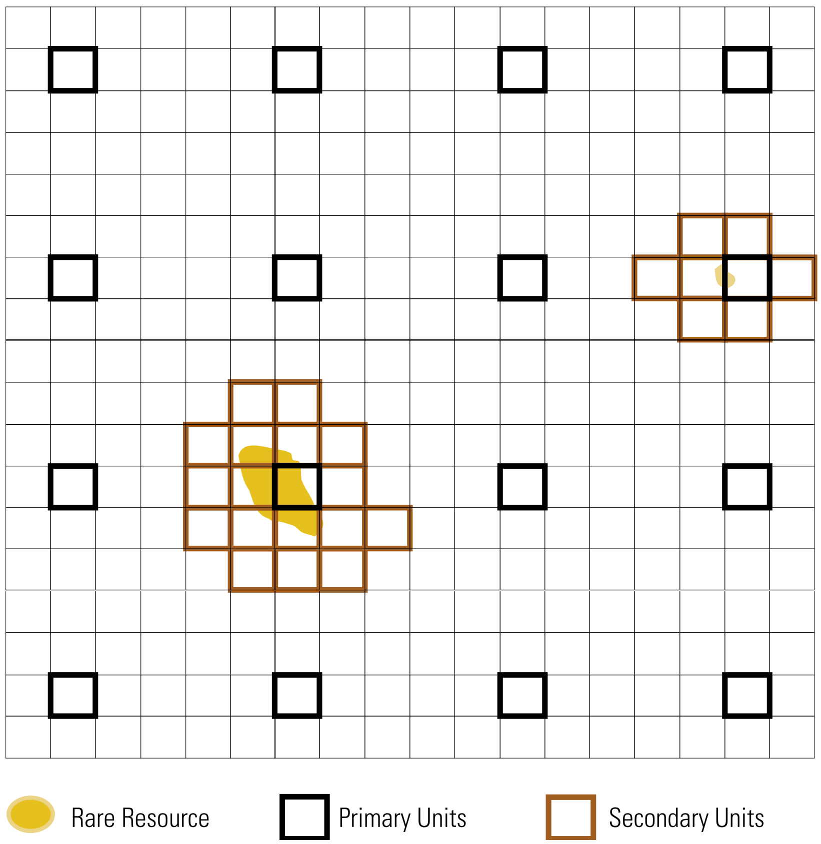


FIGURE 4.6 Conceptual illustration of adaptive sampling where the primary units are drawn from a systematic sample, and the secondary units are drawn when a rare resource is encountered, and continue until such time that the resource is no longer encountered.

mation on the quality of waters within national parks at larger scales (e.g., networks, regions and national). To facilitate this goal, the GRYN has entered into a partnership with the Rocky Mountain Network to develop jointly a sampling design that will enable interferences to be scaled up or down from local to more regional scales (see section below on "A Generalized Design for Aquatic Resources").

2. INTEGRATION ACROSS AGENCIES

Although the inventory and monitoring program is a National Park Service endeavor, many of the vital signs that we will monitor cross over jurisdictional boundaries, and concerns about these vital signs are often shared by other agencies. There can also be increased efficiency and broader application through cooperative efforts among agencies. Thus for vital signs that have a common interest among agencies and organization, we will attempt to coordinate, and where possible, collaborate, with other agencies for a more effective monitoring program.

GRYN Example

Concerns about whitebark pine have been shared by several agencies within the Greater Yellowstone Ecosystem (GYE) for several years. Several efforts to assess the status of white pine blister rust in whitebark pine communities have been conducted in the GYE, although efforts to monitor whitebark have generally been sporadic with little coordination among agencies. Consequently, the GRYN has joined forces with several organizations including the Forest Service (Forest Health Monitoring Program and six National Forests), the USGS (Northern Rocky Mountain Science Center), the Interagency Grizzly Bear Study Team (a cooperation among USGS, NPS, USFS, and the states of Wyoming, Idaho and Montana), and the Greater Yellowstone Coordinating Committee (a cooperation among NPS, USFS and USFWS). In this effort, we have formed a small working group that meets on a regular basis. This group is made up of representatives from the cooperating agencies. The group provides a forum for discussion and resolution of ideas ranging from agreement on the specific monitoring objectives to development of a cooperative design. The result will be to implement an interagency whitebark pine monitoring effort for the Greater Yellowstone Ecosystem.

3. INTEGRATION AMONG VITAL SIGNS

Vital signs are not environmentally and ecologically independent entities. Rather, they are often the products of complex interactions among other vital signs and/or other ecosystem components or attributes. Without some consideration of how our vital signs interact, the GRYN program has no added value apart from the sum of its parts. Thus, consideration is needed as to how the parts fit together as a whole. Some level of integration among vital signs is needed if we expect to (1) understand the dynamic responses to changes in drivers or stressors, (2) understand the interaction effects among vital signs, and (3) reduce the confounding effects of other vital signs in the interpretation of a given vital sign.

Considerations for Use of a Generalized Overall Design

One solution for achieving some level of integration is a generalized overall design (i.e., one used for several vital signs). A systematic design is probably the most reasonable for common use among vital signs. Using simple random sampling or cluster sampling will present the problem of which units to select. A reasonable unit (sample unit or cluster) for one vital sign may not be reasonable for another. In contrast, a systematic design would enable a distribution across space regardless of the units. Systematic designs are typically relatively simple and robust; they have reasonable precision; and they can be an effective way to ensure that areas are sampled in proportion to their size. Use of a common design among networks can enable scaling up or down from local to more regional inferences. Co-location of samples from different vital signs within a common design can enable increased ability for assessing the effects of drivers or stressors, as well as interaction effects (see below). However, adopting a generalized overall design is not without its limitations. Depending on how much overlap there is among vital signs in space and time, a generalized overall design may be inefficient compared to some alternative directed at sampling a particular resource. There are other considerations, such as compatibility with existing efforts or with partner organizations. A summary is presented below of the primary factors contributing to a decision about whether or not to incorporate a given vital sign of the GRYN within a generalized overall design, or whether an alternative approach would be warranted.

1. National vs. Local Objectives

Virtually any reference regarding environmental and ecological monitoring will emphasize the importance of understanding the objectives of monitoring when developing a sampling design (e.g., Hellawell 1991, Spellerberg 1991, Olsen et al. 1999, Noon 2003). The value of an overall systematic design is probably at its greatest in large-scale monitoring programs (e.g., Forest Inventory and Analysis, Forest Health Monitoring, Environmental Monitoring and Assessment Program, Global Observation Research Initiative in Alpine Environments, etc.) whose goals are heavily focused on being able to scale up inferences from local to more regional or global scales. The NPS I&M Program differs from these other large-scale monitoring programs by emphasizing the information needs of individual parks that are linked together into networks. While maintaining the ability to detect regional and national level trends is desirable, the first priority of the GRYN is to meet the local information needs of the parks.

2. The Role of History and Existing Efforts

Many of the vital signs selected by the GRYN have also been selected for monitoring as part of cooperative efforts with other organizations. Consequently, the GRYN must consider the advantages and disadvantages of being part of a cooperative or pre-existing sampling design, as opposed to fitting within a generalized GRYN design.

GRYN Example

The Amphibian Research and Monitoring Initiative (ARMI) began in 2000 as a national program (coordinated by the USGS), whose aim is to better understand the dynamics of amphibian population trends. ARMI is currently establishing a north/south transect along the Rocky Mountains that would include Glacier, Yellowstone, Grand Teton and Rocky Mountain National Parks, among other locations. Given that the ARMI design is based on watershed units, rather than a systematic grid, our options are to design our amphibian monitoring program to be consistent with the Rocky Mountain Transect of ARMI, or to deviate from this approach to be part of a more generalized design for the GRYN. Given that our objectives for amphibians are consistent with those of ARMI, we believe that our best option is to conform to the ongoing effort rather than to deviate from the design currently in place.

3. Efficiency of Sampling Rare Resources

Another reason that we may chose not to adopt a generalized systematic approach is efficiency for some vital signs. For example, rare resources can be poorly represented in systematic designs. Encountering rare resources can be accommodated to some extent by increasing the overall sample size to better ensure that rare resources are included. However, such a solution can be costly in terms of effort and money, and it doesn't ensure adequate sampling of rare resources. The problem of sampling rare resources in a simple random or systematic design can be offset by stratification, although this assumes both that sufficient information exists to enable effective stratification and that there are not other resources concurrently being sampled that would not be conducive to a particular stratification for the rare resource.

4. Feasibility and Need for Co-location of Samples

One consideration in the sampling design(s), regardless of whether or not a generalized design is used, is whether or not samples for different vital signs should be physically co-located. Co-location of samples can facilitate assessment of the response to drivers or stressors and interaction effects. Under some circumstances co-location can also aid in the interpretation of confounding effects and increase efficiency of sampling. However, co-location of samples is not a panacea for ecological insights, and the costs and benefits need to be considered. To decide whether or not samples warrant co-location the GRYN considers: (1) the specific objectives of the vital sign(s) being sampled, (2) the feasibility of co-locating samples, (3) the probability of expected increased insights, and (4) the compatibility of domains and scales (see below).

One tool used by the GRYN to assess possible co-location of vital signs is conceptual models that focus on associations among the vital signs. For example, the simple conceptual model of whitebark pine presented in Chapter 2 (Figure 2.2) reveals several potential linkages among GRYN vital signs. Forest insects and disease (e.g., mountain pine beetle and white pine blister rust) and fire may have important influences on whitebark pine. Similarly, large carnivores (i.e., grizzly bears) and landbirds (i.e., Clark's Nutcrackers) also have strong associations with whitebark pine. Grizzly bears feed extensively on whitebark pine seeds. Clark's Nutcrackers also feed extensively on whitebark pine seeds and also play a major role in seed dispersal of whitebark pine. Thus, the feasibility and benefits of co-locating samples of these other vital signs and whitebark pine should be considered.

Another tool used to assess whether or not sampling from different vital signs should be co-located within a generalized design is a table of the overlapping domains (Table 4.2). This table summarizes some of the factors influencing feasibility of co-locating samples, including (1) geographic extent [i.e., parks], (2) aquatic vs. terrestrial system (3) primary habitat type and (4) potential for major partners or collaborators that may require design constraints. From such a table it can be seen that there is considerable overlap in some vital signs across these domains. For example, several of the aquatic and water quality vital signs have substantial overlap across all of these domains. Such overlap would indicate high feasibility for co-locating samples within a generalized design. Other vital signs have little overlap with others in these domains. For example, in the context of the GRYN, soil structure and stability is primarily focused on biological crust soils in aridland habitats of BICA, which may reduce its feasibility for inclusion within a generalized design for the entire network.

GREATER YELLOWSTONE NETWORK DESIGNS

Based on the considerations described above, it was determined that a single overall design was not warranted for several GRYN vital signs, with the exception of aquatic resources (described below). Here we describe the general designs for those vital signs for which the development has reached the design stage. We have grouped these according to the major spatial design themes.

TABLE 4.2 Domains of each vital sign currently under development that are used to assess the feasibility of co-locating samples.

Vital Signs	Park			Aquatic vs Terrestrial Resource	Habitats	Major Collaboration with other organizations
	BICA	GRTE	YELL		Zone	
Climate	X	X	X	Terrestrial	Multiple	Ongoing
Soil structure and stability	X			Terrestrial	Aridland	
Arid seeps and springs	X			Aquatic	Wetlands	
Steamflow	X	X	X	Aquatic*	Perennial lakes/streams*	
Water chemistry	X	X	X	Aquatic*	Perennial lakes/streams*	
Aquatic invertebrate assemblages	X	X	X	Aquatic*	Perennial lakes/streams*	
Invasive plants	X	X	X	Terrestrial	Multiple	
Exotic aquatic assemblages	X	X	X	Aquatic*	Perennial lakes/streams*	
Whitebark pine		X	X	Terrestrial	Sub-Alpine	Ongoing
Amphibians	X	X	X	Aquatic	Wetlands	Ongoing
Landbirds	X	X	X	Terrestrial	Multiple	Ongoing
Land use	X	X	X	Terrestrial	Disturbed/Developed	

* Shared domain indicated in gold.

Complete Census

1. Land Use

The primary sampling units for this vital sign are counties (agricultural) and 1 m2 township/ range/section (TRS), for which information is recorded annually for each home located outside of city boundaries. In each case all of the sampling units within the GRYN will be measured, thus comprising a census of the units, rather than a sample of the units. However, this does preclude measurement error that arises when the responsible agency measures the parameter of interest within each unit.

The temporal design for monitoring land use will be a repeating panel design, with each panel sampled during one sampling occasion (year) and then sampled again after five years (housing density and agriculture) or ten years (roads). This temporal design is based on the anticipated rates of change for this vital sign, as well as the intervals of measurement by the responsible agencies.

Systematic Designs

1. Landbirds

The general sampling design for landbird pilot effort at GRTE is a two-stage systematic design, where a systematic grid was overlaid on a GIS sample frame of the targeted habitat types with a random start point. The grid was scaled to enable the approximate number of transects (with an oversampling rate of approximately 25%) to occur over the entire area. This enabled a reasonable degree of spatial balance. Grid points were randomly selected from this overlay and the selected points served as the starting point of a 2 km transect with a random vector from the start point. Distance sampling (either point or line transects) was then used to sample each secondary unit (transect). An alternative to this design would have been a GRTS design, although the software was not generally available at the time selection was made. A GRTS design may be used if the pilot transects are not used for the final transects or when the pilot effort is extended to full implementation.

The temporal design for landbird monitoring is an always visit design. The abundance of landbirds at a given site can be highly variable from year to year. Thus, revisit designs that have intervals between sampling occasions (years) can provide spurious results if they happen to fall on occasions that the parameter of interest is particularly high, low or coincidentally different. Sampling at intervals greater than one year can also greatly reduce our ability to interpret results in light of a fluctuating environment

Cluster Designs

1. Amphibian Monitoring

Amphibian monitoring will be conducted in collaboration with the USGS Amphibian Research and Monitoring Initiative (ARMI). Within ARMI, a unified effort for monitoring amphibians along the Rocky Mountains from Colorado to Montana has been developed (Corn et al. 2005). The general design will be a single stage cluster design, with unequal probability of samples. The primary sampling units are hydrologic catchments equivalent to what would be approximately an 8th-order hydrologic unit code (HUC). Within each primary unit all wetlands will be surveyed. Identification of all wetlands requires an extensive ground search in addition to remote-sensing applications. Consequently, it is a prohibitively laborious task. Using cluster sampling only requires that this task be accomplished for the selected clusters. The size of the primary units that are currently being used resulted from an extensive collaborative effort with the USGS EROS Data Center as well as field testing as part of a pilot effort. The size of these units was intended to achieve a balance between having a sufficient number of wetlands to be efficient in detecting the presence of amphibians, but to eliminate oversampling of wetlands so that variation in occupancy would be difficult to detect and sampling could not be efficiently accomplished by a small crew within a short period of time (1-3 days). The general suitability of hydrologic units based on the quantity of NWI wetland types within each unit will be used to define unequal sampling probabilities. This is necessary because most hydrologic units within the parks have low value for amphibians. Thus, using an unequal inclusion probability will enable us to invest most of our resources to those units most important to amphibians.

The temporal design for amphibian monitoring will be an always revisit design. This temporal design was based on a collaborative decision with the USGS ARMI Program that estimating change over time within sampling units will be most informative, provided that we have a reasonable spatial representation in the initial panel. Preliminary attempts at defining clusters have indicated that this condition would be satisfied, given that the areal size of the units is carefully chosen (see above).

2. Whitebark Pine Monitoring

An existing protocol has been developed by the Whitebark Pine Ecosystem Foundation (Tomback et al. 2004), although modification was needed to meet GRYN objectives and I&M standards, particularly related to site selection. We have been working with partner organizations (USGS, U.S. Forest Service, the Greater Yellowstone Coordinating Committee, and the Statistics Department of Montana State University) to make revisions that will meet NPS standards, yet will still make use of those parts of the existing protocol that are acceptable. The resulting design from this effort is a two-stage cluster design with stands (polygons) of whitebark pine comprising the primary units and 10x50 m plots being the secondary units. The primary units (forest stands of whitebark cover classes) are selected from a sample frame derived from a GIS layer of predicted whitebark pine distribution. Within these stands, secondary units (plots) are selected from random points such that these plots comprise a subset of the potential plots within any given stand. Initially, we are sampling two secondary units within each stand to determine the extent of within-stand and between-stand variations. This may be modified at a later date if our results indicate that within-stand variation is such that a more efficient scheme would be to sample a greater number of stands. Within the secondary units, all live whitebark pine trees >1.4 m height within the transect are individually marked for future revisits to determine change in status of blister rust infection and survival.

The temporal design for monitoring whitebark pine will be a repeating panel design, with each panel sampled during one sampling occasion (year) and then sampled again after several years (probably five). This temporal design works well for this vital sign because white pine blister rust (the focus of our monitoring objective) is a slow acting pathogen that has relatively little inter-annual variation. Thus, sampling a given panel every year would be extremely inefficient. Sampling panels at longer intervals allows us to develop a sufficient sample size over several years while maintaining a reasonable ability for potential changes to be detected.

Generalized Random-Tessellation Stratified (GRTS) Design

1. WATER CHEMISTRY

The details of our GRTS design for water chemistry are discussed in greater detail in the following section on "A Generalized Design for Aquatic Resources", but the general framework will be a dual-frame design where a targeted list of fixed sites is used in combination with probabilistic sampling using a GRTS design.

The temporal design will be a split-panel design where an always visit design will be used in combination with a repeating panel, such that the sites sampled every year will help to interpret the temporal variation that may be confounded with spatial variation from a repeating panel. For YELL, the repeating panel may be based on hydrologic basins because of logistical constraints of access and permits. These constraints are less prevalent at the other units where the rotating panels are not restricted to specific basins.

2. STREAMFLOW

A field measurement of discharge will be made at all sample sites of "flowing waters" within the same design framework as water chemistry.

3. AQUATIC INVERTEBRATE ASSEMBLAGES

A field measurement of aquatic invertebrate assemblages will be made at the same sample sites as water chemistry using the same general design framework.

4. EXOTIC AQUATIC ASSEMBLAGES

We anticipate sampling for exotic aquatic assemblages at either all or a subset of the sites sampled for water chemistry using the same general design framework. One of the advantages of GRTS is that a subsample that maintains the spatial balance of the overall sample can be collected.

Non-Probability Sampling

3. CLIMATE

Unlike most vital signs, GRYN climate has been monitored continuously for over 100 yr. There is also a legacy network of monitoring stations maintained by a variety of state and federal agencies. Most of the existing sites were selected using a professional judgment selection process. Selection of sites through a probability sample in this case would not be practical given access and other logistic constraints. Further, changing the existing sites at this point could severely compromise the existing legacy of climate data for the GRYN. Consequently, protocol development and design for this vital sign is focusing on evaluating the following: (1) if the legacy network provides adequate sampling of spatial and temporal variability in GRYN climate and (2) how best to address shortfalls in the current system.

Our basic approach involves a detailed analysis of existing climate monitoring stations in the GYE to determine if:

1. Current stations in the GRYN can adequately capture the key spatial and temporal components of climate variability in the region.
2. Strata of management interest or scientific importance are being adequately sampled.

A GENERALIZED DESIGN FOR AQUATIC RESOURCES

Based on the considerations described above, it was determined that a generalized overall design was warranted for several aquatic resources within the GRYN. A summary of such a design is presented below.

General Overview

Several considerations influenced our choice of a specific generalized design. These included:

Inferences scalable from individual parks to inter-network— The final design must be able to accommodate inferences at a local scale (e.g., parks) as well as at more regional scales.

Good spatial representation and dispersion— Having a good spatial representation of targeted water bodies will help ensure the inferences to parks or higher are reliable. Similarly, water bodies that are connected or even in proximity to each other are subject to the same environmental influences and are not likely to be independent. Thus, a good spatial representation includes having reasonable dispersion of our sample.

Complete and accurate sample frame— To be consistent with other aquatic programs, the national hydrologic database (NHD) (USGS 1999) is the preferred sample frame for the GRYN. However, the NHD does not always provide accurately identified perennial streams, currently targeted by the GRYN objectives (Stevens and Olsen 2004). Thus the chosen design needed to be able to account for this problem.

Complete availability of all potential sampling units within the sample frame— Another potential problem to be considered is that for any reasonable sample frame, there are likely units that are unavailable within the GRYN because of safety constraints (e.g., bear closures or avalanche danger) or resource protection (e.g., nesting areas for sensitive species). Thus, the chosen design needs to be able to accommodate this problem.

Systematic designs are generally well suited for obtaining good spatial representation (Cochran 1977). Systematic sampling can also generally perform well in the presence of spatial autocorrelation, although under some circumstances a stratified random sample may be superior (Cochran 1977). In general, systematic sampling should also be well suited to scaling of inference from local to more regional scales. However, incomplete or inaccurate sample frame and the unavailability of some sample units can be problematic for some systematic designs. Stevens and Olsen 2004 present a systematic design called the Generalized Random-Tessellation Stratified Design (GRTS) which is well suited to accommodate these concerns about the sample frame. This design was also developed in the context of, and has been applied to, water quality monitoring; thus solutions for many potential problems that might arise have already developed.

Properties of the Generalized Random-Tessellation Stratified (GRTS) Design

Details of the GRTS Design and how it works to achieve spatial balance are beyond the scope of this report, but have been reported in Stevens and Olsen (2004). Essentially, the GRTS design uses a hierarchical randomization process to achieve spatial balance across the region and the resource (Figure 4.7). A sample frame is created; in this case the NHD. A grid is randomly overlaid on the frame and

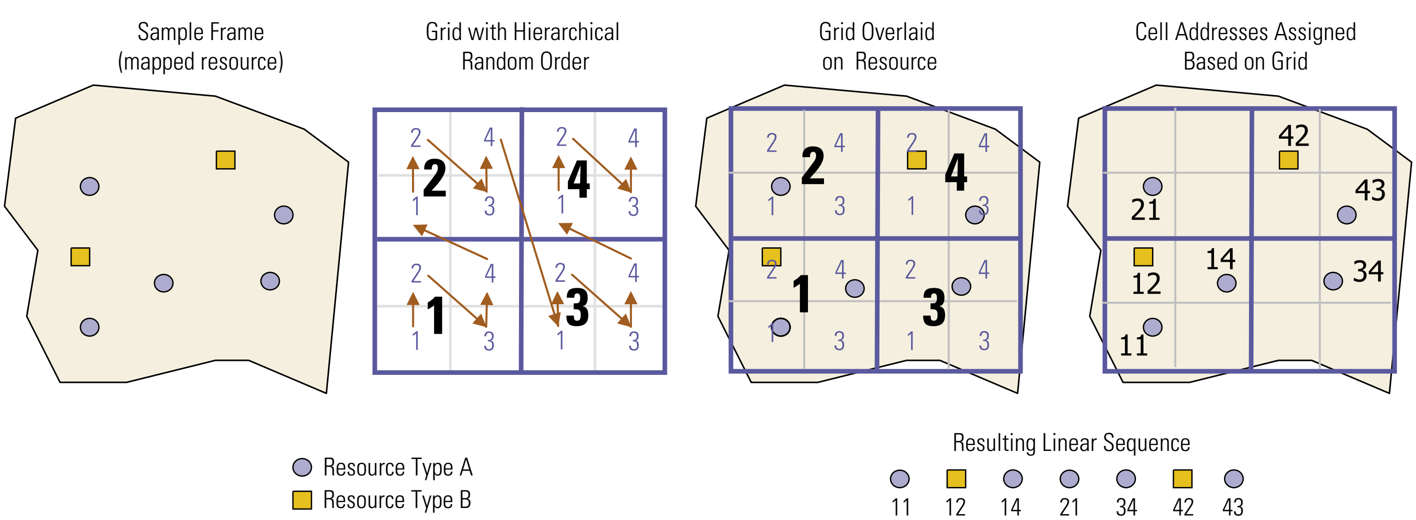


FIGURE 4.7 Graphical representation of the steps leading up to selection of sample units using the generalized random-tessellation stratified design (adapted from Stevens and Olsen 2004, unpublished presentations).

subdivided until there is only one sample unit per cell. Cell addresses are assigned via a hierarchical random process, and each sample unit is assigned to its corresponding cell address, creating a linear sequence of sample unit cell addresses. By reversing the order of address digits and re-sorting this sequence, a systematic sample can be drawn with a random start point that maintains the spatial balance of the sample. Some of the resulting properties of this design that make it an attractive choice for water quality monitoring are:

- Sample is spatially balanced across the resource, resulting in improved precision and a more 'realistic' suite of statistics
- Spatial balance is maintained even at different sampling intensities and among samples and subsamples
- Nested subsamples are easily accommodated, which facilitates different suites of indicators to be measured at different subsets of sample sites. This can be important for accomplishing multiple objectives within the same general design
- Enables design-based estimators and their variances
- Applicable to point, network or areal resources
- Stratification and unequal sampling probabilities of subpopulations are easily accommodated. This can improve precision of estimates as well as increase the efficiency of sampling.

The Probability of Selecting Sample Units within the GRYN

One approach to probability sampling is to assign equal weight to all sample units such that any particular unit has the same probability of being selected. However, there are many reasons why this may not always be the best approach. Taking into account groups of sample units can allow for inferences to be made for the group, increase precision of estimates, increase the efficiency of sampling, etc. There are two primary means by which the GRYN would consider groups, stratification and subpopulations. Stratification treats each group as a separate population for which samples are drawn independently for each stratum. Likewise, inferences are made for each stratum, but estimates can be combined across strata and weighted appropriately. An alternative to stratification is to designate groups of interest as subpopulations, which may have different probabilities of inclusion in the sample for each subpopulation. This approach can be an effective way to achieve some of the benefits of grouping (e.g., improved precision or efficiency), particularly when specific inference for the group is not essential. Tentative groups being considered for each of these approaches are listed below.

1. STRATIFICATION

Because parks are a basic unit of management, having estimates of water quality at the park level is essential. To ensure that a sufficient sample is obtained within each park to enable inference at that scale, the GRYN will stratify water quality sampling by parks.

2. SUBPOPULATIONS

The final details of what subpopulations will be recognized are pending further discussion, but tentative subpopulations are:

Access Class— Many locations within the GRYN are extremely difficult or costly to access, and considering access class as a subpopulation may be one solution to this difficulty. Units far from roads, trails and overnight facilities could be assigned sampling weights smaller than more accessible units.

Major Watershed— It is likely that major watersheds will constitute subpopulations. In the GRYN, features such as geothermal activity tend to correspond with particular watersheds.

Strahler Order— Similarly, the stream order (e.g., Strahler) has also been found in many systems to correlate well with important basin properties and is a likely candidate for consideration as a subpopulation unit.

Perennial/Non-perennial Streams— If there is a decision to include non-perennial streams, then this would likely constitute a subpopulation.

A Dual Frame Component

As previously discussed, existing cooperative efforts need to be taken into consideration. In the case of the water resources vitals signs considered under the GRTS design, there are existing data from fixed stations that function in the context of integrator sites of NAQWA (Shelton 1994). Because the locations of these sites were specifically selected, inferences from such sites cannot reliably be extrapolated to the entire parks, the GRYN, etc. However, inferences about changes over time at these sites are quite legitimate, even if the spatial extrapolation to other sites is not reliable. Such continuous records over time are also quite valuable for other NPS programs (e.g., monitoring geothermal activity). Thus, there would be a great loss of valuable long-term information by abandoning these sites, even if a GRTS design is adopted from more generalized inference. A dual-frame approach will be considered that enables stronger inferences about temporal changes from existing fixed sites to complement broader scoped inferences from probabilistic sampling via the GRTS design.

RESEARCH VS. MONITORING

The distinction between monitoring and research is not always clear. Monitoring is generally focused on the detection of changes or trends, whereas ecological research is focused more on the causes or associations of ecological patterns or processes. Monitoring is typically carried out over long time frames; whereas research is typically, but not exclusively, more limited in duration. Research can be conducted over relatively long time scales (e.g., the Long-term Ecological Research [LTER] Program), although it is still focused on answering questions, rather than estimating status and trends. In its "purest" form, research incorporates controlled experiments with random assignment of experimental treatments (Figure 4.8). In contrast, monitoring has typically entailed descriptive surveys of status and trends, occasionally including correlation surveys, and sometimes quasi-experiments, which can be considered as hypothesis generating, rather than hypothesis testing.

One goal of the vital signs monitoring program is to "monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environment" (National Park Service 2004). Accomplishing an understanding of the dynamics of park ecosystems is not likely to be accomplished by only estimating status and trends. This presents somewhat of a paradox in that monitoring alone may not be able to effectively achieve one of its primary goals (understanding of ecosystem dynamics), while at the same time, use of the I&M program for research purposes is neither practical nor its intended purpose. At the very least, the vital signs monitoring program is intended to work in conjunction with research to gain this understanding. Many of our vital signs were selected primarily because they are a major driver or stressor on park resources. With this in mind, we have described below a few ways that the GRYN program has considered the complementary roles of research and monitoring in the design of our program.

Identification of Research Needs

As specific monitoring objectives for each vital sign are developed, it is determined whether the objective is better suited a research objective, rather than part of the I&M program. In some cases, research may even be needed to facilitate the formulation of meaningful monitoring objectives. This provides a source for proposing and/or prioritizing research conducted by or for the parks.

Confounding Variation and Auxiliary Variables

Many vitals signs were selected because they are a known or suspected agent of change (e.g., ecosystem driver or stressor). In a research context, such variables are frequently incorporated as explanatory variables with the intent to determine if there is an association with a response variable of interest. However, there are additional reasons to include auxiliary variables that may not be vital

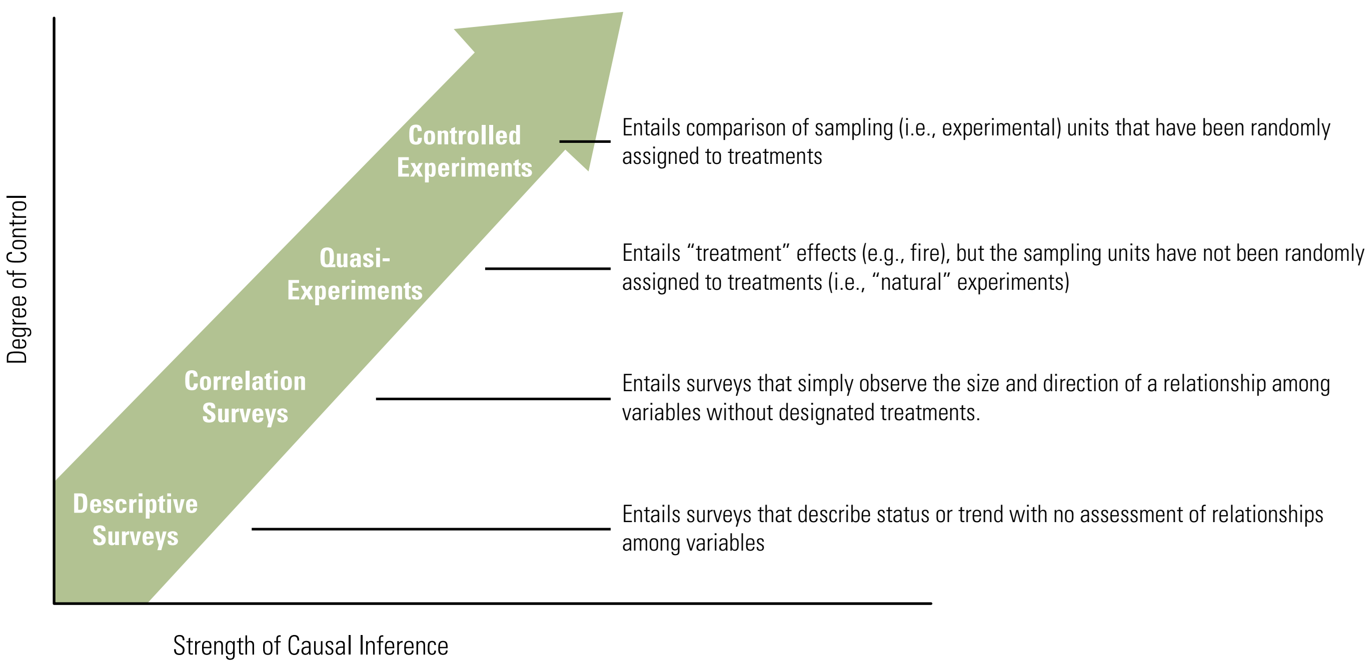


FIGURE 4.8 Types of surveys or experiments in relation to their degree of control and potential to infer causality (adapted from Schwartz 1998).

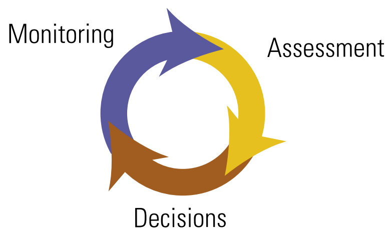


FIGURE 4.9 Conceptual diagram of adaptive management illustrating the iterative cycle of monitoring, assessment and decisions. A science portion of the learning comes from monitoring and assessment and a policy portion comes though incorporating what has been learned into the decision process.

signs themselves in our monitoring. Including auxiliary variables into a monitoring program may increase the precision of parameters of interest by accounting for otherwise unexplained variation (Thompson 2002), particularly when a strong and direct relationship exists between the primary and auxiliary variables (Schwartz 1998). Accounting for such variation may also reduce the risk of misinterpreting results that are artifacts of confounded variables.

GRYN Example

For example, landbird monitoring will likely include measurement of vegetation structure as an auxiliary variable(s) with the intent to obtain more precise estimates of the trends in bird abundance by taking into account the confounding effects of vegetation structure. The intent is not to determine if an association exists between vegetation structure and bird abundance or distribution; there have been numerous papers illustrating such an effect. This will improve the precision of the estimates of interest and reduce the chance for misinterpretation of the trends.

Design vs. Model-based Inference

Currently, the objectives that have been created by the GRYN fall primarily under a design-based framework (e.g., Hansen et al. 1983), which uses probability sampling to derive estimates of state variables and/or rates of change. An advantage of this approach is that it minimizes the number of assumptions required to drawn inference, which makes it defensible in cases of litigation and in making controversial public policy decisions (Olsen et al. 1999). However, a design-based approach also tends to be poorly suited for making future predictions. Predictive inferences are generally better suited to a model-based approach (Olsen et al. 1999). A model-based approach enables incorporation of hypothesized relationships, which can better lead to predictive capabilities. However, this advantage comes at a cost of requiring a greater number of simplifying assumptions (Olsen et al. 1999). Additionally, even with reliable parameter estimates, our predictive capabilities will only be as good as the models from which they are derived. However, in the future, a model-based approach may better enable the GRYN to move from a purely descriptive approach to a more scientific (e.g., quasi-experimental) approach to monitoring that can provide advantages for understanding the system and predicting the outcome of management decisions (see also Yoccoz et al. 2001).

Although there can be several advantages in moving toward a model-based approach, it is also premature at this stage of our program development. There are many hypotheses about ecosystem functioning within the GRYN, but in most cases these are not sufficiently conceptualized for an efficient incorporation into a model-based approach. However, as the GRYN program matures, specific hypotheses can be refined and articulated so as to be considered in a model-based context.

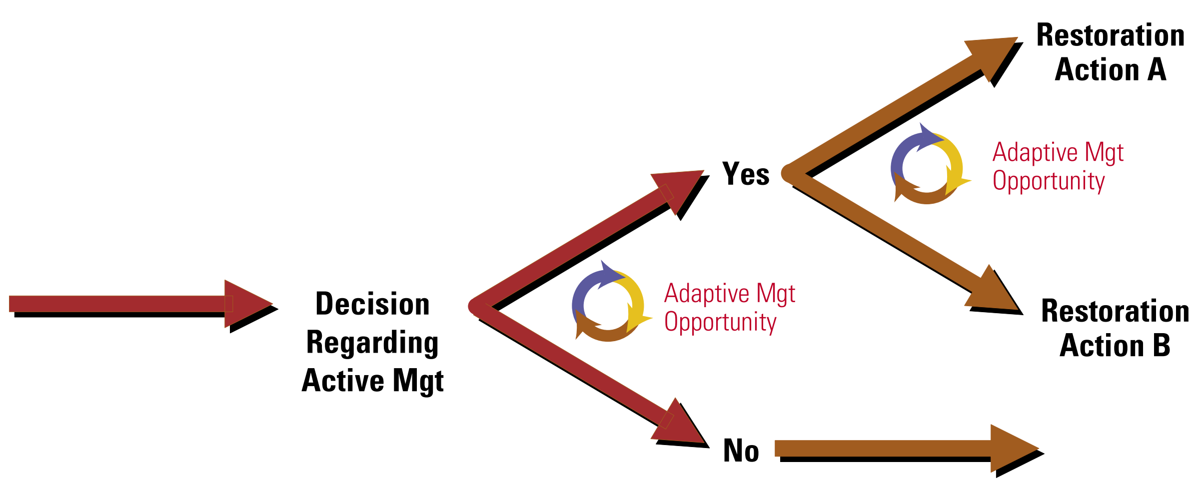


FIGURE 4.10 Conceptual diagram of potential decisions that could benefit from incorporating an adaptive management approach to design.

Adaptive Management

One goal of monitoring vital signs is to provide the information needed to make better-informed management decisions. Yet, a common mistake of environmental monitoring is a failure to link indicators to decisions (Failing and Gregory 2003). Adaptive management is one tool that could facilitate this linkage between the information derived from monitoring and decisions. Adaptive management is an iterative process of assessment, decision making and monitoring to achieve management goals, whereby learning is facilitated through an experimental approach (e.g., Holling 1978, Walters 1986) (Figure 4.9).

GRYN Example

Whitebark pine is considered a "keystone" species throughout the Greater Yellowstone Ecosystem. It serves a variety of roles ranging from a food source for grizzly bears to having an effect on snow accumulation and distribution. In recent decades whitebark pine stands have been decimated in areas of the Cascades and northern Rocky Mountains due to the introduction of an exotic fungus—white pine blister rust—as well as mountain pine beetles. Our specific monitoring objectives are intended to determine if white pine blister rust is increasing within the Greater Yellowstone Ecosystem, and whether or not the resulting mortality of whitebark pine is sufficient to warrant consideration of management intervention (e.g., active restoration)? Thus, several potential decisions are foreseeable (Figure 4.10). The first decision is whether or not active restoration should be initiated. If it is initiated, there is considerable uncertainty about the effectiveness of alternative management activities for achieving the management objectives of restoration. Both of these decisions have the potential to benefit from an adaptive management approach. If the decision for whether or not to implement active restoration is not universally applied to all areas, then there is the possibility of designing the monitoring to compare management intervention (i.e., active restoration) with an alternative of allowing the process to continue uninterrupted by such intervention. Similarly, if a decision is made to initiate active restoration, then there is an excellent possibility of designing the monitoring to compare alternative restoration practices (e.g., different levels of planting or overstory release, or different types of genetically resistant stock).

5. SAMPLING PROTOCOLS

INTRODUCTION

Throughout the development of the monitoring program, GRYN has emphasized three elements: (1) the applicability of our program, (2) the reliability (i.e., scientific defensibility) of our program, and (3) the feasibility of our program. These elements have been addressed somewhat independently in previous chapters. This report is intended to provide the overall framework by which our entire program fits together. Similarly through the monitoring protocols described in this chapter, the pieces are woven together to form a coherent picture for a given vital sign or suite of vital signs. Through the protocols we enable the reader to see by whom, how, why, where and when these pieces fit together. Another intention of this chapter is to illustrate how these pieces contribute to our major thematic elements of applicability, reliability and feasibility of our vital signs. In keeping with this intention, a conceptual diagram of how these pieces contribute to these thematic elements is presented in Figure 5.1.

GREATER YELLOWSTONE NETWORK PROTOCOLS

The GRYN is currently developing monitoring protocols for 12 vital signs planned for implementation within the next 3-5 years. The relationship between vital signs and protocols is illustrated in Table 5.1. In addition the GRYN is developing a regulatory water quality monitoring protocol specially to address surface waters that are listed as 303 (d) impaired by either the state of Wyoming or Montana. The schedule for implementation is further described in Chapter 9.

PROTOCOL DEVELOPMENT

Background

The background section of our monitoring protocols is intended to describe the history and context for a given vital sign. This is intended to serve three distinct purposes. The first purpose of this section is to lay out the rationale for why this vital sign was chosen to be monitored. The second purpose is to provide the foundation and substance from which the specific monitoring objectives are derived. The third purpose is to describe the context within which this vital sign fits within our overall monitoring program.

1. THREATS AND CONCERNS

Many changes in the status or trend of the GRYN vital signs can result from being influenced by a known threat or concern for a given vital sign or in some cases changes in the status or trend of a vital sign can itself be a threat or concern for other vital signs. This section describes our current state of knowledge for the threats and concerns for a given vital sign in the GRYN. Wherever possible, we have tried to distinguish the extent of the empirical evidence for a given

TABLE 5.1 The GRYN has identified 12 vital signs summarized in 10 protocols that are targeted for implementation. In addition the GRYN is developing a regulatory water quality monitoring protocol specifically to address surface waters that are listed as 303 (d) impaired by the state of Montana or Wyoming.

Vital Sign	Protocol
Climate	Climate
Soil structure and stability	Soil structure and stability
Arid seeps and springs	Arid seeps and springs
Stream flow	Stream flow
Water chemistry	Integrated Water Quality and Regulated Water Quality
Aquatic invertebrate assemblages	
Exotic aquatic assemblages	
Invasive plants	Invasive plants
Whitebark pine	Whitebark pine
Amphibians	Amphibians
Landbirds	Landbirds
Land use	Land use

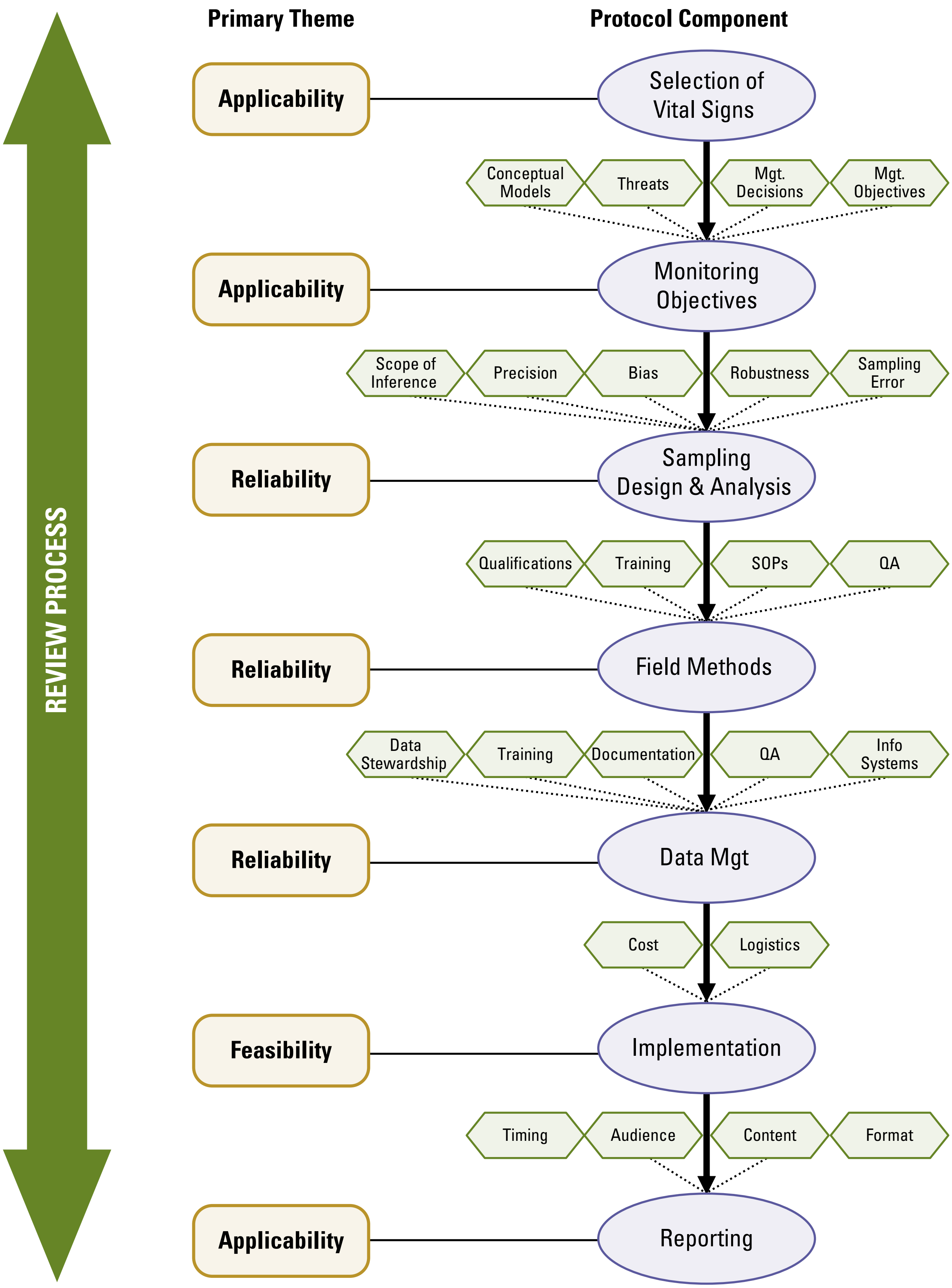


FIGURE 5.1 Conceptual framework for how the individual protocol elements contribute to the overall applicability, reliability and feasibility for a given vital sign or protocol.

threat or concern from that which is speculative. However, we have not limited our efforts to those for which empirical evidence exists. To the contrary, in some cases our monitoring effort is even intended to determine if a perceived threat exists, thereby providing empirical evidence for or against the speculated threats. We have also explicitly tried to extract out of reference material several concepts that will be necessary for selection of specific monitoring objectives and development of a sound sampling design. These included the known or expected magnitude of the threat or concern, the spatial extent of the threat or concern, and the time scales over which the threat or concern operates. Knowing, for example, whether or not the threat is cumulative or whether there are daily or seasonal patterns contribute to the development of the sampling design.

2. CONCEPTUAL MODELS

Conceptual models are constructed for a variety of purposes within the I&M program and have been previously discussed in Chapter 2. Relevant conceptual models are presented within each protocol as part of the background to better understand the context of a given vital sign. The I&M Program uses two types of conceptual models, stressor models and control models (Gross 2003). Stressor models identify the relationships between stressors (or drivers), ecosystem components and effects. In the context of GRYN protocols, stressor models help the network to identify which drivers and/or stressors have an influence on a given vital sign and/or what other vital signs (or other system components) this vital sign might influence as a driver or stressor. Given that stressor models do not typically incorporate feedbacks and interactions, they tend to be descriptive and retrospective. In contrast, control models represent key processes, interactions and feedbacks (Gross 2003). In the context of GRYN protocols, control models are likely to serve as a stronger foundation for understanding the mechanistic functioning of the ecosystem. As such, they may form a basis from which more quantitative and predictive models emerge. Thus, control models will likely play a key role as the GRYN evolves from design-based inferences toward model-based inferences (see Chapter 4).

3. OTHER MONITORING EFFORTS: PAST AND PRESENT

Also as part of the background, the past and existing efforts related to a given vital sign will be summarized. Existing efforts and partnerships need to be an integral part of the consideration for any protocol development. Maintaining the integrity of pre-existing data sets, understanding how GRYN efforts fit (or don't fit) within existing sampling designs, the experience of what has worked or not worked during past efforts, etc., all contribute to a foundation from which GRYN efforts can be built.

Measurable Monitoring Objectives

When reviewing the literature on ecological monitoring, there is virtually universal consensus that setting realistic, clear, specific and measurable monitoring objectives is a critical, but often difficult first step (e.g., Spellerberg 1991 Elzinga et al. 1998). Olsen et al. (1999) noted that "Most of the thought that goes into a monitoring program should occur at this preliminary planning stage. The objectives guide, if not completely determine, the scope of inference of the study and the data collected, both of which are crucial for attaining the stated objectives." They further went on to state that a "clear and concise statement of monitoring objectives is essential to realize the necessary compromises, select appropriate locations for inclusion in the study, take relevant and meaningful measurements at these locations, and perform analyses that will provide a basis for the conclusions necessary for meeting the stated objectives." It is for these reasons that the GRYN has taken the task of formulating monitoring objectives very seriously.

First we distinguish management objectives from monitoring objectives. Management objectives focus on the desired state or condition of the resource; whereas monitoring objectives focus on the measurement of the state or condition of the resource. In some cases monitoring objectives may directly reflect management objectives and provide the basis for evaluating achievement of the latter.

Despite the recognition of the importance of establishing good monitoring objectives, a clear understanding about what constitutes a good monitoring objective is often lacking. For this reason, a checklist of key elements for consideration was developed by the GRYN to ensure the quality of our monitoring objectives:

1. Does the objective clearly relate to one or more of the I&M program goals (see Chapter 1)?
2. Is the objective clear and specific?
3. Is the objective measurable?
4. Is the target population (i.e., intended scope of inference) clear?
5. Is it clear what parameters are being measured or estimated?
6. Have targeted levels of precision been identified?
7. Are there temporal patterns outside of the primary sampling interval (e.g., diurnal and seasonal patterns) that need to be considered?

8. Does the objective focus on the end result (i.e., what is being measured and when is it being measured or estimated), rather than the means (i.e., how) to achieve that result? (see Text box 5.1).
9. If the monitoring objective relates to a known threat or concern, is there also measurement of that threat or concern that would enable assessment of the association between changes in the vital sign and changes in that threat or concern?
10. If the monitoring objective is a science-based objective, is it better suited as a research question to complement monitoring, or is it better suited as part of the monitoring?
11. If the monitoring objective is a science-based objective (i.e., intended to increase our understanding of how the system functions or is affected by a particular stressor(s)), then is there a corresponding *a priori* hypothesis(es)?
12. Does the monitoring objective relate to one or more management objectives, and if so, has the management objective(s) been clearly stated?

Sampling Design

The sampling design ensures that the Inventory and Monitoring Program will provide information on the status and trends of our natural resources that is reliable and based on the best science possible. It is through the sampling design that we ensure that the data collected are representative of the target populations and sufficient to draw defensible conclusions about the resources of interest. The guiding principles regarding how the GRYN will approach sampling design are presented in Chapter 4. The sampling design section of the protocol provides the details of how those principles are realized. Some of the specific elements that will be included within the sampling design section of a given protocol are:

1. Units
    - Target population
    - Sample frame
    - Sample units
2. Sample size determination
    - Targeted detection level
    - Existing estimates of expected variation (if available), including source
    - Procedure for determining appropriate sample size (including power estimation)
3. Spatial Design
    - General spatial sampling design (random, systematic, cluster, etc.)
    - Logic or justification for design
    - Sample unit selection process
    - Stratification (including justification)
4. Temporal Design
    - Panel description (see Chapter 4)
    - Revisit design

TEXT BOX 5.1

In a recent paper on common mistakes in designing biodiversity indicators, Failing and Gregory (2003) identified confusion of the means and the ends as one common mistake. It is quite common for agencies and organizations to express objectives in terms of the means to achieve an end, rather than the end itself. While this approach may be well suited for directing the actions of an organization, it does little for enabling better management decisions through science.

For example, consider a management objective, taken from a southeast land management agency:

Use fire to maintain and encourage dry prairie within pine flatwood habitats.

On the surface, this seems like a reasonable objective, and for the purpose of directing management actions, it is probably fine. However, when evaluating the degree to which this objective was accomplished, the agency determined that the objective was met 100 percent; not because dry prairie was established (which was never assessed), but because fire (the action) was used. For science to have been of much value in this context an alternative objective stated in light of the end rather than the means would have been required. An objective such as:

To maintain at least 20 percent of the overall area of pine flatwood habitat as dry prairie.

is better suited to determining whether the desired state or condition has been reached (although there certainly could be considerable refinement). Further, a corresponding monitoring objective that results in a measurement of the area of dry prairie as a percentage of the overall pine flatwood habitat is relatively easy to construct.

Field Methods

Our ability to reliably detect differences in resources over time or among sites is only assured if data are gathered in a consistent and well-documented manner (Beard et al. 1999). The field methods section of each protocol is intended to ensure consistent methodology. The detail of this section should be sufficient to ensure repeatability in light of changing personnel (Beard et al. 1999). Those aspects of field methodology that are repeated in different locations and/or by different personnel will be written in the form of a standard operating procedure (SOP). SOPs are detailed written instructions intended to ensure uniformity and consistency of a given procedure within the protocol. SOPs need to be easy to read and implement. SOPs also need to be reviewed and updated, if necessary, to ensure that they are current and relevant. The protocol will clearly define the strategy and procedure (i.e., via an SOP) for documentation and changes to existing SOPs (see section below on continual improvement).

Some of the specific elements that will be included within the field methods section of a given protocol are:

1. Pre-season preparation includes any preparation that need be completed before field efforts commence in a given sampling period including, but not limited to:
    - Permits
    - Equipment preparation
    - Training (may be part of an overall training SOP)
2. Data collection protocol(s) includes all field sampling procedures,
    - Data forms and data dictionary (may be part of an overall data management SOP)
    - Field measurement procedures
    - Safety procedures (may be part of an overall field safety SOP)
3. Post season processing
    - Lab processing (if applicable)
    - Voucher specimens (if applicable)
    - Equipment maintenance and storage

Data Management

Data management requirements for monitoring protocols include explicit procedures to enter, edit, document, store and archive data according to the scope of each vital sign protocol as well as for programmatic analysis and reporting. Standard operating procedures for data management activities address many of the common tasks among protocols. Chapter 6 summarizes the Network's overall plan for data management (Appendix VIII).

1. METADATA PROCEDURES

Developing and maintaining complete and accurate documentation of data sets is a fundamental requirement of the Program and the Network. Metadata establishes the basis for interpreting and appropriately using data in analyses and products by recording information about the data source(s), and the methodology by which the data were collected or acquired. The Network Data Manager works with other staff, partners and contractors to include directions in each protocol and standard operation procedures for:

- generating metadata using current Federal Geographic Metadata Committee's (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM) and the Biological Data Profile of the CSDGM
- scheduling necessary reviews and updates
- recording full metadata in ESRI ArcCatalog© or in a structured format for import to ArcCatalog
- recording brief metadata in NPS Dataset Catalog
- distributing metadata at the NPS Natural Resources Metadata and Data Store.

2. OVERVIEW OF DATABASE DESIGN

Databases for monitoring protocols are designed to meet the data entry, quality assurance, and reporting or output requirements specified by the monitoring objective(s). Where possible, existing databases from other NPS units (from the NPS Protocol Clearinghouse) or external sources are adopted and adapted to promote consistency among data sets. Examples of database designs shared between the Network, other NPS units and other agencies include those for Whitebark pine (Whitebark Pine Ecosystem Foundation, a not-for-profit foundation), amphibians (Amphibian Research and Monitoring Initiative, USGS), and water quality (STOrage and RETrieval - STORET, Environmental Protection Agency). For monitoring protocols without suitable or available database designs, the Network will develop databases according to the NPS Natural Resource Database Template model for Microsoft Access and the ESRI Geodatabase model.

3. DATA ENTRY, VERIFICATION AND VALIDATION

Data management procedures for each protocol identify the tools, format and quality assurance requirements for data collected using the protocol. Step by step instructions and screen captured images from each database guide the user through the appropriate tasks. Each data record includes the name, version and date of the monitoring protocol used for data collection and processing. Data recording tools include both hardcopy field forms and electronic portable data recorders. Based on the requirements of the monitoring objective(s), data entry procedures include information about manual and automated quality controls, data verification procedures and data validation routines.

4. DATA ARCHIVAL PROCEDURES

Network protocols include instructions for archiving physical and digital data to support the long-term monitoring goals of the Program. Standard procedures address the long-term data storage requirements for most protocols and additional specifications are listed as necessary with each protocol's data management procedures. Each protocol discusses the plan to archive original or replicated data sets from other sources, and/or rely on external data repositories for certain data such as weather and streamflow data. The Network data management plan provides overall guidance for data archiving and addresses issues like future evolution of storage technology that permits or requires the migration of data to new platforms and storage media.

Analysis

Having a sound data analysis helps to ensure that the data we have collected using sound designs provide valid inferences about the resources we are trying to assess. Data analysis design should address the following questions.

1. Who is responsible for the data analysis?
2. What is the purpose of the analysis (parameter estimation, hypothesis testing, etc.)?
3. What are the analysis procedures? This section should provide a full overview of any anticipated analyses.
4. What is the validity of the estimate of certainty being obtained (i.e., standard error)?
5. At what frequency are routine analyses to be conducted?

Reporting

For the GRYN to be successful in communicating its purpose and progress toward inventory and monitoring, it is essential for the network to develop a clear and comprehensive strategy for reporting our results. This section of the protocol is a description of that strategy for a given vital sign (or as a general SOP) which includes at least the following elements:

1. Who is responsible for reporting?
2. Who is the intended audience?
3. At what frequency are reports to be made?
4. What is the anticipated content of the reports (general content, analyses and presentation)?
5. How will reports be made available (Web access, etc.)?

Quality Assurance/Quality Control

Quality assurance (QA) is a significant part of every monitoring program. It is the cornerstone of our ability to furnish reliable information. Quality assurance and control has been addressed in the context of data management in Chapter 6. However, quality assurance goes beyond data management and must be an integral component of all aspects of the GRYN program including field and laboratory systems for sample collection and measurement, survey design, equipment preparation, maintenance tasks, data handling and personnel training. The U.S.F.S. Forest Inventory and Analysis Program (FIA) identified three aspects of quality assurance (prevention, assessment and correction) that they refer to as the QA triangle (Figure 5.2).

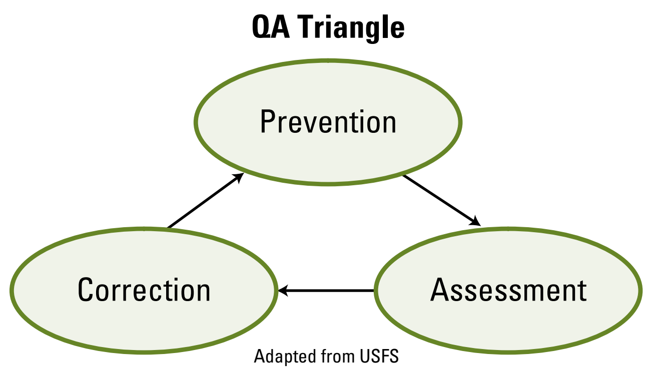


FIGURE 5.2 Quality assurance triangle adapted from U.S.F.S. Forest Inventory and Analysis Program (FIA).

The objectives of quality assurance are to assure that the generated data are meaningful, representative, complete, precise, accurate, comparable, and scientifically defensible. The network will establish and document protocols for the identification and reduction of error at all stages in the data lifecycle. Although specific QA/QC procedures will depend upon the individual vital signs being monitored and must be specified in the protocols for each monitoring vital sign, some general concepts apply to all network projects. Each vital sign protocol will include specifics that address quality control. These may include:

- Field crew training
- Standardized data sheets
- Equipment maintenance and calibration
- Procedures for handling data (including specimens) in the field
- Data entry, verification and validation

The Regulatory Water Quality Monitoring Protocol (O'Ney 2005) includes a QA/QC standard operating procedure (SOP) that addresses data representativeness, comparability, completeness, precision, systematic error/bias and accuracy. The SOP includes instructions on the use and frequency of quality control samples, such as blanks, duplicates and spikes and indicates the acceptable range and corrective actions for each QC sample. The SOP also includes instructions for completing/maintaining instrument calibration log books, field log books and chain of custody forms.

I. Continual Improvement

In the context of the overall GRYN program, prevention is addressed through sound development of sampling design, data management and analysis. These have been addressed in greater detail in other chapters and in the corresponding sections of each protocol. Although prevention is extremely important, it is not sufficient by itself, due to changing programs, funding, environments, technologies, etc. Thus as part of each protocol, a section for continual improvement will also include the strategy for assessment (i.e., the review process) and correction.

1. Review Process

Each protocol will have a section (or general SOP) describing the strategy for periodic review. Such reviews may be periodic (planned at a predefined interval) or episodic (resulting from changing mandates, funding, priorities, etc.). The review process should permeate through all phases of our monitoring. It also should permeate through all of our thematic elements (i.e., applicability, reliability and feasibility), although it may not be the same review process for each element. Rather, the details of a given review should reflect which element(s) is being targeted. For example, a review intended to assess the scientific reliability is likely to be conducted by qualified scientists. In contrast, a scientific review panel may have little insight if a review is intended to assess whether or not the monitoring meets the needs of managers. Consequently, the review strategy should also clearly specify the purpose of the review and, at least in general terms, who should conduct the review.

2008 Program Review— A special case of the general review process for each protocol is that an overall program review is planned for 2008. This review would explicitly examine the suite of protocols using criteria discussed below for whether or not the individual protocols are meeting park information needs and I&M standards for scientific defensibility. More importantly, all of our initial twelve protocols should be completed by this time, and this review would be an opportunity to examine whether we have the best compliment of vital signs and/or have made the best compromises during implementation between the expected costs and benefits.

2. Process for Change

Determining the status and trends of selected indicators of the condition of park ecosystems is an essential and critical goal of the I&M program. Understanding the spatial and temporal scales over which change occurs is paramount to achieving this goal. We have considered the spatial and temporal scale in several elements of this report, including sampling design and implementation. However, many ecosystem attributes of interest operate at such long time scales that implementing a temporal sampling design requires a long-term commitment that enables teasing apart true change from environmental noise (i.e., variation). Thus, one of the key values of the I&M program is its long-term prospect. Frequent changes in monitoring protocols in the attributes being monitored and how they are being monitored would likely lead to a ever-weakening ability to meet the program goals, leading to erosion of support, further weakening the program, etc. Thus, at the outset the GRYN needs to be vigilant about disruptive change in our monitoring, while at the same time recognizing that changing resources and management regimes may require some degree of flexibility. The difficulty lies in finding the right balance between maintaining the necessary consistency to meet our program goals with enough flexibility to meet the challenges of changing natural and political environments. Thus, when making changes in protocols, the following questions should be addressed:

1. What are the criteria for determining whether or not a change is warranted? These should reflect the general themes identified above:
    - Reliability— The data are not reliable in their present form
    - Applicability— The data are not applicable to managers, the public, etc. in their present form
    - Feasibility— The data are not feasible to obtain in their present form (e.g., funding, logistics, priorities, etc.).
2. If it is determined that a change is required, what programmatic element needs to be changed?
    - Vital Sign?
    - Objectives?
    - Design?
    - Field Methods?
    - Data Management?
    - Analysis?
    - Reporting?

Note: Changing a vital sign or an objective is far more drastic than changing a reporting method. Thus the criteria for making changes to different elements may reflect their relative degree of severity.

3. What is the procedure for making the change?
4. What precautions will be taken to ensure that the revised protocol will be acceptable?
   - Pre-change reviews (based on planned changes)?
   - Post-change reviews (based on results from implemented changes)?
   - Testing concurrent with existing protocol?
   - Post-change analyses
5. How will the transition to the revised protocol be accomplished?
   - Will there be a period of overlap (*sensu* Newell and Morrison [1993]), if so how?

Operational Requirements

All of the elements that are required to implement the monitoring of a given vital sign need to be summarized in this section of the protocol, including:

1. Roles and responsibilities— This section of the protocol needs to include the specific roles of the personnel, including technicians, involved in sampling design, data collection, entry and analysis.
2. Qualifications— The necessary qualifications for the project coordinator, as well as the field technicians, should be stated here. An example of a skill that might be required of a field technician who will be monitoring for wildlife species is knowledge of wildlife habitat types.
3. Training— Often some form of on-site training before the field season begins is necessary. In some cases, such as when monitoring water quality, an agency other than NPS leads the training session. Any such situation should be noted here along with contact information for the training session and/or start date for on-site training due to seasonal limitations on sampling (i.e. sampling must occur during June and July; therefore, training must occur prior to June).
4. Annual workload and field schedule— This section of the protocol needs to explain the general timing and frequency of sampling. Also included here are the number of days needed for sampling, the number of personnel needed for each stage of sampling and the number of samples to be collected during each field day. If the data are coming from another source (i.e. climate stations), include here the timing of data collection (i.e. when and how often) and the contact information for the collecting agency.
5. Facility and equipment needs— This section of the protocol should include a list of all facility and equipment needs for each group of field personnel involved in sampling, along with a list any equipment sharing possibilities (and appropriate contact information where necessary).
6. Start-up costs and budget considerations— It is important to include all costs in the protocol. These costs should include all personnel, travel, space needs, laboratory analysis costs, new equipment needs and/or equipment sharing costs and equipment maintenance and storage costs.

PROTOCOL SUMMARY INFORMATION

The full protocols are developed as stand alone documents beyond the scope of this report. However, a complete summary of their development is presented in Appendix VII and in Table 5.2 we present a more abbreviated version of some of the key information contained within each protocol.

TABLE 5.2 Key information from each protocol including justification for why the vital sign is being monitored, the specific monitoring objectives and in which parks the protocol will be implemented. Monitoring objectives are revised and updated as protocols are completed.

<table>
<tr><th>Vital Signs</th><th>Justification[1] and Monitoring Objectives[2]</th></tr>
<tr><td>Climate</td><td>Protocol name: Climate

Justification: Climate is a primary driver of almost all physical and ecological processes in the GRYN. Climate controls ecosystem fluxes of energy and matter as well as the geomorphic and biogeochemical processes underlying the distribution and structure these ecosystems (Jacobson et al. 1997, Schlesinger 1997, Bonan 2002). Global surface temperatures, in particular, have risen by 0.6 ºC ± 0.2 over the past century (IPCC 2001). These global-scale changes will inevitably lead to significant alterations of the Greater Yellowstone Network's regional climate. Changing regional climate will, in turn, have a tremendous effect on natural systems in the GRYN (Bartlein et al. 1997, Baron 2002, Wagner 2003). It is imperative that the parks of the GRYN have a climate monitoring system in place that allows for the detection and characterization of GRYN climate change and provides climate data for use in monitoring and predicting the dynamics of other vital signs.

Monitoring objectives:
1. Measure precipitation and air temperature in the GRYN, including BICA, GRTE, YELL and surrounding areas.
2. Measure secondary climatic elements including wind speed/direction, relative humidity, soil temperatures and incoming solar radiation in the GRYN, including BICA, GRTE, YELL and surrounding areas.

Parks where this protocol will be implemented: BICA, GRTE and YELL</td></tr>
<tr><td>Soil structure and stability</td><td>Protocol name: Aridland soil structure and stability

Justification: The National Park Service is concerned about the impacts of grazing animal populations on the structure and function of soils in Bighorn Canyon NRA. This concern is based on personal observations in the field and on the results of the rangeland health assessment of the Pryor Mountain Wild Horse Range (PMWHR) (Natural Resources Conservation Service 2004). The NRCS states that rangeland within the NRA portion of the PMWHR is in an unhealthy condition, reflecting attributes of the soils and plant communities that "may not be able to recover from degradation without energy inputs, such as mechanical alteration" (Natural Resources Conservation Service 2004). These poor soil conditions include: severe erosion, excessive loss of biological soil crust cover, and high bare soil and erosion pavement cover. The NRCS also states that "conditions are right for an explosion of noxious weeds" (Natural Resources Conservation Service 2004). Through development of a long-term monitoring protocol, we can provide more precise monitoring of soil structural and functional conditions and potentially allow for more precise correlation of soil characteristics with increases and decreases in ungulate population sizes.

Monitoring objectives:
1. Determine the status and trend of unprotected bare soil, i.e. without biological crust cover or armoring by rocks, between vascular plants on each soil mapping unit paired both inside and outside of the Pryor Mountain Wild horse Range at three-year intervals.

Parks where this protocol will be implemented: BICA</td></tr>
</table>

Vital Signs	Justification[1] and Monitoring Objectives[2]
Arid seeps and springs	**Protocol name:** Aridland seeps and springs **Justification:** Aridland seeps and springs have three unique features that separate them from the surrounding landscape – water, biologically diverse biota (some endemic) and often sustained flow duration - and underscore the importance of monitoring. Seeps and springs are often the only localized water source within a desert/arid environment during the drier periods of the year when other sources of water have diminished. Plant and insect populations thrive in seeps and springs. By supporting the base of the food chain, seeps and springs indirectly support upland communities through trophic energy transfer. Some springs support known rare, endemic flora (e.g. Sullivantia hapemanii var. hapemanii) and possibly rare invertebrates. Other fauna are strongly dependent on these scarce and vital water sources. There are threats to seeps and springs within Bighorn Canyon that could reduce their potential to support wildlife, biodiversity, and streamflow. These threats include: trampling and herbivory of vegetation and degradation of water quality by human visitors and ungulates (cattle and wild horses); and potential degradation of water quality and loss of water quantity through the influence of industrial and agricultural activities and changes in water rights both inside and outside of the NRA. **Monitoring objectives:** 1. Estimate discharge, variation in discharge and change in discharge over time of seeps and springs within BICA, taking into account seasonal annual and decadal variation. 2. Determine the status and change over time of water chemistry parameters at the orifice of seeps and springs within BICA including, but not limited to, conductivity, dissolved oxygen, pH, and water temperature. 3. Determine the status and change over time of aquatic macroinvertebrate composition along the first 100 m of runout of seeps and springs within BICA. 4. Estimate spatial extent and change in spatial extent over time of mesic vegetation along the first 100 m of runout of seeps and springs within BICA. 5. Determine species composition and change in composition over time of vegetation along the first 100 m of runout of seeps and springs within BICA. **Parks where this protocol will be implemented:** BICA.
Streamflow	**Protocol name:** Streamflow **Justification:** Streamflow measurements are useful for water quality data comparisons over time, interpretation of water quality data and calculation of parameter loads. Streamflow at any point in time is an integration of the streamflow generation and routing mechanisms in a watershed. This integration also defines the water quality at that time, including land use activities, point source discharges and natural sources (NPS 1998). Thus streamflow measurement is an essential component of water quality monitoring. Streamflow measures will help determine how water withdrawals and impoundments are influencing river and streamflow dynamics. **Monitoring objectives:** 1. Estimate trends in baseflow characteristics of rivers within or adjacent to the GRYN that are permanently gaged by the USGS. 2. Estimate trends in the timing of annual extreme water conditions of rivers within or adjacent to the GRYN that are permanently gaged by the USGS. 3. Compare annual hydrographs of rivers within or adjacent to the GRYN that are permanently gaged by the USGS. **Parks where this protocol will be implemented:** BICA, GRTE and YELL

Vital Signs	Justification[1] and Monitoring Objectives[2]
Water chemistry; *E. coli;* Aquatic invertebrate assemblages	**Protocol name:** Regulatory Water Quality **Justification:** Regulatory water quality monitoring is being conducted in response to the requirements of the Clean Water Act (CWA) and the direction of the vital signs monitoring program. The monitoring program views the monitoring of state-identified impaired waters as fulfilling the fundamental requirement of Goal 1a4 of the NPS Strategic Plan (NPS 2001b), and partially fulfilling the requirements of the Government Performance and Results Act. Four water bodies in the GRYN have been identified by the states of Montana and Wyoming (in response to the CWA) as being impaired and appear on their respective 303(d) lists. **Monitoring objectives:** 1a. Determine fecal coliform concentrations at the sampling location Shoshone River at Kane and compare to Wyoming state standards. 1b. Determine E. coli concentrations at the sampling location Shoshone River at Kane and compare to Wyoming state standards. 2a. Determine nitrate concentrations at the sampling location Bighorn River near St. Xavier and compare to Montana state standards. 2b. Determine the natural range of variability of nitrate concentrations at the sampling location Bighorn River near St. Xavier based on monthly measurements. 2c. Determine the Montana impairment score for macroinvertebrates at the sampling location Bighorn River near St. Xavier and compare to Montana state standards. 3a. Determine levels of dissolved and total metals at the sampling location Soda Butte Creek at the park boundary, both in the morning and evening at snowmelt and baseflow and compare with Montana state standards. 3b. Determine levels of metals in sediment at the sampling location Soda Butte Creek at the park boundary and compare with the probable effect concentration (PEC) at snowmelt and baseflow. 3c. Determine the diurnal variation of dissolved metals and total metals at the sampling location Soda Butte Creek at the park boundary during snowmelt and baseflow. 3d. Determine the Montana impairment score for macroinvertebrates at the sampling location Soda Butte Creek at the park boundary and compare with Montana state standards. 4a. Measure discharge continuously at Reese Creek and compare with recommended minimum flows (0.037m3/s between April 15 and October 15). **Parks where this protocol will be implemented:** BICA and YELL.

<table>
<tr><th>Vital Signs</th><th>Justification[1] and Monitoring Objectives[2]</th></tr>
<tr><td>Water chemistry;
Aquatic invertebrate assemblages;
Exotic aquatic assemblages</td><td>Protocol name: Integrated Water Quality

Justification: Water quality monitoring is a fundamental tool in the management of freshwater resources. The chemical, physical and biological health of waters is considered of national value and is protected by the Federal Water Pollution Control Act. Chemical and physical tests give information that is accurate only at that moment the sample is taken. Thus the GRYN incorporates a complimentary program of chemical, physical and biological components. The use of macroinvertebrates as indicators of aquatic ecosystem health developed out of observations that specific taxa were restricted under certain environmental conditions (Richardson 1925, 1929 and Gaufin 1958). The presence of a mixed population of healthy aquatic insects usually indicates that the water quality has been good for some time. This then led to the development of list of indicator organisms and the acceptance of using macroinvertebrates for use in water quality monitoring.

Monitoring objectives:
1. Determine the status and trend of a primary set of water chemistry parameters including, but not limited to, conductivity, dissolved oxygen, pH, water temperature and discharge in perennial surface waters of all GRYN parks.
2. Determine levels of substrate composition and embeddedness in perennial surface waters of GRYN parks.
3. Determine the status and trend in benthic macroinvertebrate communities in flowing perennial in surface waters of GRYN.
4. Determine the status and trend in the acid-neutralizing capacity of high-risk alpine lakes of the GRYN and estimate the rate at which water chemistry is changing over time.
5. Determine concentrations of polycyclic aromatic hydrocarbons (PAHs) and other constituents associated with two-stroke and four-stroke engines at targeted marinas within GRYN.
6. Determine input of nutrient enrichment and wastewater effluents through analysis of fecal coliform bacteria and macroinvertebrate communities at a small number of targeted sites of high concern within the GRYN.
7. To detect occurrence of aquatic invasive plant and animal species at select targeted locations most susceptible to initial invasion (marinas, areas of high fishing access, etc.) with an emphasis on areas that coincide with water quality monitoring samples with GRYN.

Parks where this protocol will be implemented: BICA, GRTE and YELL</td></tr>
<tr><td>Whitebark pine</td><td>Protocol name: Whitebark pine

Justification: Whitebark pine is a “keystone” species throughout the Greater Yellowstone Ecosystem, the cones of which serve as a major food source for grizzly bears and other species. Whitebark pine stands have been decimated in areas of the Cascades and northern Rocky Mountains due to the introduction of an exotic fungus—white pine blister rust—as well as mountain pine beetles. This vital sign is intended to estimate current status of whitebark pine relative to infection with white pine blister rust as well as to assess the vital rates that would enable us to determine the probability of whitebark pines persisting in the Greater Yellowstone Ecosystem.

Monitoring objectives:
1. Estimate the proportion of whitebark pine trees within the Greater Yellowstone Ecosystem (GRTE, YELL and six national forests) infected with white pine blister rust, and to determine whether that proportion is changing over time.
2. Determine the relative severity of white pine blister rust infection in trees > 1.4 m in height within stands of infected whitebark pine within the Greater Yellowstone Ecosystem (GRTE, YELL and six national forests). Severity is indicated by the number and location (trunk or branch) of blister rust cankers.
3. Estimate the survival of individual whitebark pine trees > 1.4 m in height within the Greater Yellowstone Ecosystem (GRTE, YELL and six national forests), explicitly taking into account the severity of infection with white pine blister rust (from objective 2).

Parks where this protocol will be implemented: GRTE and YELL</td></tr>
</table>

Vital Signs	Justification[1] and Monitoring Objectives[2]
Invasive plants	**Protocol name:** Invasive plants **Justification:** There is a strong consensus among scientists around the world that, after habitat loss and landscape fragmentation, the second most important cause of biodiversity loss now and in the coming decades is invasion by alien plant, animal and other species (Allendorf and Lundquist 2003, Chornesky and Randall 2003, Walker and Steffen 1997). In all of the parks, exotic plant species are a serious threat to natural and cultural resources. Terrestrial exotic plants have replaced native vegetation in large areas of Grand Teton and Bighorn Canyon, are widespread in the Northern Range of Yellowstone, and there is an ongoing threat of further displacement. This displacement affects not only native vegetative community structure, composition and succession, but can also cause extirpation or extinction of endemic and/or endangered plant species (Walker and Smith 1997, Mack et al. 2000). Exotic plants that become invasive, aggressive and widespread create detrimental impacts on animal habitat and nutrition, soil nutrient cycling and fire and flood processes in parks (DiTomaso 2000, Goodwin 1992, Mack et al. 2000). NPS management policy states that native species will not be allowed to be displaced by exotic species if displacement can be prevented (National Park Service (US) 2001a) **Monitoring objectives:** 1. Detect occurrences of invasive exotic plants new to the parks (currently on the GRYN watch list) before they become viable populations. 2. Detect new occurrences of high priority (1-3) invasive exotic plants in weed-free zones of the park before they become viable populations. 3. Determine status and trend of high priority (GRYN priority 1-3 species) invasive exotic plants outside of control boundaries at 5 year intervals. 4. Determine distribution and abundance of exotic plants (GRYN priority 4-5 species) at 5 year intervals. 5. Determine status and trend of selected native plant community and ecosystem attributes at locations (e.g. in targeted habitats) infested with invasive exotic plants (GRYN priority 4 species) and compare with similar sites not infested with invasive exotic plants at 5 year intervals. 6. Determine status and trend of native plant community and ecosystem attributes at locations where selected invasive species have been treated/controlled and compare with similar sites not infested with invasive exotic plants at 5 year intervals. **Parks where this protocol will be implemented:** BICA, GRTE and YELL
Amphibians	**Protocol name:** Amphibians **Justification:** Declines in the abundance and distribution of amphibians have been widely recognized as an emerging issue (Stuart et al. 2004). Concerns regarding such declines resulted in the funding of the Amphibian Research and Monitoring Initiative (ARMI) in 2000. Specific objectives of the GRYN are intended to determine if the occurrence of amphibians is decreasing and if there is any evidence regarding likely underlying causes of any observed declines that might warrant further directed research or management actions consistent with the NPS management policies. **Monitoring objectives:** 1. Estimate the proportion of catchments (approximately 8th order) within YELL and GRTE used for breeding by each species of amphibian (other than Boreal toads) and to estimate the rate at which use of these sites for breeding is changing over time. 2. Estimate the proportion of catchments (approximately 8th order) and targeted breeding sites within YELL and GRTE used for breeding by boreal toads (Bufo boreas) and to estimate changes in occupancy of targeted breeding sites over time. 3. Estimate the proportion of potential breeding sites (i.e. wetlands) that are minimally suitable for breeding (i.e., have standing water) in any given year. Parks where this protocol will be implemented: BICA, GRTE and YELL

Vital Signs	Justification[1] and Monitoring Objectives[2]
Landbirds	**Protocol name:** Landbirds **Justification:** Protection of native species and their habitats is one of the primary challenges outlined in the NPS Natural Resource Challenge (National Park Service (1999). The National Park Service Inventory and Monitoring Guidelines (NPS-75) further states that "Preserving the natural resources (and natural processes) in the national parks may be the most important legacy the Park Service can provide American conservation." Thus, monitoring the composition of native communities of concern and the changes occurring within and among these communities is essential to meeting our Natural Resource Challenge. Because of the large number of habitat types within the Greater Yellowstone Network (GRYN) and the enormous variability within these habitat types, our initial efforts on landbirds will focus on estimating the status and trends of landbirds within four habitats (communities) of concern: alpine, aspen, shrub steppe (sage), and riparian. **Monitoring objectives:** 1. Estimate the proportion of sites occupied (MacKenzie et al. 2002) in habitats of concern in BICA, GRTE, and YELL and to estimate the changes in occupancy over time. Although we will estimate occupancy and changes in occupancy for all species with sufficient data, our emphasis will be species identified as dependent on or obligates of the particular habitat of concern. 2. Estimate the abundance (density) of birds in habitats of concern in BICA, GRTE, and YELL and to estimate the changes in abundance over time. 3. Estimate community composition and associated parameters of landbirds in habitats of concern in BICA, GRTE, and YELL and to estimate trends in these parameters over time. Specific parameters to be estimated include, but are not limited to, species richness and relative species richness (e.g., richness of native to exotic species). **Parks where this protocol will be implemented:** BICA, GRTE and YELL
Land use	**Protocol name:** Land use **Justification:** Land use activities surrounding park borders can significantly influence the status of ecological condition and functioning within parks. The GRYN has identified land use change as a top priority vital sign for defining ecosystem health within parks. Long-term monitoring of land use activities surrounding parks of the GRYN will provide information on trends in land use and land cover change, and allow for analyses which quantify potential consequences for park resources. This will provide managers with the scientific background for incorporating the consequences of surrounding land use activities into park management decisions. **Monitoring objectives:** 1. Determine the density and location of homes on private and public lands within the 20 counties comprising the Greater Yellowstone Ecosystem (Rasker 1991) plus two additional counties surrounding BICA and measure change over time. 2. To determine the number, length and type (i.e. size) of roads within 22 counties within and surrounding the GRYN, as well as measure changes in the existence and characteristics of roads over time. **Parks where this protocol will be implemented:** BICA, GRTE and YELL

[1] Justification for individual objectives is provided in the protocols and protocol development summaries (Appendix VI).

[2] Specific objectives presented here are in abbreviated form. Details about targeted populations, scales, state variables, etc are presented within a given protocol. Some monitoring objectives, such as those for invasive plants, require further refinement and possible reductions.

6. DATA MANAGEMENT AND ARCHIVING

The data management mission of the GRYN is to provide data and information resources that are organized, available, useful, compliant and safe. To achieve these fundamental requirements, the data management plan focuses on the following objectives:

- Provide data management services and guidance in support of the I&M program goal to identify, catalog, organize, structure, archive and make available relevant natural resource information
- Initiate and invest in data management activities based on data and information needs defined in network monitoring protocols and inventory study plans
- Integrate data management activities with all aspects and at all stages of network business
- Specify data stewardship responsibilities for all personnel
- Collaborate internally and externally to address data management issues with individuals at all organizational levels.

The I&M program provides a framework for natural resource information management (Figure 6.1) aimed at achieving maximum returns on investments made in data gathering, such that relevant data and information is available long term to multiple levels of the organization (park, network, regional, national). This framework includes these elements:

- Provide standards for natural resource inventories
- Develop and support Service-wide online natural resource database applications
- Provide desktop database applications that mirror master databases and promote standard data entry and organization
- Recommend a natural resource database template that allows local flexibility but also promotes design consistency for the purpose of sharing database designs and content
- Direct networks to hire data management staff and emphasize data management
- Mandate written network data management plans
- Require written data management procedures and responsibilities in inventory study plans and vital sign monitoring protocols.

The network builds on this framework by applying data management guidelines for a monitoring vision (Figure 6.2) that is directly related to

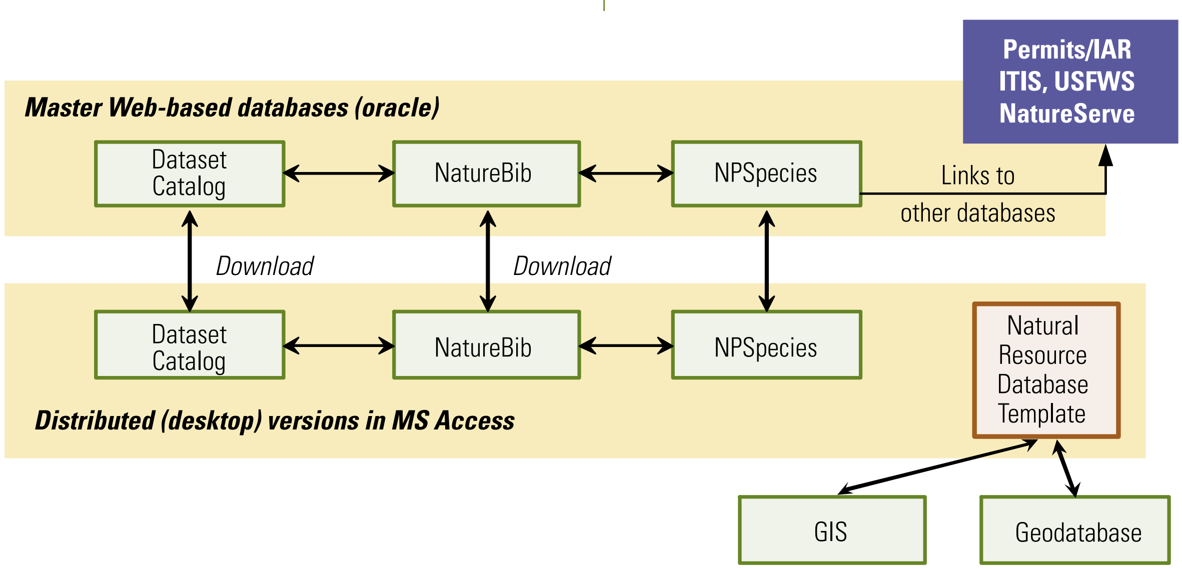


FIGURE 6.1 Integrated natural resource data management framework.

the needs of local scientists and natural resource managers. The network manages all forms of inventory and monitoring data and information, provided they support one or more of the following program goals:

- Goals and objectives of the Inventory and Monitoring program
- Specific information needs defined in approved Vital Sign monitoring protocols
- Network inventory study plan objectives
- Other specific natural resource management projects that network personnel and park staff agree to cooperate in developing and managing.

FIGURE 6.2 Monitoring vision (adapted from National Water Quality Monitoring Council 2004).

The Network Data and Information Management Plan (Appendix VIII) outlines the strategy and guidelines for thorough, integrated and coordinated resource information management activities that attempt to link Service-wide information requirements and data management tools with park-level inventory and monitoring information needs.

Roles and Responsibilities for Data and Information Stewardship

The benefits to managers and scientists from inventory and monitoring projects are substantially affected by the ability to track data from the time they are gathered until and while they inform a decision-making process. In many cases this involves time frames of several years and includes changes in information technology, turnover in staff, new scientific insights and shifting priorities. The purpose of data stewardship is to share the responsibility for managing data and information resources. The network works to ensure mutual accountability for specific tasks (responsibilities) assigned to each position (role) involved with data as a producer, analyst, manager or end user. Table 6.1 lists primary roles and responsibilities for all data steward roles, some of which are commonly assigned to a single position, e.g. a resource specialist may serve as project leader. Individual monitoring protocols and inventory study plans draw on a more complete Data Stewardship Framework (Appendix VIII) for guidance in assigning specific jobs and detailed tasks related to data management.

TABLE 6.1 Programmatic roles and responsibilities for data stewardship

Role	Programmatic Data Stewardship Responsibilities
Project Crew Member	Collect, record and verify data
Project Crew Leader	Supervise crew and organize data
Data/GIS Specialist or Technician	Process and manage data
Information Technology Specialist	Provide IT/IS support
Project Leader	Oversee and direct project operations, including data management
Resource Specialist	Validate and make decisions about data
GIS Manager	Support park management objectives with GIS and resource information management
Network Data Manager	Ensure inventory and monitoring data are organized, useful, compliant, safe and available
Database Manager	Know and use database software and database applications
Curator	Oversee all aspects of the acquisition, documentation, preservation and use of park collections
Statistician or Biometrician	Analyze data and present information
Network Ecologist	Integrate science in network activities
Network Coordinator	Coordinate and oversee all network activities
I&M Data Manager (National Level)	Provide Service-wide database availability and support
End Users (managers, scientists, publics)	Inform the scope and direction of science information needs and activities. Apply data and information services and products

The network data manager plays a fundamental role as coordinator of data management roles and activities. This involves understanding program and project requirements, developing and maintaining data management infrastructure and standards, and communicating with all responsible individuals. Integration and communication with GIS staff, natural resource information managers and I&M project leaders promotes common understanding and efficiency. Integration may include such activities as training, guidance and assistance for inventory and monitoring efforts and, where practical, for park stewardship requirements related to the broader realm of Service-wide natural resource information management. The network data manager works closely with each project leader to meet the data management requirements specified in monitoring protocols and inventory study plans. This includes substantial involvement in project planning, crew training, field work, progress and deliverable tracking, and other relevant project operations.

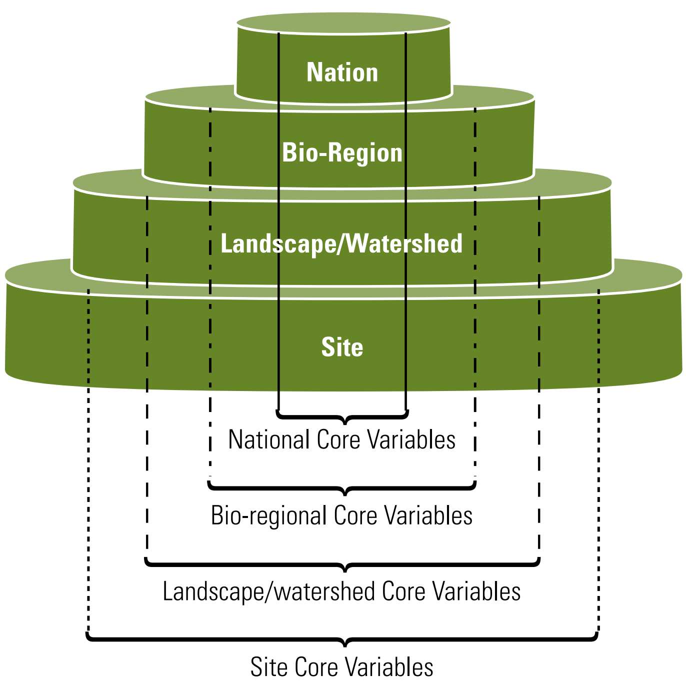


FIGURE 6.3 The "wedding cake" model of variables (Powell 2000).

Data Management Program Overview

Data and information management in the GRYN will attempt to support an adaptive yet consistent approach to managing and delivering a useful suite of natural resource inventory and monitoring data and information. The network relies primarily on the general and interrelated data and geodatabase models of Microsoft® Access and Environmental Systems Research Institute (ESRI®) GIS software applications. Department of Interior (DOI) Enterprise Resource Management efforts and the NPS GIS and natural resource data management communities are heavily invested in these products and tools like GIS Theme Manager, AlaskaPak and the NPS Metadata Tools and Editor. Since Access databases and ESRI personal geodatabases can be scaled to enterprise level solutions as the Service continues to develop its corporate information management strategy, it is appropriate for the network to use these data models to meet objectives for managing and delivering monitoring data. The network expects Service-wide information needs (the core of the wedding cake in Figure 6.3) to be identified, coordinated and addressed at the highest levels of NPS. As these institutional requirements and solutions for enterprise business needs evolve, the network will continue to coordinate with internal and external stakeholders on data management activities.

Information Technology (IT) Infrastructure for Data Management

The organization, availability and security of data and information resources depend on a solid computer system foundation. Where possible, the Greater Yellowstone Network uses DOI and NPS solutions for computer network, hardware and software requirements for data and information management, including: DOI Enterprise Resource Management hardware licensing for desktop, laptop and server hardware; virtual private network access; client and server operating systems; asset management software; email; security (Antivirus); desktop office and publishing; image processing; database and geographic information system applications.

The network is self-supporting for many of its IT needs. Most aspects of the network's local computer system are managed by network staff using assistance and services from regional and national IT personnel to support and maintain an updated system. Park computer support staff also provide assistance when requested by the network.

Network data and information resources are compiled, organized and archived using a structured file system on a local server that is backed up to tape and Network Attached Storage (NAS) devices (Figure 6.4). The network staff will incorporate and follow NPS information technology policies, standards, procedures and guidelines available from the Office of the Chief Information Officer.

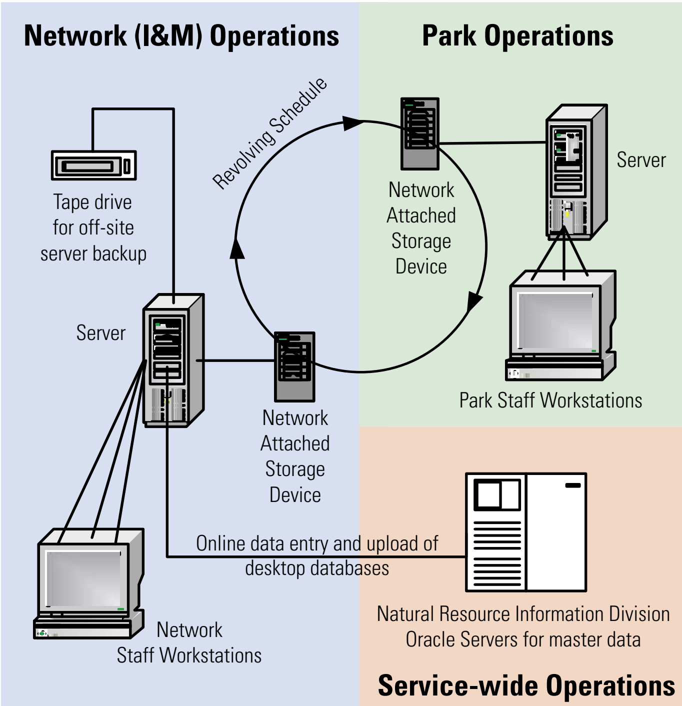


FIGURE 6.4 IT Connectivity Diagram

Acquiring and Processing Data

The network's three-phase planning process resulting in peer-reviewed vital sign protocols provides a robust link between specific measurable information needs and user requirements. A critical result of this process is that data required for the long term monitoring of park vital signs are distinguished from all other existing and potentially new data sources. This provides a manageable scope for acquiring, processing and administering monitoring data. In order to provide a synthesis of scientific information based on vital signs and related data, the network also gathers and processes relevant data and information from other park-based and external inventory and monitoring efforts.

Past investments in data gathering in the GRYN have resulted in a legacy of products that vary widely in format, consistency and value for park stewardship (GRYN 2000). Future work and expense to link legacy data with management requirements must be carefully scrutinized by a group of professionals representing management, science and technical branches of park stewardship. Although GRYN-funded inventories have been completed, parks will continue to perform inventories according to the spirit and goals of the Natural Resource Challenge. The network expects to coordinate with these projects to preserve existing partnerships and integrate data management activities. To help address the volume of natural resource data stored at the parks, the network directly supports annual work by park staff to obtain, catalog, report and archive data in NPSpecies, NatureBib and Dataset Catalog. This involves working with research permit and reporting staff, park natural resource specialists and external researchers to receive and compile new data as well as discover and process existing data sources.

New data are only acquired and processed by the network if they support specific objectives outlined in one of the following plans:

- Greater Yellowstone Network Vertebrate and Vascular Plant Inventory Study Plan (GRYN 2000)
- Monitoring protocols for vital signs listed in chapter three of this monitoring plan
- Reporting requirements listed in chapter seven of this monitoring plan
- Service-wide natural resource inventories
- Relevant projects with management-approved work plans in which the network is one stakeholder and contributor.

TABLE 6.2 Abbreviated Data Development Model

1. Identify issues and concerns
2. Define the purpose and need for data collection and analysis
3. Develop explicit monitoring objectives or inventory criteria (these are key questions addressing the issue or concern within the scope of the purpose and need)
4. List measurable, observable and predictable variables associated with each key question
5. Formalize and document information needs
6. Develop a data dictionary for field names, lists of values, quality factors and metadata characteristics
7. Select or develop an appropriate sample design
8. Identify and assign explicit data stewardship roles and responsibilities
9. Write a complete monitoring protocol or inventory study plan
10. Design or adopt/adapt a database (including quality control elements)
11. Plan for data acquisition **(beginning of data life cycle)**
12. Collect data— field and office components
13. Process data (includes verification, transfer, addition of required attributes)
14. Store, organize and secure data
15. Use, analyze and report data
16. Maintain and serve data and derived products
17. Archive data (long term storage that may require media and/or platform transfer)
18. Delete data that are no longer needed, if appropriate **(end of data life cycle)**

Ensuring Data Quality

The network approaches quality assurance as "an integrated system of management activities involving planning, implementation, documentation, assessment, reporting and quality improvement to ensure that a process, item or service is of the type and quality needed and expected by the consumer" (Palmer 2003). The network strives to achieve appropriate data quality by:

- documenting requirements for data quality
- implementing data quality assurance activities in all stages of network operations
- using relevant quality control procedures throughout the data life cycle
- incorporating, teaching, and applying direction from NPS Director's Order #11B: "Ensuring Quality of Information Disseminated by the National Park Service."

The specific observed, measured or predicted elements that address the objectives for each vital sign monitoring protocol or inventory study plan include documented quality factors in the data dictionary for that plan. Once these are defined and recorded (step 6 from Table 6.2) appropriate quality assurance procedures can be applied. These include:

- training and awareness in quality assurance
- equipment selection, calibration and maintenance
- data collection procedures and data entry controls
- automated and user-assisted data verification routines
- user-assisted data validation routines
- pertinent quality controls based on water quality data collection and processing procedures.

Documenting Data

Documenting data sets, the data source(s) and the methodology by which the data were acquired establishes the basis for interpreting and appropriately using data. The network requires the following documentation elements as insurance to protect investments in data gathering.

1. Feature-level metadata— characteristics about each feature/record in a database. Data records collected according to network protocols will include the name, date and version of the associated protocol. This is an example of feature-level metadata that promotes the longevity and utility of a data asset.
2. Data set metadata— documentation meeting Federal Geographic Data Committee and NPS standards.
3. Notes from field, laboratory and analysis work.
4. NPS Dataset Catalog records for brief metadata on all data holdings, including locally published geospatial data sets (themes and images).
5. Monitoring plan or inventory study plan with complete background, objectives and methods that directly relate to the metadata and vice versa.

To achieve the required content and detail for metadata, the network uses a number of techniques, including:

- FGDC metadata content standards for geospatial and biological data sets
- specific metadata requirements outlined in task agreements and contracts with cooperators
- NPS training, online resources and software tools including Dataset Catalog
- educating personnel about roles and responsibilities for data documentation
- tracking project, data set and metadata status
- following up with responsible individuals to complete metadata
- incorporating feature level metadata into data gathering procedures.

The network creates, maintains, and publishes metadata according to NPS metadata standards and guidelines. All network metadata records meeting FGDC content standards for digital geospatial metadata are available on the NPS NR-GIS Metadata Clearinghouse Web site.

Summarizing and Analyzing Data

Providing meaningful results from data summary and analysis is a cornerstone of the I&M program and characterizes the network's data management mission to provide useful information for managers and scientists. Each monitoring protocol establishes requirements for on-demand and scheduled data analysis and reporting. Based on these requirements, the associated database(s) for the protocols include functions to summarize and report directly from the database as well as output formats for import to other analysis software programs. In addition to tabular and charted summaries, the network provides maps of natural resource data and GIS analysis products to communicate spatial locations, relationships and geospatial model results. Please see Chapter 7 for a more detailed description of the network's analysis and reporting schedule and procedures.

Distributing Data and Communicating Information

The network uses a variety of means to obtain, secure and share all network-generated data and scientific information while protecting the integrity and privacy of sensitive or protected data. The network's Web site provides an information portal that assembles and links existing and planned internet services that provide for most of the network's data and information distribution requirements. In the following list, access to virtually all network data and information represented in Figure 6.5 is permitted according to the security level of the user. All data are available to network parks, most data are available Service-wide, and non-protected data are available to all external users.

- Inventory and monitoring planning and project reports are online at the GRYN Web site.
- Park and network monitoring protocols and database designs are online at the NPS Protocol Clearinghouse.
- Searchable metadata are online at the NPS Natural Resource and GIS Metadata Database.
- Original and processed data sets from the parks and network are online at the NPS Biodiversity Data Store and/or the NPS Natural Resource and GIS Data Store.
- Annually updated water quality data are online at the Environmental Protection Agency's STORET Web site.
- Biodiversity data and information are available online at the NPSpecies Web site.
- Scientific citations are online at the NatureBib Web site.

Data sharing between the network and parks is scheduled and coordinated to ensure data in useful formats are regularly available to park natural resource managers. Until the GRYN server and park servers can share data on the same computer network, data transfer occurs via electronic file transfer, exchange of digital media and a system of revolving external hard drives or NAS devices.

The network also serves data requests using file transfer protocol (FTP), attaching reports and other products with small file sizes to email and shipping digital media such as DVD, CD-ROM, diskette and magnetic tape cartridge.

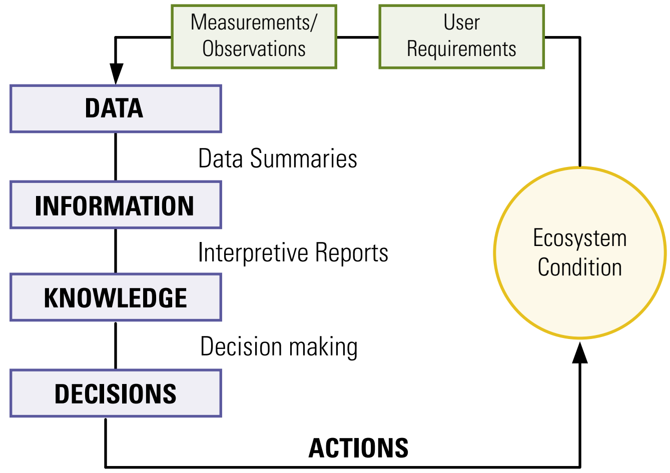


FIGURE 6.5 Decision Support Model (adapted from Palmer 2003).

Maintaining, Storing and Archiving Data and Information

The data distribution mechanisms discussed above also provide data storage and archiving solutions. In addition to posting and submitting data to NPS and external data stores, the network maintains an organized file system stored on local server hard disks as well as backup media that includes optical, tape and Network Attached Storage devices. As future evolution of storage technology permits or demands, the full complement of network data will be migrated to new platforms and storage media. The maintenance requirements and associated roles and responsibilities for a given data set are specified in the monitoring protocol or inventory study plan and in the associated metadata. The network data manager keeps track of data maintenance schedules and works with project leaders and GIS specialists to review data maintenance requirements. Where nec-

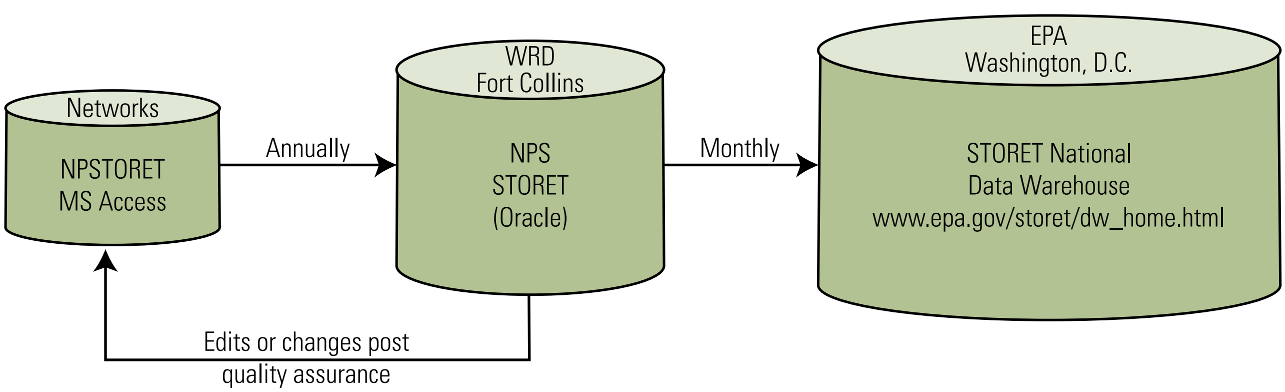


FIGURE 6.6 Natural Resource Challenge vital signs water quality data flow.

essary, the network acquires and archives data sets from multiple sources, but also relies on external repositories as the master data store for some ancillary data.

Water Quality Data

Water quality data, including macroinvertebrate characteristics, are managed according to guidelines from the NPS Water Resources Division (Figure 6.6). This includes using the NPSTORET desktop database application at the parks to help manage data entry, documentation and transfer. The network oversees the use of NPSTORET according to the network's integrated and regulatory water quality monitoring protocols and ensures the content is transferred at least annually to NPS Water Resource Division for upload to the STORET database.

7. DATA ANALYSIS AND REPORTING

Data analysis and reporting are essential components to monitoring long-term ecosystem health, due to the importance of communicating important information to various constituents. Reporting and analysis are directly connected to the overall goals for the program, presented in Chapter 1. To be successful in communicating the value of monitoring, however, it is essential to identify goals of reporting and appropriate audiences for each reporting type. Following are a list of objectives for analysis and reporting that the GRYN would like to accomplish:

- To ensure scientific defensibility of the results of monitoring, which we will achieve by including parameter estimates, test results and model selection
- To aid in interpretation of results for various constituents (i.e., general public, park managers, etc.)
- To synthesize the strengths and weaknesses of the monitoring effort in meeting National I&M program goals
- To provide a measure of the state of the parks to various constituents (i.e., park managers, general public, etc.)
- To identify possible warning signals of abnormal conditions and bring this information to the attention of managers and the public
- To provide information from monitoring that will help to assess the performance of the I&M program and the parks with respect to legal mandates (i.e., GPRA), and to report such information in a usable format for park staff

The way in which the analytical methods the GRYN uses will help the network reach the overall I&M goals listed in Chapter 1 are shown in Figure 7.1. In the subsequent sections, the methods the GRYN will use to analyze and report on monitoring are outlined.

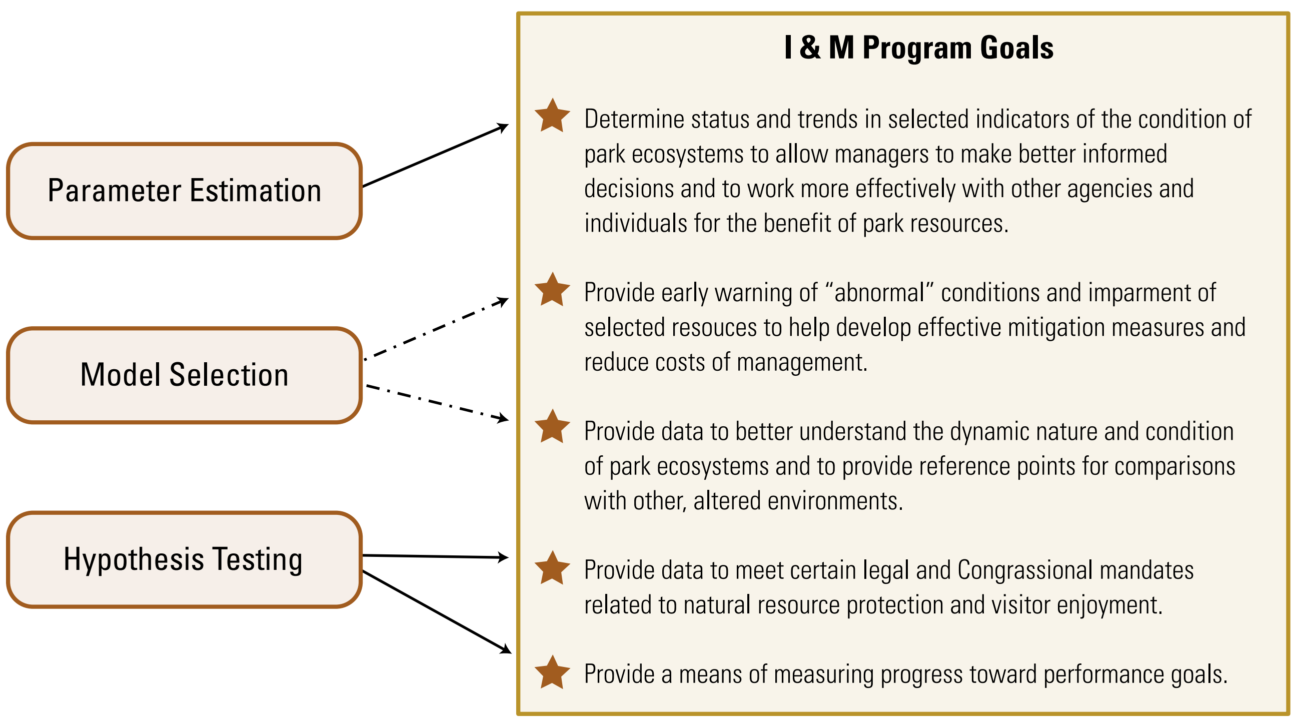


FIGURE 7.1 Conceptual relationship between major types of analysis and the primary, but not exclusive, I&M goals that they will facilitate achieving.

DATA ANALYSIS

One of the guiding principles in the National Park Service FY2001-2005 Strategic Plan (NPS 2001b) is "applying scientific information to park management decisions to preserve park resources." This goal was also outlined in the Natural Resource Challenge (NPS 1999) and the development of the I&M program (NPS 2004a). Using the sampling designs described in Chapter 4 will ensure that the data collected meets the highest standards of scientific quality. Then, through analyses and interpretation, the GRYN will communicate valid inferences about the resources being monitored. The following sections outline the guiding principles used to determine the appropriate analysis in a given context. Due to the detailed nature of analysis techniques, the specific analyses used for each vital sign will be found in the monitoring protocol; this chapter serves as a conceptual overview of the analytical methods the GRYN plans to use.

Parameter Estimation

Although there are many ways of categorizing analyses, three primary types of analyses are considered here (parameter estimation, hypothesis testing and model selection). While these broad categories are not entirely mutually exclusive, parameter estimation is primarily concerned with measuring and describing the attributes of a population in terms of its distribution and structural features. Because one of the primary goals of the I&M program is to determine the status and trends of selected vital signs, the appropriate category of analyses will be most likely in the form of parameter estimation: either estimation of the state of a given resource (status) or the change in that resource state over time (trend). Therefore, parameter estimation will certainly be one, if not the, most common type of analysis in our program. Using this method will require an understanding of the structural features of the distribution from which the sample is drawn, including estimates of central tendency and variability. Some of the properties that we will be concerned about in our estimation of parameters are bias, precision and confidence; each is discussed below.

1. BIAS, PRECISION AND CONFIDENCE

With respect to parameter estimation, bias represents the tendency for a parameter estimate to systematically differ from the true value. In other words, if the expected value of the estimate (e.g., the average from repeated samples) is equal to the true value of the parameter, then the estimator is considered unbiased. This differs from precision, which represents how much variation there is in the estimates (Figure 7.2). The GRYN will attempt to ensure unbiased estimates by using a sound sampling design and unbiased estimators (e.g., based on maximum likelihood), and staff will ensure the most precise possible estimates by considering the sample sizes required for estimates of a given precision (see Chapter 4).

Precision can reflect variation in the data (i.e., the standard deviation) or confidence in the estimates (i.e., the standard error). Because the estimate of the population parameter is based on random sampling, the estimates themselves can be considered a random variable (Williams et al. 2001). Consequently, it is necessary to recognize an important distinction between these components of precision. Variation in the data is estimated by the standard deviation (SD) and is not a function of sample size. In contrast, variation in the estimates must take into account the variation in the data, in addition to how well the population was sampled (i.e., sample size), and is measured by the standard error (SE). Thus, the SD will be reported where appropriate to illustrate variation in the data; however,

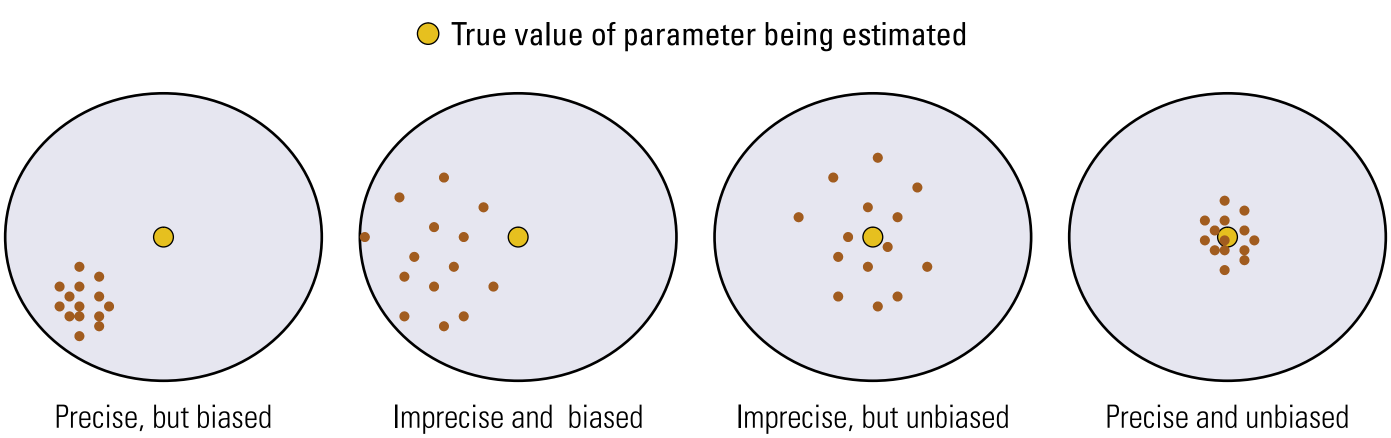


FIGURE 7.2 Conceptual diagram illustrating the difference between bias and precision for a given parameter estimate.

for most parameter estimates, the primary concern will be the level of confidence in the estimates, and therefore the SE and confidence intervals will always be reported.

Hypothesis Testing

The second general category of analysis is hypothesis testing and most likely will be more limited within the network protocols. This method of analysis will be used when the state (status) of a given resource is tested against a specified reference such as a legal threshold or desired condition. In the context of I&M program goals, this would likely be for testing whether or not certain legal or congressional mandates have been met or whether or not performance targets have been achieved. Thus, the GRYN does not plan to test scientific hypotheses, which might be better suited to a research program using an experimental approach; rather, the GRYN will use this approach to test whether or not the uncertainty about the parameter estimates warrants conclusions about the relationship between a given resource state and the reference to which it is being compared. This method is considered as a type of statistical hypothesis testing primarily because it will be extended to included comparisons with a priori reference values. However, the focus of the network will be on estimating parameters to ensure that biological and statistical significance are appropriately distinguished, following Yoccoz (1991).

Model Selection

The third general class of analyses that the GRYN will use is model selection, which helps to better understand the dynamic nature and condition of park resources. To understand these dynamics, it is necessary to advance beyond the estimation of parameters (although it is likely that parameter estimation will be included in the context of specified models) to include the relationships among resources, ecosystem drivers and stressors. A model-selection approach considers the evidence within the data in support of a suite of candidate models that represent multiple hypotheses, in contrast to a hypothesis testing framework, which seeks to determine "the" correct alternative hypothesis.

1. PRINCIPLE OF PARSIMONY

Our model selection is based on the principle of parsimony: the notion that an appropriate model should contain just enough parameters to adequately account for the variation in the data, since adding and deleting parameters has important consequences (Burnham and Anderson 2002). Under fitting (i.e., having too few parameters) can result in a model that does not adequately represent the information contained within the data. In contrast, over fitting (i.e., having too many parameters) may improve the fit of the model to the data at a cost of reducing the precision of the parameter estimates, sometimes to the point of them being of little value. Thus, the principle of parsimony leads to finding the right balance between under and over fitting the model. This balance can be expressed in terms of a tradeoff between bias (i.e., systematic lack of fit) and precision (i.e., the confidence of our parameter estimates) (Figure 7.3). The addition of parameters in a model reduces bias but also decreases precision. Likewise, reducing the number of parameters increases the precision of parameter estimation, but also increases bias. Model selection does not seek to find the "true" model (Burnham and Anderson 2002); rather, it seeks to find the best approximation of the information contained within the data by summarizing the major systematic effects together with the nature and magnitude of the unexplained (random) variation (McCullagh and Nelder 1989). Because, as Box (1979) once said, "all models are wrong, but some are useful."

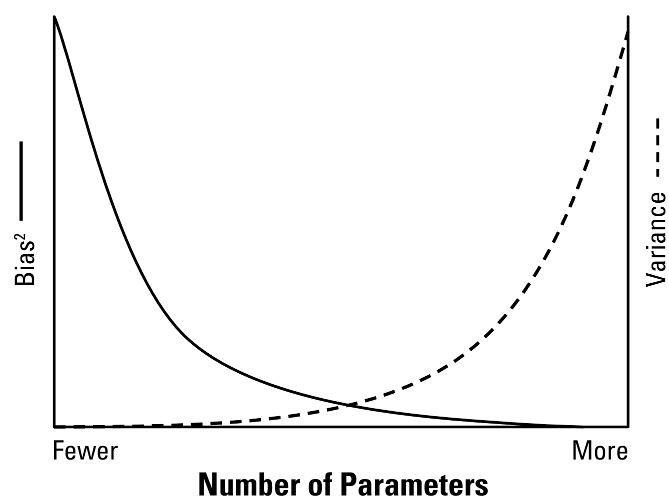


FIGURE 7.3 Conceptual diagram illustrating the tradeoff between bias and precision imposed by the number of parameters included in a given model (adapted from Burnham and Anderson 1992).

2. AN INFORMATION THEORETIC APPROACH

Given that essentially all model-selection approaches embody the principle of parsimony to some extent (Hosmer and Lemeshow 1989, Breiman 1992, Burnham and Anderson 2002), the question arises as to how the network will use this principle. Step-wise procedures, which tend to automate the model selection process by progressively filtering model terms either through the addition (forward selection) or subtraction (backward elimination) of terms in a given model have been widely criticized for producing spurious and inconsistent results (summarized by Hocking 1976, James and McCulloch 1990). In a sense, step-wise approaches to model selection essentially treat each "step" as if it were an independent hypothesis test to be "rejected" or "accepted." Further, step-wise and other mechanical selection processes (e.g., best subsets) have also been widely criticized because they can result in biologically implausible models (Greenland 1989, Hosmer and Lemeshow 1989) that frequently include "noise" variables (i.e., irrelevant) (Flack and Chang 1987). Hocking (1976) concluded that any advantages of step-wise procedures seemed to be outweighed by "all-possible" or optimal algorithms. Clearly, "all-possible" approaches can suffer from the same criticism of including irrelevant variables that are not biologically plausible.

Considerable attention has emerged in recent years regarding the use of information theoretic approaches such as Akaike's Information Criteria (AIC) (Akaike 1973) as a basis for model selection (e.g., Burnham and Anderson 2002). In contrast to treating steps of the model selection process as a series of hypothesis tests, AIC treats the model selection process as a problem in optimization of the balance between model fit and precision (Spendelow et al. 1995). AIC optimizes the fit of a model balanced against the cost of adding excessive parameters. The statistical foundation for this approach has been well described (e.g., Akaike 1973, Anderson et al. 1994, Burnham and Anderson 2002). One variation on this basic form of AIC is when overdispersion (i.e., the sampling variance exceeds the expected value for the model) is present. In such a case, traditional likelihood theory, from which AIC was derived, is not reliable and the variance may need to be generalized by using an estimated inflation factor. In this case, AIC is then modified to an alternative quasi-likelihood QAIC to account for overdispersion. The second variation on the basic form is a correction factor to account for small sample sizes which can be applied to either of the above forms as AICc or QAICc. The modifications for overdispersion and small sample sizes are discussed in detail elsewhere (e.g., Anderson 1994, Burnham and Anderson 2002).

It is recognized that this approach is not a panacea for all cases (i.e., AIC does not work equally well for all model types and situations), although it does embody the principle elements that are sought for model selection. Thus, AIC will be an essential tool for model selection, although in some cases where the situation is not conducive to AIC, the network may depart from this approach. These will be considered on an individual basis as they arise.

3. MODEL AVERAGING

When deriving inference about the dynamics and condition of park resources using model selection, we must recognize that there is uncertainty associated with the model selection itself. Buckland et al. (1997) proposed a procedure to better account for the uncertainty of model selection for deriving parameter estimates based on an average of several plausible models, rather than a single "chosen" one. This approach weights the models according to AIC values; thus the most plausible models receive the highest weight, while the least plausible models receive little or no weight. The GRYN will use model averaging for estimating parameters of interest when the parameters are derived from a selected model where alternative models exist.

Sampling Error vs Process Variation.

One of the key components of the I&M program is assessing how particular vital signs change over time. However, it is important to note that it is seldom possible to estimate parameters without some sampling error. Consequently, when looking at changes over time, it is necessary to consider that, in addition to real environmental variation that occurs over space and time in the population (and is thereby reflected in our measurements), there is also a sampling error associated with the measurement. Distinguishing these real changes in the population from measurement error is sometimes difficult. The traditional "sampling variance" that is estimated from the data typically includes an element of both types of error, which are highly confounded. Burnham et al. (1987) provide a theoretical framework for partitioning the variance into error that is attributable to sampling and parameter (process) variation. Where feasible, the network will use this, or alternative approaches as they are developed, to estimate the true variation in the populations of interest over time.

Frequentist vs Bayesian Statistics

Traditional statistical approaches, often called frequentist (and described in the above sections), are founded in the notion of probability, and rely on data generated from a given study (or studies) to derive inference. These data are typically assumed or fitted by a statistical distribution from which parameters are estimated. Inferences are typically derived from summaries and/or comparisons of the parameters being estimated in the context of hypotheses, the most common of which is the null hypothesis. As such, the inferences derived rely on the dataset(s) being used in the analysis and auxiliary information for the analysis is limited to that which can be coupled with the dataset(s) being analyzed. Thus, one of the criticisms of this approach is that information regarding the states of the system, which are not part of the study being analyzed, are either ignored completely or synthesized in an ad hoc manner to derive inference beyond the particular study.

An alternative approach that has gained increasing recognition is Bayesian statistics, where cumulative information about the parameter(s) of interest is used as a starting point in the form of a prior probability distribution. The analysis for a given dataset then derives a new (updated) distribution called a posterior probability distribution that incorporates the likelihood of the data given the prior beliefs (i.e., prior distribution). Such an approach is intuitively appealing because it takes into account all of the information accumulated on a given problem and enables a more direct assessment and description about the probability of a given hypothesis being true, rather than merely a rejection or acceptance of it being true based on a subjective threshold (i.e., the α-level or p-value of traditional statistics). Some of the drawbacks of this approach include: it is computationally more difficult; and a lack of universal agreement exists among statisticians about the nature and behavior of the distributions (particularly the prior distribution, which may incorporate subjective components as part of a probability distribution). The most logical place where a Bayesian approach seems appropriate for the network is when (if) a model-based approach to inference is undertaken (see Chapter 4). In this context, a Bayesian approach may be well suited to continually updating the beliefs about a particular model (hypotheses) as data are accumulated.

Avoiding Spurious Results

This chapter has been a basic outline of the general philosophy and guidance of the analytical approaches the network will use, and as a final component it is essential to identify the possible pitfalls associated with analyzing natural resource monitoring data. These concerns are mostly based on the overemphasis of statistical analysis as a replacement for well-designed, objective-based design and analysis and were recently reviewed by Anderson et al. (2001).

To begin, data mining is a particular area that warrants caution. The problem with data mining is not its use as a tool for exploring data for possible relationships that warrant further investigation; rather, data mining is often inappropriately used as a hypothesis-testing tool instead of a hypothesis-generating tool. An example of possible data mining within the I&M program is co-location of samples under a generalized design. Although co-locating samples may generate new hypotheses, assuming that such insights will emerge without a priori thought about the expected relationships has a high risk of producing spurious results.

Another commonly encountered pitfall is the overuse or inappropriate use of statistical tests of significance (Cherry 1998). One problem is overuse of null hypothesis testing, which may have little or no biological meaning (Anderson et al. 2000). Another problem is that statistical tests are usually based on probability (e.g., Yates 1951, Cox 1977, Cherry 1998, Anderson et al. 2000) with an arbitrary P=0.05 level frequently used as a standard. Such an arbitrary threshold may have little or no relationship with what is considered biologically meaningful (Cherry 1998).

A corollary concern relates to analysis of multidimensional data. Multidimensional data often have an inherently complex structure that, when analyzed using many common multivariate statistical techniques, have a high probability of producing spurious results (Rextad et al. 1988, Anderson et al. 2001). This is less a result of inherent flaws with the underlying statistical theory of such approaches as it is a tendency for the practitioners to extend the inference beyond the analysis. James and McCulloch (1990) reviewed this topic and concluded that such approaches "can only hint at roles, processes, causes, influences and strategies". Other authors (e.g., Stauffer et al. 1985, Flack and Chang 1987) have recognized that "statistically significant" results can emerge even when the source data are random numbers. Therefore, while multivariate methods may be a valuable exploratory tool, interpreting these approaches as emerging ecological insights should be approached with caution.

GRYN Analysis Summary

In the previous sections of this chapter, we described the general philosophy and types of analyses we anticipate for the GRYN program. Here we summarize specific analyses we anticipate for those vital signs for which the development has reached this stage.

1. AMPHIBIANS

Estimating Occupancy Our measure of amphibian populations, and changes in those populations, would be based on the proportion of sites occupied (MacKenzie et al. 2002). This measure: (1) explicitly enables estimation of local extinctions and colonization rates (MacKenzie et al. 2002); (2) takes into account detectability of individual species (MacKenzie and Kendall 2002); (3) enables estimation of confidence intervals; (4) is comparable across sites and

(5) is becoming a widely accepted approach for reliable estimates of occupancy.

The general canonical estimator of occupancy follows that of capture-recapture models where the estimate of the population is:

$$\text{Population} = \frac{\text{Count}}{p}$$

where the count represents the number of animals observed and p represents the proportion of the animals present that are detected (Nichols 1992). Occupancy is an extension of this estimator such that:

$$\text{Occupancy} = \frac{\text{Presence}}{\hat{p}}$$

where occupancy of a given site can be represented over time and/or space as an encounter history where the sample occasion is assigned a "1" if the species is observed to be present and a "0" otherwise. In this fashion, an encounter history can be constructed such that 101 represents a species that was observed on the first sampling occasion, not observed on second sampling occasion, and observed again on the third (last) sampling occasion. From this encounter history likelihood can be constructed such that the likelihood for occupancy of site i with encounter history 01010 is:

$$\Psi_i = (1 - p_{i1})\, p_{i2}\, (1 - p_{i3})\, p_{i4}\, (1 - p_{i5})$$

and for which covariates can be incorporated into the model as a logistic model. Model selection (e.g., using AIC or alternative approaches) can then be incorporated to evaluate a suite of models with and without spatial or temporal effects including covariates of interest. Two software programs, PRESENCE (Mackenzie et al. 2003) and MARK (White and Burnham 1999) were developed for estimating a variety of parameters using marked individuals and can accommodate occupancy estimation and associated parameters. Both programs are available free of charge.

2. LANDBIRDS

Our field sampling approach for monitoring landbird populations is based on distance sampling (Buckland et al. 1993, 2001) with some minor refinements in the design to facilitate estimation of some parameters. Our objectives, and consequently analyses would focus on estimating the (1) distribution of select species within a given habitat of concern, (2) the abundance (density) of select species within a given habitat of concern, and (3) the community composition (e.g., species richness) within a given habitat of concern. The specific species of concern would be those that are obligates or depend substantially on the habitat of concern and species that have particular management interest or relevance.

Estimating Distribution The estimation of site occupancy, as described for amphibians, would be our primary type of analysis for evaluating distribution and changes in distribution. However, as it was originally conceived (e.g., MacKenzie et al. 2002) multiple visits to a given site over time is used to estimate detectability. In this framework the presence-absence (encounter history) of a given species is defined as a binary random variable assigned as 1 if a given species is detected at site i at time t and 0 if a given species is not detected at site i at time t. A problem for application of this framework for monitoring landbirds within the GRYN is that a given site will not be visited more than once within a year. Thus, an alternative is to consider replication over space rather than time. For this approach, the transect is considered as the sampling unit and the presence-absence of a given species is similarly defined as 1 if a given species is detected at a given point or section along the transect and 0 if otherwise.

Based on our sampling design we have drawn a sample of units (transects) from a given habitat type. Thus, the general inference for a given species that can be derived from this approach is to estimate the proportion of a given habitat type that is occupied by that species.

The general likelihood for estimating site occupancy was described by MacKenzie et al. (2002), and estimation of occupancy and its variance can be accomplished using either program PRESENCE (Mackenzie et al. 2003) developed explicitly for estimating occupancy and associated parameters, or the more general program MARK (White and Burnham 1999) developed for estimating a variety of parameters using marked individuals. Both programs are freely available and can be downloaded.

Estimating Abundance (Density) The estimation of density based on distance sampling would be the primary analysis for our objective related to abundance. Distance sampling represents a unification of its precursors in transect sampling (Hayne 1949, Eberhardt 1968, Gates et al. 1968, Burnham and Anderson 1976, Burnham et al. 1979) and variable circular plot sampling (e.g., Ramsey and Scott 1979) and has been summarized in considerable detail by Buckland et al. (1993, 2001). Central to the concept of distance sampling is the detection function. This is the probability of detecting an object, given that it is at a specified distance from the transect line or point. Using this approach, our primary analyses would be deriving estimates of species specific densities within our habitats of interest. Details of how detection functions are constructed and selected is beyond the scope of this report and provided by Buckland et al. (2001). Available software (Program DISTANCE) (Thomas et al. 2004) is available free of charge and accommodates a full suite of options for estimating parameters, incorporating covariates and selecting among alternative models using the model selection concepts described earlier in this chapter.

Estimating Community Level Parameters Biological diversity is recognized as one of the core indicators of the productivity and sustainability of the earth's ecosystems (Christensen et al. 1996, Nichols et al. 1998). Additionally, the protection of native species and their habitats is one of the primary challenges outlined in the NPS Natural Resource Challenge (National Park Service 1999). Thus, estimating species richness and change in species richness over time will be integral components of our analyses of bird monitoring data. One of the problems with estimating species richness from observations of animals is that, like individuals within a population, all species are not detected with equal probability (Boulinier et al 1998). To account for this concern an approach was developed that incorporates detection probabilities derived from encounter histories using the general approached described above for estimating occupancy (Boulinier et al. 1998, Nichols et al. 1998). Software to estimate species richness and associate parameters using this approach (i.e., program COMDYN) (Hines et al. 1999) is also available free of charge.

For the GRYN, one of the primary parameters of interest is not just species richness, but relative species richness. Nichols et al. (1998) defined relative species richness as the ratio of species richness for two locations, which is estimated as:

$$\hat{\lambda}_i^{xy} = \frac{\hat{N}_i^y}{\hat{N}_i^x}$$

Relative species richness, as defined by Nichols et al. (1998) enables comparison among areas receiving different management or experiencing different disturbances. An additional application would be to include relative species richness among groups of interest. For example, we may be interested in the ratio of native species to exotics. We would anticipate also assessing how the ratio of such groups (e.g., native and exotics) is changing over time.

3. Whitebark Pine

Estimating the Proportion of Infected Trees One of the key parameters we want to estimate for whitebark pine monitoring is the proportion of trees infected. There are two widely used approaches for such estimates from two-stage cluster designs, an unbiased estimator and a ratio estimator. An unbiased estimator certainly sounds intuitively appealing, since knowingly allowing bias seems undesirable. However, this estimator tends to be inefficient when cluster sizes (i.e., the primary sampling units) are of unequal size (as is the case for whitebark pine stands) and when the population sizes of the primary sampling units tends to be proportional to the cluster sizes (as we might also expect for whitebark pine). Further, the variance derived from this estimator tends to be large when cluster sizes are unequal. The alternative approach, to which we are most likely to use, is a ratio estimator. The variance of the ratio estimator has two components; one measuring the between cluster variability and one measuring the within cluster component. Although the ratio estimator is biased, it is preferred in this case because the bias tends to be very (negligibly) small and the precision of our estimates would likely be substantially better than for the unbiased estimator. The formula of these estimators, including the variance components can be somewhat complicated and are readily found in most sampling texts (e.g., Lohr 1999). We would use the same analysis approach to estimate the mean severity index.

Estimating Survival There are several analytical approaches (models) available for data in which the status (i.e., fate in the context of survival estimation) of an individual can be determined at any given time. Whitebark pine would fit into this category because all trees in our sample have been individually marked and trees do not move between sampling occasions (at least with respect to determining their fate). These known-status models can be further classified based on how they treat time (Conroy et al. 1996). In one approach, time corresponds to the discrete intervals separating sampling periods and survival is viewed as a binomial process. Thus, familiar statistical models (e.g., logistic regression) can be applied (Nichols 1996). The second class of models is based on time to a specified event (e.g., death or censoring) (Lee 1980). We anticipate using both approaches in our analyses of whitebark pine. Time-to-event models such as the Kaplan-Meier estimator (Kaplan and Meier 1958) would likely be used for deriving estimates of survival and its variance; whereas, discrete interval models, such as logistic regression, would likely be used in the context of evaluating the effects of covariates on survival.

4. CLIMATE

Climate is a primary driver of almost all physical and ecological processes in the GRYN. As such, most of our analyses are likely to be descriptive summaries at various spatial and/or temporal scales that would be used in a variety of contexts including assessment of change and as covariates for analyses of other vital signs.

Primary Climatic Elements For our primary climatic elements (i.e., temperature and precipitation), we would anticipate the flowing summaries at a minimum:

Daily Summaries

- Daily Precipitation (mm)
- Daily minimum and maximum temperature (° C)

Monthly Summaries

- Mean monthly precipitation intensity (mm)
- Mean monthly minimum and maximum temperature (° C)
- Number of wet and dry days
- Number of days with temperature below 0° C
- Number of days with temperature above 35° C

Annual Summaries

- Mean annual precipitation intensity (mm)
- Mean annual minimum and maximum temperature (° C)
- Number of wet and dry days
- Number of days with temperatures below 0° C
- Number of days with temperatures above 35° C

Secondary Climatic Elements For our secondary climatic elements, we would anticipate the flowing summaries:

15-minute intervals

- Wind Speed (m/s)
- Wind Direction (degrees)
- Relative Humidity (percentage)
- Soil Surface/Near Surface Temperatures (~10 cm) (° C)

Hourly

- Incoming Solar Radiation (W/m2)

Daily

- Soil Temperatures at Depth (~ 1 m)
- Daily mean, minimum and maximum (° C)

5. LAND USE

Changes in characteristics of land use and cover are usually expressed as rates of change from one time period to the next. Change in all of the metrics described above for land use will be assessed in this way. Specifically, percent change will be calculated as [(current value – value at last time period)/value at last time period]. For example, if there are 50 rural homes in a given section in one time period, and 75 homes in the next time period, the rate of change would be [(75-50)/50] = 0.5, or 50%. Rates of change in characteristics of land use can be charted starting with the second monitoring time period and trend analysis should occur at each monitoring time period after that. Additionally, trajectories of change can be calculated by overlaying maps from two time periods.

6. WATER QUALITY

Once the water quality data have been collected, they will be summarized and presented in an organized manner. This will help identify potential outliers or errors. Descriptive statistics (readily available with the MS Excel Data Analysis Toolpak) should be performed for all data collected. Data will be summarized in this manner each time results are received (from lab or field). These statistics include:

- Mean
- Standard Error
- Median
- Mode
- Standard Deviation
- Sample Variance
- Kurtosis
- Skewness
- Range
- Minimum
- Maximum
- Sum
- Count
- Confidence Level (99.0%)

Routine trend and other standard statistical analyses will be done according to Helsel and Hirsch (1992), which has been re-published as an online text at: http://water.usgs.gov/pubs/twri/twri4a3/html/pdf_new.html.

REPORTING

For the GRYN to be successful in communicating its purpose and progress toward inventory and monitoring, it is essential for the network to focus on the following internal audiences: 1) the National I&M Program and Congress; 2) the GRYN Board of Directors, Technical Committee and Science Committee; 3) Yellowstone National Park, Grand Teton National Park and Bighorn Canyon National Recreation Area park managers and employees; and external audiences, including: 4) the academic community; 5) other government agencies; 6) nonprofit/non-governmental organizations; and 7) the general public. Reports directed towards these audiences, including the purpose and frequency of each report, are described in Table 7.1. This list includes both those reports required by the National I&M Program and additional reporting mechanisms developed by the GRYN to communicate its progress in an effective manner. These reports should also provide a source of accountability for mandates, such as the Government Performance and Results Act, as outlined in the Strategic Plan.

In addition to developing reports for the aforementioned audiences, the GRYN will begin the task of expanding its reporting procedures through a Web-based interface. This Web-based communication mechanism will allow the GRYN to provide background data and information to a large audience with relative ease, compared with printed reports. The network is also pursuing a Web-based interface due to its easy accessibility by park managers and the ease with which it may be updated when new information is acquired. A possible format for the design of the Web-based interface is included in Figure 7.4.

Making the Reporting Relevant

The greatest science in the world will do us little good if it does not find its way into the management decision process. The goal of the GRYN is to provide the right type of information, in the right form, to the right people, at the right time. Previous discussions in this report regarding selection of vital signs and determining the objectives focused on obtaining the right type of information. Getting it in the right form, to the right people, at the right time is a different matter altogether.

It is naive to assume that the form in which information is distributed to the scientific community (e.g., technical reports and peer-reviewed journal articles) will be equally useful to managers. Scientific articles and reports serve to establish the credibility of the information, but do little to ensure the utility of the information. Effective transfer of information will not likely occur without consideration of the audience and the needs of that audience. For example, the scientific community would likely need to see detailed methods, statistical analyses, models, etc. to establish the validity of the science. In contrast, such detailed information might be excessively cumbersome for a park superintendent who may need a synthesis of the information (see text box 7.1 on the following page) that is concise, understandable and applicable to the management context.

Getting the information in the right form also requires recognition that, in addition to the network distributing information in various forms to different users, users also seek information from the network, most notably via the Internet. This group of users can be loosely divided into casual or opportunistic users, who obtain information from the network infrequently and for specific purposes or just through Web surfing. For network information to be useful to this group, the information must be accurate, interesting and well presented. Another anticipated subset of users within those that seek information from the network is those that use the network information as a routine resource. For this group, the information must meet all of the standards above but must also be consistent in presentation and form. Users intending to use the network as a resource may quickly lose interest if they find it difficult to find the information they need and/or the information is not of consistent form and quality. Consequently, our Web-based information delivery will incorporate a hierarchical structure that should enable different targeted audiences to quickly find the information that they need and in a usable form (Figure 7.5).

FIGURE 7.4 Example of hypothetical Web site that might be used to report information being distributed by the GRYN.

TEXT BOX 7.1 Example of Synthesis Intended for Park Managers

Each year, in an effort to increase the availability and usefulness of monitoring results for park managers, the network coordinator will take the lead in organizing a one-day "Science briefing for park managers" (possibly in conjunction with other resource management workshops currently being conducted by network parks) in which network staff, park scientists, USGS scientists, collaborators from academia, and others involved in monitoring the parks' natural resources will provide managers with a briefing on the highlights and potential management action items for each particular protocol or discipline. These briefings may include specialists from the air quality program, fire ecology program, Research Learning Center, and collaborators from other programs and agencies to provide managers with an overview of the status and trends in natural resources for their parks. Unlike the typical science presentation that is intended for the scientific community, someone representing each protocol, program, or project will be asked to identify key findings or "highlights" from the past year's work and to identify potential management action items. The scientists will be encouraged to prepare a one or two page "briefing statement" that summarizes the key findings and recommendations for their protocol or project; these written briefing statements will then be compiled into a 'Status and Trends Report' for the network. In the process of briefing the managers, the various scientists involved with the monitoring program will learn about other protocols and projects, and the process will facilitate better coordination and communication and will promote integration and synthesis across disciplines.

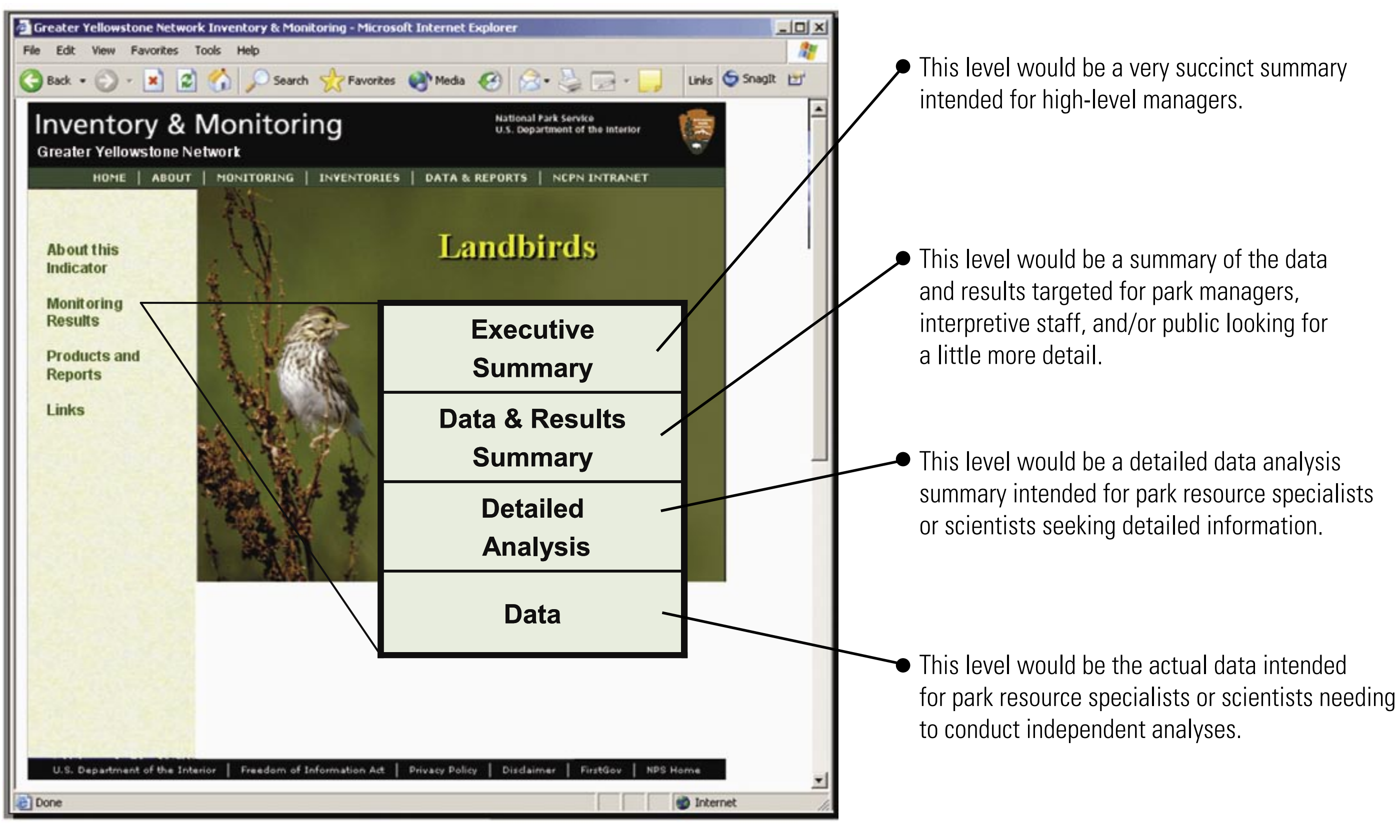


FIGURE 7.5 Example of hierarchical structure of results that would target different audiences.

The timing of our reporting is also critical for making information useful. Providing a manager with important new information about the effects of fire on an ecosystem three months after the fire management plan is due is not an effective way to incorporate learning into decisions. In contrast, knowing something about when decisions are made can be a great asset if information delivery is planned from the outset to coincide with when decisions are made. Clearly, communication between scientists and managers will shed some light on this issue, but another form of conceptual model can also help to clarify this information. One approach that the GRYN will use to help facilitate timely delivery of information will be to develop a simple model of the decision space (Figure 7.6). Such a model can include processes or plans for which decisions are expected. It can also include relevant information about who the key players are for a given decision. Unfortunately, it will not likely include all of the decisions for which information would be useful and, thus, will not replace the need for communication.

Even with the right type, form and timing of information, there still needs to be a planned mechanism to effectively enable monitoring information to influence the decision process. There have been a wide variety of approaches for integrating information into the decision process, ranging from formal mathematical procedures for deriving an optimal policy using discrete stochastic dynamic optimization (e.g., Kendall 2001) to scientists and managers simply sitting down at the table to discuss the implications of the science to management. The GRYN does not advocate that the decision process must follow a specific approach; instead, we advocate using the most suitable approach for a given context and suggest that the approach should be explicit and planned.

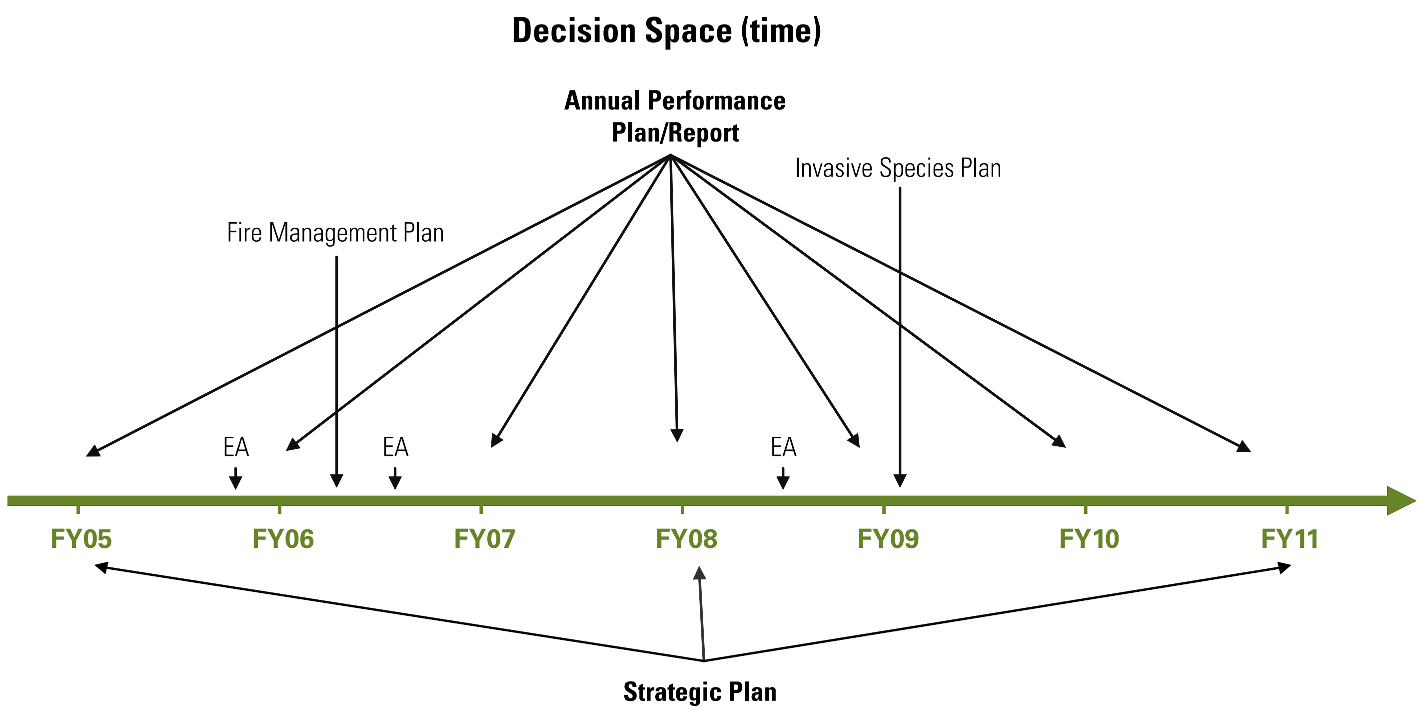


FIGURE 7.6 A conceptual model of the decision timing (e.g., plans likely to require decisions) for a given national park.

TABLE 7.1 Reports developed by the GRYN, including the frequency, purpose, author and format of each report.

Title	Purpose of Report	Frequency	Primary Audience	Author	Format
Annual Administrative Report and Work Plan	Account for funds and FTEs expended. Describe objectives, tasks, accomplishments, products and budget for the previous year and those proposed for the following year	Annual; due to WASO with draft work plan in early November and final work plan by January 31	Superintendents, technical committee, GRYN staff, regional coordinators and service-wide program managers. Administrative report used for annual report to Congress	Network program manager, with additional input from network staff; Technical Committee reviews; Board of Directors approves	Format of the report is outlined by the service-wide I&M program each year
Monitoring Protocols	Document the rational for why a particular resource is being monitoring and describe measurable objectives, sampling design, field methodology, data analysis and reporting, personnel and operational requirements	Once for each vital sign (or group of vital signs), with revisions as needed	Network staff and others who implement all or portions of the monitoring protocol	Individual investigators or responsible GRYN staff	Should follow the guidance outlined in Oakley et al. 2003 (see also Chapter 5)
Inventory Project Reports	Document the methods and results of the inventory project; provide a list of species officially documented and locations sampled	At least once at the end of the inventory, although annual progress reports are recommended	Superintendents, park resource managers, GRYN staff, service-wide inventory program managers, external scientists and public	Inventory project leader	Varies by project
Trend Analysis and Synthesis Reports	Describe and interpret trends of individual monitored resources in order to provide a picture of overall ecosystem health. Highlight resources in need of management action	Trend Analysis and Synthesis Reports at 5 year intervals	Park resource managers, GRYN staff, external scientists and interested public	Network staff (particularly the ecologist)	To be determined
Program Review Reports	Review operations and protocols and determine needed changes. Used as a formal review of program and protocols	Five-year intervals, starting in 2008	Superintendents, technical committee and GRYN staff	Initiated by program manager, with input from staff and cooperators	To be determined
Annual Report to Superintendents	Summarize annual activities of the network. Highlight key findings and recommendations for non-technical audiences	Annual	Superintendents, park staff and interested public	Program manager, with staff contributions	To be determined

Journal Articles and Book Chapters	Document and communicate advances in knowledge	Variable	External scientists, park resource managers	Program manager, staff and cooperators	Determined by journal or book publisher
Symposia, workshops and conferences presentations	Communicate I&M goals, network activities and specific results. Review and summarize latest findings and emerging issues	Variable	Symposia, workshop and conference participants	GRYN staff	Varies
GRYN newsletter	Describes current happenings in the GRYN and findings of general interest.	Quarterly	Park staff, agency partners and cooperators	GRYN staff	Follows standard newsletter format
Public Brochures	Describe ongoing monitoring efforts and problem statements pertaining to vital signs of interest	Variable	To provide a synopsis of the reasons for monitoring various vital signs in a format written for the general public	GRYN staff (generally, ecologist and research associate)	Varies; should generally follow the format for whitebark pine for interagency projects
Data Management Report	Describes the plan for managing data pertinent to GRYN monitoring	Final version complete in FY05, with continual revisions as needed	GRYN and park staff	Data manager (with help from other network data managers)	Determined by national data management report team of authors
Web site	Online method for distributing information about GRYN activities	To be determined	Various audiences; Web design offers multiple levels of information	Data manager (with help from a Web designer)	To be determined

8. Administration/ Implementation of the Monitoring Program

This chapter includes information on the administrative structure of the Greater Yellowstone Network, including staffing, operations and integration with other programs.

Administration

Governing Structure

The governing structure of the network includes a Board of Directors and a Technical Committee made up of National Park Service representatives. Program administration is governed by the Service-wide I&M program, which provides monitoring program goals and overall planning guidance.

1. Board of Directors

Overall direction for the GRYN is provided by a Board of Directors (BOD), which consists of the superintendent (or superintendent's designee) of Grand Teton and Yellowstone National Parks and Bighorn Canyon National Recreation Area and the Intermountain Regional I&M coordinator. The major responsibilities of the BOD include promoting accountability and reviewing, and approving annual accomplishments, work plans and budgets.

2. GRYN Charter

The GRYN charter—approved by the BOD in August 2003—describes the basic practices used to plan, organize, manage, evaluate and modify the efforts of the GRYN. The charter also explains the roles and functions of the BOD and Technical Committee and establishes a Science Committee for help and guidance during the three phase planning period. The network charter is located in Appendix X.

3. Periodic Review

A schedule for periodic review of the monitoring program will be added to the network charter to encourage continuous improvement and allow for modification of the program. Reviews will focus on implementation of the program and the effectiveness in achieving programmatic goals (as well as specific monitoring objectives) and will serve as a way to determine if the program is meeting the needs of the network parks.

Table 8.1 The GRYN will undergo several types of periodic reviews to ensure accountability and continuous improvement in the program.

Category of Review	Schedule/ interval between reviews	Principle reviewers
Annual data summaries	Annual and when sampling frame is complete	Project manager; program staff
Evaluate progress and results in order to inform work plans and protocols.		
Evaluate QC/QA and data stewardship practices to ensure data quality.		
Protocol review	At the completion of sampling frame	Staff ecologist; Science advisors
Has the targeted population/strata been adequately presented in the sample?		
Program review	Five-year interval	Board of Directors
Are monitoring protocols meeting park information needs and I&M standards for scientific defensibility?		

Administrative Structure

1. Administrative Support

The network receives the majority of its administrative support from the Intermountain Region (IMR) in Lakewood, Colorado. This support includes personnel functions such as: 1) position classification, recruitment, human resources and development; 2) budget and contracting obligations through cooperative agreements, interagency agreements and contracts; and 3) property management and inventory. This arrangement is made possible through a one-year service agreement between the IMR and the participating networks (GRYN and Rocky Mountain Network), and involves a shared administrative assistant (duty stationed in Lakewood) who is supervised by the regional I&M coordinator. The assistant handles time and attendance (payroll input), requests for personnel actions, travel authorizations and vouchers, small purchasing, budget tracking and expenditure transfers.

2. Supervision

The program manager is supervised by the IMR inventory and monitoring program coordinator. The program manager supervises permanent and temporary NPS employees.

3. Office Location

The Greater Yellowstone Network is currently located on the campus of Montana State University (MSU) in Bozeman, Montana.

STAFFING

Core Network Staff

Three staff members make up the "core staff" of the GRYN, including the program manager, data manager and ecologist. These three hold responsibility for vital signs planning and, together with affiliate park staff and cooperators, will implement the program. During the three-phase planning, Big Sky Institute augmented core staff with a research associate and project coordinator. Core staff members are duty stationed at network headquarters in Bozeman, Montana.

Flexible Staffing Plan

Staff needs during implementation will be driven by the overall monitoring design and resultant technical needs. The roles, responsibilities and duty stations of staff, particularly field sampling crews, will depend on the requirements described in the monitoring protocols that are under development (see Appendix VI - Protocol Development Summaries). For this reason, the GRYN requires a flexible pool of capable individuals to initially implement monitoring protocols, conduct pilot studies, perform data management projects and assist in the analysis and reporting of monitoring data. Options include: hiring NPS personnel; hiring CESU cooperators (normally through universities); creating interagency agreements; and hiring government contractors.

At the same time, experience demonstrates that having a professional NPS staff bridge the planning and implementation process fa-

TABLE 8.1 Duties of core network staff.

Core Staff	Role & Responsibility
Program Manager	The program manager is responsible for the overall management and supervision of the program. The program manager carries out these duties by developing work plans and schedules, scopes of work and coordinating network activities with the Technical Committee. The program manager coordinates with similar programs on adjacent lands and appropriate regional and national monitoring programs. The program manger also serves as staff to the Board of Directors and the Technical Committee.
Data Manager	The data manager is responsible for the information and data stewardship of the program. The data manager performs the following duties: designs, develops and manages complex database systems for the long-term maintenance, analysis and dissemination of natural resource data sets; and management of the GIS and database management software, GPS data dictionaries and spatial data inventories.
Ecologist	The ecologist is responsible for the scientific and statistical components of the program. The ecologist designs, develops and tests long-term monitoring protocols, as well as directing data collection procedures and conducting analysis of data. The ecologist also reports the significance of findings to park managers and interested public.

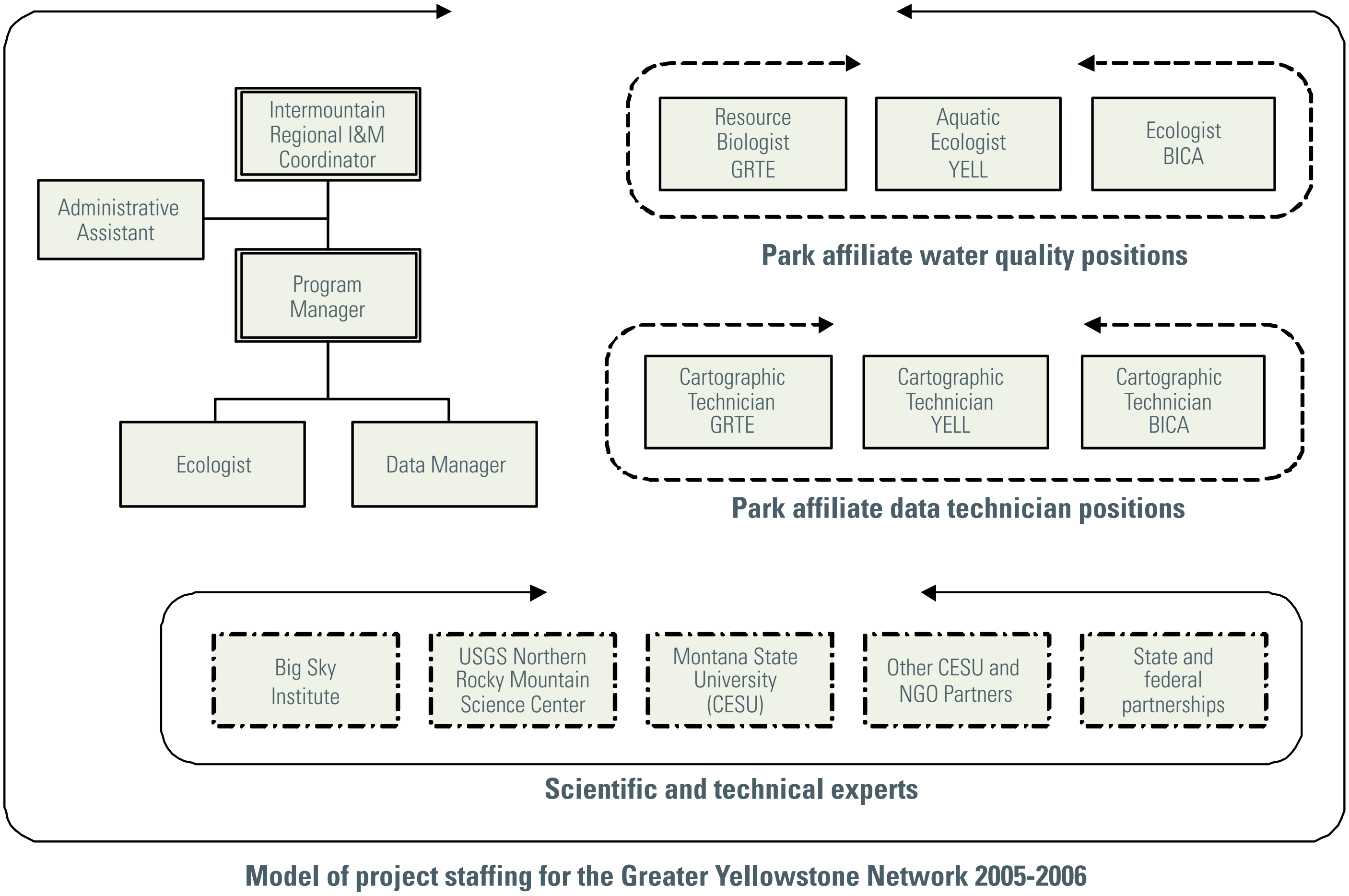


FIGURE 8.1 Staff organizational chart showing core and affiliated staff positions.

cilitates working with network parks and will ensure stronger, more relevant products emerging from these cooperative relationships. To increase overall effectiveness, the GRYN may hire staff members who are duty stationed in network parks or rely on existing park natural resource staff for part of the monitoring. A core staff, along with affiliated park staff can provide the continuity among program staff and a programmatic history essential to the success of a long-term monitoring program.

Decisions to identify affiliated park positions such as project leaders and/or crew members will only be exercised when the following requirements can be met: 1) capable staff already exist at the park and are available to conduct monitoring; 2) the park can provide work space; and 3) there are mechanisms in place to assure the work is completed following the guidelines in the monitoring protocol and the schedule established in the annual work plan. One example where GRYN is working with affiliated park staff is in the integrated and regulatory water quality monitoring program.

Critical results

Once staffing needs have been filled and individuals are assigned to monitoring projects, it is important that the employee has a clear understanding of his/her roles and responsibilities. Managing individual performance and seeing that the employees carry out their assigned duties according to established protocols is the responsibility of the supervisor. Communication is especially important when a park employee is assigned to the responsibility of collecting data for the network. In these instances, it is essential that the primary supervisor interact with the network program manager to develop and evaluate employee performance, as established in the annual employee performance plan.

OPERATIONS

Safety

Safety of field personnel is the first concern in conducting a monitoring program. Numerous safety issues and concerns arise as field personnel come in direct and indirect contact with waterborne pathogens, chemicals and potentially hazardous plants and animals. Weather conditions can be extreme. Field work requires an awareness of potential hazards and knowledge of basic safety procedures. Network safety procedures (Safety and Health Standard Operating Procedure) provide for safety checklists and employees are referred to Chapter A9 of the USGS National Field Manual (NFM) for the complete recommended safety procedures. In addition, employees are instructed to contact local park safety officers for information regarding local problems or issues such as bear or fire closures or avalanche hazards.

Training

Well-trained employees who repeat the monitoring protocol year after year provide for continuity and a successful quality assurance program. The development of standard operating procedures (SOP) alone does not guarantee that high-quality data will be collected. A training program will assist field and laboratory staff in obtaining a clearer understanding of data collection procedures described in the SOPs and should be held prior to the initiation of routine data collection and include a trainee certification process. Core network staff will see that employees engaged in monitoring have adequate skills and experience to conduct monitoring.

Equipment

The network will normally supply the equipment and supplies necessary to conduct monitoring. Property and equipment will be managed according to Directors Order #44: Property Management. Sensitive property (cameras, computers, etc.) and property sensitive to theft, loss or damage (GPS units, radios, binoculars) will be managed as accountable property and furnished according to need using form DI-105: Receipt of Property. The purchases of equipment likely to depreciate will be scheduled over time to reduce the impact of replacing substantial amounts of equipment in any given year. Calibration of equipment will follow manufacture directions and will be included as part of an appendix to the monitoring protocol. Vehicles will normally be leased through General Services Administration (GSA), although the network has purchased one multi-passenger vehicle that is available for use.

Laboratory Space

There is an anticipated need for laboratory operations for the water quality monitoring program. The Yellowstone Center for Resources – Aquatic Resource Division has an aquatic lab in operation during the summer at Lake. This lab is equipped with a muffle furnace, gravity flow Isotemp drying oven, analytical balance, and a Millipore water purification system and has the capacity to prepare samples for storage and transport, sort macroinvertebrate samples to identify and count New Zealand mudsnails, and oven dry and weigh samples to calculate total suspended sediments. Samples collected for water chemistry, nutrients and/or metals will be shipped to a certified lab for analysis. GRTE and BICA each have the capacity for a wet lab where samples can be stored and packaged for transport to a lab for analysis.

INTEGRATION

Following is a hypothetical example of how the I&M program might integrate with ongoing monitoring for fire in the parks to develop a highly informative, cost-effective program based on Key and Bennetts (2004). Integration of monitoring programs within and among agencies can be a long and arduous process due to a variety of extenuating circumstances, such as different objectives, dissimilar levels of funding and/or different funding sources and disagreement as to the best way to integrate. Yet, a lack of integration can lead to wasting resources and duplicating effort. Therefore, while the GRYN realizes the possible difficulties of partnering with other agencies, it is essential to the monitoring effort to share information and resources to produce the most informative monitoring data available in the GRYN parks. Thus, while the GRYN has already begun to create partnerships with other agencies, it is also necessary to identify an overall plan for integration, particularly in areas where the potential is obvious, such as with fire, invasive plants and water quality. Following is an example of how the I&M program may integrate with ongoing monitoring for fire in the parks to develop a highly informative, cost-effective program.

Fire management in the national parks consists of a fairly developed program concentrated on fuels reduction, fire behavior and threats to human life and property. Thus, while the fire management program is always in place, the focus of its resources is centered upon an actual fire event, instead of the long-term pre-burn and post-burn ecology of the area. Conversely, the I&M program focuses on long-term ecological monitoring, which could include post-burn effects of fire on the ecology of the system, including both vegetative and animal communities. Furthermore, the fire management program also promotes the use of fire for restoration of communities. While their objectives (i.e., reduction of shrub cover by 50%) may have a different focus than I&M objectives (i.e., improvement of wildlife habitat for pronghorn), many times the objectives can be complementary. In addition, the fire management program may have used the objective of the I&M program as the impetus for performing a prescribed burn. Thus, integration between the groups could lead to increased efficiency and knowledge. This example illustrates the ability of the programs to integrate on prescribed burn issues; however, it is also important to integrate on post-burn monitoring. While the fire management program may receive most of it's funding to prevent and fight fires, the I&M program's focus will be on the long-term, or "second-order", effects of fire on an ecosystem. These long-term effects may include landscape recovery, seed bank availability, erosion potential, etc.

While these illustrations are cursory, it is important to note that integration among agencies is essential to a successful monitoring program, as resources are always limited. These methods of integration can be applied to other programs, such as invasive species and water quality.

Partner agencies and organizations

1. GREATER YELLOWSTONE COORDINATING COMMITTEE

The Greater Yellowstone Coordinating Committee (GYCC) was developed in 1964 when the National Park Service and the U.S. Forest Service signed a formal Memorandum of Understanding (MOU) that provided for mutual cooperation and coordination in the management of core federal lands in the GYE. Revised in 1986, the committee includes the following participants: park superintendents from Grand Teton and Yellowstone National Parks; the regional director of the NPS Intermountain Region; the regional forester of the USFS Rocky Mountain Region; forest supervisors from six national forests; and refuge managers from two wildlife refuges within the GYE. The role of the GYCC is to provide leadership, guidance and coordination among the national parks, national forests and national wildlife refuges. The GYCC has established several priority areas that overlap with the vital signs selected for the network. These include land patterns, GYE waterways invasive species management and whitebark pine management (Greater Yellowstone Coordinating Committee 2004).

Various subcommittees carry out the on-going coordination within the GYCC. The Northern Yellowstone Cooperative Wildlife Working Group, which includes biologists from Yellowstone NP, Gallatin NF, USGS and Montana Fish Wildlife and Parks, coordinates and standardizes survey methodology, timing and reporting and also identify research priorities for antelope, mountain goats, bighorn sheep, mule deer and elk using the Northern Range (Greater Yellowstone Coordinating Committee 2005).

2. ROCKY MOUNTAINS COOPERATIVE ECOSYSTEM STUDIES UNIT

The Rocky Mountains Cooperative Ecosystem Studies Unit (RM-CESU) is a National Park Service program whose mission is to "improve the scientific base for managing ecosystems in the rapidly changing social, cultural and environmental landscape in the Rocky Mountain Region…" (RM-CESU 2004). Through the CESU, the network can gain access to university and nonprofit members for technical assistance needed to develop and implement the monitoring program. Appendix IX shows a list of past and present CESU cooperators involved in helping the network design the monitoring program.

3. BIG SKY INSTITUTE AT MONTANA STATE UNIVERSITY

The Big Sky Institute for Science and Natural History (BSI) was established in 1999 to "increase the understanding, knowledge and appreciation of the natural and cultural environment by linking education and interpretive programs related to natural ecosystems and the human communities that depend on them " (Big Sky Institute 2004). BSI plays an important role in day-to-day operations of the network by providing guidance as well as professional staff and students instrumental in planning and preparing monitoring protocols.

4. UNIVERSITY OF WYOMING— NATIONAL PARK SERVICE RESEARCH CENTER

The University of Wyoming – National Park Service (UW-NPS) Research Center is a cooperative effort between the University of Wyoming and the National Park Service to "provide excellence in research by furnishing housing, laboratory space, transportation, equipment and financial support to enable investigators in the biological, physical and social sciences access to the rich and diverse environments of Grand Teton and Yellowstone National Parks…" (University of Wyoming 2004). The research station is located at AMK Ranch in Grand Teton National Park and has furnished housing and laboratory space to university cooperators working with the network on biological inventories.

5. USGS NORTHERN ROCKY MOUNTAIN SCIENCE CENTER

The USGS Northern Rocky Mountain Science Center (NRMSC), based at Montana State University, conducts "research in support of natural resource management in the mountains and plains of Wyoming, Montana and Idaho" (USGS 2004). Examples of research that are relevant to GRYN vital signs monitoring include: the Interagency Grizzly Bear Study Team (IGBST), which conducts research on the status and trends of threatened grizzly bear populations and their food sources in the

GYE and the Amphibian Research and Monitoring Initiative, which conducts amphibian monitoring along the Rocky Mountain Transect (Rocky Mountain National Park to Glacier National Park). Additionally, the NRMSC is the regional node for the National Biological Information Infrastructure (NBII). This node will provide Internet access to existing and late-breaking information as well as educational and analytical tools needed to make effective use of the information.

6. National Forest Inventory and Analysis Program

The mission of the USDA Forest Service Forest Inventory and Analysis (FIA) program is to conduct and continuously update a comprehensive inventory and analysis of the present and prospective conditions of the renewable resources of the forest and rangelands of the United States. The FIA is the only program that provides consistent and credible annual data for all forest lands (public and private) within the United States. Public and privates lands in the GRYN are covered by the Interior West FIA (IW-FIA) unit, part of the Rocky Mountain Research Station (USDA 2005)

7. National Weather Service

The National Weather Service (NWS) provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. The NWS data and products form a national information database and infrastructure which can be used by other governmental agencies, the private sector, the public, and the global community (NWS 2005).

9. SCHEDULE

INTRODUCTION

Scheduling is an important aspect of a successful monitoring program. Scheduling in the GRYN is used to balance short- and long-term planning requirements with timely implementation, data analysis and reporting. Once the vital signs monitoring program is fully operational, a schedule of monitoring frequencies will enable the network to develop staffing plans and annual budgets. Currently, the network is focused on planning, and this chapter describes the design and implementation schedule for vital signs monitoring, along with three major activities that will take place over the next ten years.

TABLE 9.1 Schedule of field testing and implementation of monitoring protocols in the GRYN. Protocols for streamflow, climate and land use will, at a minimum, cover data handling and reporting procedures using existing data sources. The symbol ✕ indicates the year implementation of field testing phase (pilot) took place; the symbol ★ indicates the year implementation of the monitoring protocol is expected.

Protocol name	Schedule			
	2005	2006	2007	2008
Climate		★	★	★
Streamflow		★	★	★
Land use		★	★	★
Integrated water quality		★	★	★
Regulatory water quality	★	★	★	★
Invasive plants			★	★
Whitebark pine	✕	★	★	★
Amphibians	✕	★	★	★
Aridland soil structure and stability		★	★	★
Aridland seeps and springs	✕	★	★	★
Landbirds	✕	★	★	★

PROTOCOL SCHEDULE

Sample Design and Sample Protocols

Vital sign protocol development requires sufficient time and resources to ensure scientific reliability, while also meeting the information needs of the GRYN. Planning requires a commitment of staff time and, for this reason, the GRYN will implement a schedule for developing sampling design and protocols, conducting field trials and soliciting peer review and approval. This schedule is most critical during the first years of the program when substantial investment of staff time is necessary to see that the protocols are complete and ready for implementation.

The GRYN is scheduled to complete 12 monitoring protocols following the approach discussed in Chapters 4 and 5 of this report. Table 9.1 shows the planned implementation schedule for monitoring protocols under development and, where there is more than one vital sign treated in a protocol, illustrates the relationship between vital signs and protocols. For each protocol in the table, a Protocol Development Summary is available in Appendix VI. The overall schedule for developing the three-phase Vital Signs Monitoring Plan (described in Chapter 1) is established by WASO, while the protocol implementation schedule is established by the network.

Field Testing

For most vital signs, full implementation will be preceded by field testing, which will cover selected pieces of the whole protocol. An exception to field testing may be made for protocols that are well established and for which substantial refinement is not anticipated. In the GRYN, all monitoring protocols, except for climate and land use, will undergo at least one year of field testing. Monitoring protocols will undergo revision following field testing and prior to peer review and approval.

Peer Review and Approval

The schedule for submitting finished protocols to the Intermountain Regional Office for peer review and approval allows for the incorporation of field testing results, as well as peer review comments, before implementation begins (usually in the spring/summer of the same year).

MONITORING SCHEDULE

The transition from planning to monitoring signals an important milestone in the vital signs monitoring program (Figure 9.1). Implementation includes all aspects of monitoring operations such as data collection, data management, analysis and reporting. For the-GRYN program, monitoring officially starts in 2005 with the implementation of the regulatory water quality protocol. Monitoring will incrementally increase as monitoring protocols are completed and approved for implementation by the Intermountain Regional Office.

OTHER IMPORTANT PLANNING NEEDS

Park-Sponsored Monitoring Protocols

In addition to planning and implementation of the network's 12 vital signs, the GRYN will need access to monitoring information collected by park-sponsored monitoring programs. Existing natural resource monitoring programs at the network parks present a challenging integration opportunity for the GRYN. Since many of the park-sponsored monitoring programs provide essential data and information necessary in a long-term monitoring program, it is critical that the network provide resources to see that monitoring protocols in use across the network are adequately documented and include a strategy for data stewardship and reporting.

As network monitoring protocols are approved and implemented, planning will shift towards helping update and/or revise existing park monitoring protocols. Over the next ten years, the network will provide technical assistance and support to park-sponsored monitoring programs for these activities. The overarching goal is to move towards an integrated approach to acquiring and interpreting vital signs monitoring data. The technical expertise of network staff can help to standardize procedures and establish quality control, data management and reporting protocols. This step will help promote coordination and communication of monitoring activities at the park and regional levels and will promote broad participation in monitoring and use of resulting data.

Vital Sign Selection
2003
- GRYN Board of Directors approves network vital signs (August 2003).
- Phase II Monitoring Plan submitted to the IMR and WASO.

Monitoring Plans and Protocols
2004
- Protocols (step by step procedures) started and draft monitoring objectives compiled.
- Phase II Water Quality Monitoring Plan submitted to the IMR and WASO.
- Vital Signs Monitoring Plan: Phase III submitted to the IMR and WASO for administrative review (December 15, 2004).

Implementation Year 1
2005
- Vital Signs Monitoring Plan updated and approved (September 30, 2005).
- Regulatory water quality monitoring protocol complete and peer reviewed.
- Implementation of the regulatory water quality protocol begins; pilot implementation takes place for whitebark pine, amphibians and landbirds.
- NPSPecies database initial certification complete.
- First annual report to the park superintendents.

Implementation Year 2
2006
- Finish and implement monitoring protocols according to schedule.
- Second annual report to the park superintendents.

Implementation Year 3
2007
- Finish and implement monitoring protocols according to schedule.
- Third annual report to the park superintendents.

Implementation Year 4
2008
- First GRYN vital signs (I&M) program review.

FIGURE 9.1 Schedule of major milestones in the Vital Signs Monitoring Program.

User Requirements Analysis and System Design

Integration with the network parks and other ongoing monitoring programs will produce an enormous amount of data; however, for these data to be helpful they must be processed and converted into timely information products that are usable and accessible e.g. when the network prepares a synthesis report on the health and integrity of park ecosystems. For the network to effectively use monitoring data for reporting and other purposes, one must first determine the data's relevance to monitoring goals and objectives; data that are certified as valid, complete and fully documented with FGDC spatial and biological metadata can be processed to meet the requirements of the end-user. A user requirements analysis is a highly recommended starting point for data acquisition and design, especially in the complex data management environment facing the network.

A user requirements analysis is a process by which the stakeholders, in this case the park natural resource managers, scientists, technology specialists, GRYN and regional and/or WASO staff work together to specify user information needs so that a thorough understanding of these needs is understood before database system design begins. At a conceptual level, a user requirements analysis will ensure that the natural resource data and information systems developed by the network are designed to fulfill the network as well as the park business needs.

An examination of user requirements is scheduled for aquatic and terrestrial ecosystems over the next 24 months. The outcome of this exercise will be a purpose, scope and schedule for data and metadata development based on identified needs of the network vital signs monitoring program and also the needs of the network parks. Since data management is a cornerstone of each monitoring protocol, the user requirements analysis can also help the network prioritize and schedule updates and/or revisions to existing park-sponsored monitoring protocols described earlier in this chapter.

Program Review

As discussed in Chapter 5, a full program review is scheduled in 2008 to evaluate how well sample designs of individual protocols are achieving the monitoring objectives, and whether the overall program represents the best compromise between the information needs of the parks and the corresponding costs. This overall review will compliment the individual protocol reviews and focus on the full suite of our monitoring program toward achieving the overall program goals.

10. BUDGET

VITAL SIGNS BUDGET OVERVIEW

Funding for the vital signs portion of the I&M program is provided by the Natural Resource Challenge (NPS 1999). The Challenge requires that managers understand the condition of natural resources under their stewardship and to monitor long-term trends in those resources, such that:

"Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The service will use the results of and research to understand that detected change and to develop appropriate management actions" (NPS 2001).

The Natural Resource Challenge includes a budget strategy that helped provide for a permanent increase in base funds for natural resources in the National Park Service units. On an annual basis, the GRYN will receive $724,670 for vital signs and $71,000 from NPS Water Resource Division for water quality monitoring.

At the present time, the network is functioning under the assumption that funding will remain at or near existing levels for the foreseeable future, although the cost of conducting business will certainly increase. Increases are expected to come from employee salary and benefits, transportation and equipment and supplies at roughly two percent per year, and as the cost of business increases, the network will find ways to improve fiscal efficiency. Two important factors will be considered when attempting to mitigate these increasing costs, including: 1) opportunities for cost-sharing with partner agencies or organizations; and 2) adjustments in the scope of monitoring that can be conducted.

GREATER YELLOWSTONE NETWORK ANNUAL BUDGET

The annual budget for the network, including expected income and expenses, is illustrated in Table 10.1 (see also Figure 10.1). This table of budget expenses shows expected costs, including fixed costs (such as core and affiliated staff and office facilities) and non-fixed costs (such as cooperative agreements, etc.) that the network must provide for on an annual basis.

In addition, the network expects to allocate a portion of the annual funds for office equipment and supplies, field equipment and travel (Figure 10.1). The items listed under 3_Coop Agreements, plus the water quality costs under personnel address the subset of 12 vital signs scheduled for by the network. However, the specific annual allocation of funds for each vital sign will vary (along with the agency that implements it) depending on the budget described in the individual protocol.

Furthermore, the network has included an annual budget for data management projects identified on an annual basis in the Annual Administrative Report and Work Plan for the GRYN. The purpose of the budget line item for data management is to invest in data management infrastructure projects that provide a foundation for the management of data from multiple vital signs and related data that contribute to the synthesis of information required for natural resource stewardship. Examples include Web site development and the update and maintenance of the National Hydrography Dataset and contribu-

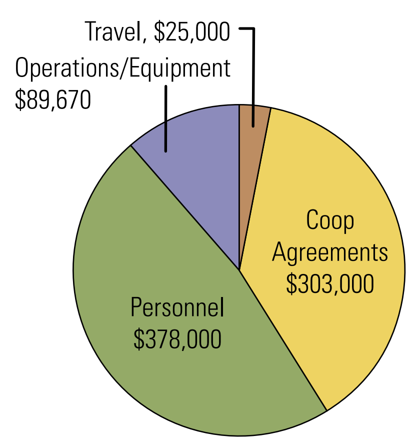


FIGURE 10.1 Pie-chart showing the amount and expense categories used by the I&M program.

tions to Greater Yellowstone Coordinating Committee projects that relate to vital signs. It is expected that I&M contributions to these data and resource information management projects are normally matched with in-kind contributions by the parks and sometimes others. These investments must be directed by the outcome of thorough user requirements analyses by managers, scientists and technology specialists. This allocation of resources in combination with the vital signs data management, analysis and reporting that is completed by network and park affiliated staff is intended to guarantee a strong commitment towards data and information management throughout the life of the program.

TABLE 10.1 Annual budget for the Greater Yellowstone Network.

1. Income			
Vital Signs Monitoring	$724,670.00	I&M - VS $$	
Water Quality Monitoring	$71,000.00	WRD - WQ	
2. Personnel			**Information management**
Program Manager[1]		I&M - VS $$	30%
Data Manager[1]		I&M - VS $$	100%
Ecologist[1]		I&M - VS $$	30%
Administrative Assistant		I&M - VS $$	0%
Hydrologist (GRTE)[1]		WRD - WQ	30%
Ecologist (BICA)		WRD - WQ	30%
Aquatic Ecologist (YELL)		WRD - WQ	30%
Network data management projects		I&M - VS $$	100%
Sub Total	***$378,000.00***		***$178,900.00***
3. Coop. Agreements[2]			
Invasive plant		I&M - VS $$	30%
Aridland soil structure and stability		I&M - VS $$	30%
Amphibians		I&M - VS $$	30%
Climate		I&M - VS $$	30%
Landbirds		I&M - VS $$	30%
Aridland seep and springs		I&M - VS $$	30%
Whitebark pine		I&M - VS $$	30%
Land use		I&M - VS $$	30%
Streamflow		I&M - VS $$	30%
Sub Total	***$303,000.00***		***$90,900.00***
5. Operations/Equipment			
Facilities	$30,670.00	I&M - VS $$	0%
Computer equipment and supplies	$10,000.00	I&M - VS $$	0%
Office equipment & supplies	$15,000.00	I&M - VS $$	0%
Water quality equipment and supplies	$29,000.00	I&M - VS $$	0%
Transportation	$5,000.00	I&M - VS $$	0%
Sub Total	***$89,670.00***		
6. Travel			
Network travel	$25,000.00	I&M - VS $$	Other
Sub Total	***$25,000.00***		
Total Expense	***$795,670.00***		

[1] Permanent NPS staff assigned to the network
[2] Also includes interagency agrements, contracts and/or affiliated park staff

11. LITERATURE CITED

Akaike H. 1973. Information theory and an extension of the maximum likelihood principle. In: Petrov B and Czakil F, editors. Proceedings of the second international symposium on information theory. Budapest: Akademiai Kiado. p 267-281.

Allen TFH, Hoekstra TW. 1992. Toward a unified ecology. New York: Columbia University Press.

Allen TFH, Starr TB. 1982. Hierarchy: perspectives for ecological complexity. Chicago: University of Chicago Press.

Allendorf FW, Lundquist LL. 2003. Introduction: Population Biology, Evolution, and Control of Invasive Species. Conservation Biology 17(1): 24-30.

Anderson DR, Burnham KP, Thompson WL. 2000. Null hypothesis testing: problems, prevalence, and an alternative. Journal of Wildlife Management 64: 912-923.

Anderson DR, Burnham KP, White GC. 1994. AIC model selection in overdispersed capture-recapture data. Ecology 75: 1780-1793.

Anderson DR, Link WA, Johnson DH, Burnham KP. 2001. Suggestions of presenting the results of data analysis. Journal of Wildlife Management 65: 373-378.

Bailey RG. 1995. Descriptions of the ecoregions of the United States: 2nd edition revised and expanded. Washington, DC: USDA Forest Service. Miscellaneous Publication 1391.

Barber MC. 1994. Environmental monitoring and assessment program indicator development strategy. Athens, GA: Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory. Report EPA/620/R-94/022.

Baron JS. 2002. Rocky Mountain Futures: An Ecological Perspective. Washington: Island Press.

Barrett WG, VanDyne GM, Odum EP. 1976. Stress ecology. BioScience 26: 192-194.

Bartlein PJ, Whitlock C, Shafer S. 1997. Future climate in the Yellowstone National Park region and its potential impact on vegetation. Conservation Biology 11: 782-792.

Beard GR, Scott WA, Adamson JK. 1999. The value of consistent methodology in long-term environmental monitoring. Environmental Monitoring and Assessment 54: 239-258.

Big Sky Institute. 2004. What is Big Sky Institute? <http://bsi.montana.edu/web/web>. Accessed 2004 Nov 15.

Bonan GB. 2002. Ecological Climatology: Concepts and Applications. Cambridge: Cambridge University Press.

Boulinier T, Nichols JD, Sauer JR, Hines JE, Pollock KH. 1998. Estimating species richness to make inference in community ecology: the importance of heterogeneity in species detectability as shown from capture-recapture analyses of North American Breeding Bird Survey Data. Ecology 79:1018-1028.

Box GEP. Robustness in the strategy of scientific model building. In: Launer RL and Wilkinson GN Robustness in Statistics. New York: Academic Press. 202 p.

Breiman L. 1992. The little bootstrap and other methods for dimensionality selection in regression: X-fixed prediction error. Journal of the American Statistical Association 87: 738-754.

Buckland ST, Anderson DR, Burnham KP, Laake JL. 1993. Distance sampling: estimating abundance of biological populations. London: Chapman and Hall.

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L. 2001. Introduction to distance sampling: estimating abundance of biological populations. New York: Oxford University Press.

Buckland ST, Burnham KP, Augustin NH. 1997. Model selection: an integral part of inference. Biometrics 53: 603-618.

Burnham KP, Anderson DR. 1976. Mathematical models for nonparametric inferences from transect data. Biometrics 32:325-336.

Burnham KP, Anderson DR. 1992. Data-based selection of an appropriate biological model: the key to modern data analysis. In: McCullough DR, Barrett RH. Wildlife 2001: populations. New York: Elsevier Applied Science. p 16-30.

Burnham KP, Anderson DR. 2002. Model selection and multimodel inference: a practical information-theoretic approach. New York: Springer-Verlag.

Burnham KP, Anderson DR, Laake JL. 1979. Robust estimation from line transect data. Journal of Wildlife Management 43:992-996.

Burnham KP, Anderson DR, White GC, Brownie C, Pollock KH. 1987. Design and analysis of fish survival experiments based on release-recapture data. Bethesda, Maryland: American Fisheries Society Monograph 5. 437 p.

Carpenter SR, Kitchell JF, Hodgson JR. 1985. Cascading trophic interactions and lake productivity. BioScience 35:634-649.

Caughlan L, Oakley KL. 2001. Cost considerations for long-term ecological monitoring. Ecological Indicators 1: 123-134.

Cherry S. 1998. Statistical tests in publications of The Wildlife Society. The Wildlife Society Bulletin 26: 947-953.

Chornesky EA, Randall JM. 2003. The threat of invasive alien species to biological diversity: setting a future course. Annals of the Missouri Botanical Garden 90: 67-76.

Christensen N, Bartuska AM, Brown JH, Carpenter S, D'Antonio C, Francis R, Franklin JF, MacMahon JA, Noss RF, Parsons DJ, Peterson CH, Turner MG, Woodmansee RG. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications 6:665-691.

Cochran WG. 1977. Sampling techniques. New York: John Wiley and Sons.

Conroy MJ, Anderson JE, Rathbun SL, Krementz DG. 1996. Statistical inference on patch-specific survival and movement rates from marked animals. Environmental and Ecological Statistics 3:99-118.

Corn PS, Hossak BR, Muths E, Patla DA, Peterson CA, Gallant AL. 2005. Status of amphibians on the Continental Divide: Surveys on a transect from Montana to Colorado, USA. Alytes 22(3-4):85-89.

Cox DR. 1977. The role of significance tests. Scandanavian Journal of Statistics 4: 49-70.

Daley R. 2005. Data and Information Management Plan, Greater Yellowstone Inventory and Monitoring Network. Bozeman, MT: National Park Service, Greater Yellowstone Network. 82 p. plus appendices.

Despain DG. 1987. The two climates of Yellowstone National Park. Proceedings of the National Academy of Sciences 47: 11-19.

DiTomaso JM. 2000. Invasive weeds in rangelands: Species, impacts, and management. Weed Science 48(2):255-265.

Eberhardt LL. 1968. A preliminary appraisal of line transect. Journal of Wildlife Management 32:82-88.

Edwards D. 1998. Issues and themes for natural resources trend and change detection. Ecological Applications 8: 323-325.

Elzinga CL, Salzer DW, Willoughby JW. 1998. Measuring and monitoring plant populations. Denver, CO: Bureau of Land Management. Report: BLM Technical Reference 1730-1; BLM/RS/ST-98/005+1730.

Environmental Protection Agency (EPA). 1994. Water quality standards handbook, August 1994. Report: EPA-823-B-94-005a.

Environmental Protection Agency (EPA). 2002. Guidance on choosing a sampling design for environmental data collection, for use in developing a quality assurance plan. Washington, DC: Environmental Protection Agency. Report EPA QA/G-5S.

Environmental Protection Agency (EPA). 2004. Clean air status and trends network (CASTNET). <http://www.epa.gov/castnet/>. Accessed 2004 Jul 15.

Failing L, Gregory R. 2003. Ten common mistakes in designing biodiversity indicators for forest policy. Journal of Environmental Management 68: 121-132.

Federal Geographic Data Committee (FGDC). 1997. Vegetation classification and information standards. <http://www.fgdc.gov/standards/status/sub2_1.html>. Accessed 2004 Nov 28.

Flack VF, Chang PC. 1987. Frequency of selecting noise variables in subset regression analysis: A simulation study. The American Statistician 41: 84-86.

Gates CE, Marshall WH, Olson DP. 1968. Line transect method of estimating grouse population densities. Biometrics 24:135-145.

Gaufin AR. 1958. The effects of pollution on a Midwestern stream. Ohio Journal of Science 58: 197-208.

Geographic Information and Analysis Center (GIAC). 2003. Greater Yellowstone Area Data Clearing House. <http://sun1.giac.montana.edu/gyadc/gyadchrome.html>. Accessed 2003 Aug 25.

Goodwin J. 1992. The role of mycorrhizal fungi in competitive interactions among native bunchgrasses and alien weeds: a review and synthesis. Northwest Science 66(4):251-260.

Grand Teton National Park (GRTE). 2004. Wildlife inventory and monitoring 2003. Moose, WY: National Park Service, Grand Teton National Park. 14 p.

Greater Yellowstone Coordinating Committee (GYCC). 2004. Priority resource management issues. <http://www.nps.gov/yell/gycc/gyccatwork/index.htm>. Accessed 2004 Oct 11.

Greater Yellowstone Coordinating Committee (GYCC). 2005. Subcommittees of the Greater Yellowstone Coordinating Committee. <http://mpin.nbii.org/gycc/committees/>. Accessed 2005 August 27.

Greater Yellowstone Network (GRYN). 2000. Biological inventory of vascular plants and vertebrates in the Greater Yellowstone Network parks: Bighorn Canyon NRA, Grand Teton NP, Yellowstone NP. Bozeman, MT: Greater Yellowstone Network Steering Committee. 114 p.

Greenland S. 1989. Modeling and variable selection in epidemiological analysis. American Journal of Public Health. 79: 340-349.

Gross JE. 2003. Developing conceptual models for ecosystem monitoring programs. Unpublished manuscript.

Groves RM, Lepkowski JM. 1985. Dual frame, mixed mode survey designs. Journal of Official Statistics 1: 263-286.

Haines DE, Pollock KH. 1998. Estimating the number of active and successful bald eagle nests: an application of the duel frame approach. Environmental and Ecological Statistics 5: 245-256.

Hansen MH, Madow WG, Tepping BJ. 1983. An evaluation of model dependent and probability sampling inferences in sample surveys. Journal of American Statistical Association 78(384): 776–793.

Hayne DW. 1949. An examination of the strip census method for estimating animal populations. Journal of Wildlife Management 13:145-157.

Hellawell JM. 1991. Development of a rationale for monitoring. In: Goldsmith FB, editor. Monitoring for conservation and ecology. London: Chapman and Hall. p 1-14.

Helsel DR, Hirsch RM. 1992. Statistical Methods in Water Resources. New York: Elsevier.

Hines JE, Boulinier T, Nichols JD, Sauer JR, Pollock KH. 1999. COMDYN: software to study the dynamics of animal communities using a capture recapture approach. Bird Study 46 (suppl.):S209 217.

Hocking RR. 1976. The analysis and selection of variables in linear regression. Biometrics 32: 1-44.

Holling CS. 1978. Adaptive environmental assessment and management. London: John Wiley and Sons.

Hosmer DW, Lemeshow SL. 1989. Applied logistic regression. New York: John Wiley and Sons.

Hurlbert SH. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54: 187-211.

Interagency Monitoring of Protected Visual Environments (IMPROVE). 2004. Overview of IMPROVE and visibility. <http://vista.cira.colostate.edu/improve/Overview/Overview.htm>. Accessed 2004 Jul 14.

Interlandi SJ, Kilham SS, Theriot ED. 1999. Responses of phytoplankton to varied resource availability in large lakes of the Greater Yellowstone Ecosystem. Limnology and Oceanography 44:668-682.

IPCC (Intergovernmental Panel on Climate Change). 2001. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Xiaosu D, editors. Climate Change 2001: The Scientific Basis. Cambridge: Cambridge University Press.

Jacobson MC, Charlson RJ, Rodhe H, Orians GH. 2000. Earth System-Science: From Biogeochemical Cycles to Global Change. San Diego: Academic Press.

James FC, McCulloch CE. 1990. Multivariate analysis in ecology and systematics: panacea or Pandora's box? Annual Review of Ecology and Systematics 21: 129-166.

Kaplan EL, Meier P. 1958. Nonparametric estimation from incomplete observations. Journal of American Statistical Association 53:188-193.

Karr JR. 1999. Defining and measuring river health. Freshwater Biology 41:221-234.

Kashian DR. 2004. Water quality and benthic macroinvertebrates threats and concerns: draft. Bozeman, MT: National Park Service, Greater Yellowstone Network. 16 p.

Kendall WL. 2001. Using models to facilitate complex decisions. In: Shenk TM, Franklin AB, editors. Modeling in natural resource management: development, interpretation, and application. Washington, DC: Island Press. p 147-170.

Key CH, Bennetts RE. 2004. Integration of the vital signs monitoring program with other NPS programs: a conceptual framework for integration with the fire monitoring program. Denver, CO: USGS Rapid Response Technical Assistance Program.

Kilham SS, Theriot ED, Fritz SC. 1996. Linking planktonic diatoms and climate change in the large lakes of the Yellowstone ecosystem using resource theory. Limnology and Oceanography 41:1052-1062.

King KW. A bioassessment method for use in Wyoming stream and river water quality monitoring. Cheyenne, WY: Wyoming Department of Environmental Quality Division.

Knauf M, Williams MW. 2004. Soda Butte Creek and Reese Creek: Vital Signs Monitoring Program, Final Report. Bozeman: National Park Service, Greater Yellowstone Network, Bozeman. 29 p plus appendices.

Knight RR, Blanchard BM, Haroldson MA. 1997. Yellowstone grizzly bear investigations, annual report of the Interagency Study Team, 1996. Bozeman, MT: USGS Biological Resources Division.

Koel T, Bigelow Koel T, Bigelow DP, Mahony D, Ertel B, Arnold J. 2002. Yellowstone Center for Resources Fisheries and Aquatic Sciences Section FY2002 Workplan. Mammoth Hot Springs, WY: Yellowstone Center for Resources, Yellowstone National Park.

Lee ET. 1980. Statistical methods for survival data analysis. New York: John Wiley and Sons.

Levy PS, Lemeshow S. 1999. Sampling of populations. New York: John Wiley and Sons.

Likens GE, Driscoll CT, Buso DC. 1996. Long-term effects of acid rain: response and recovery of a forest ecosystem. Science 272:244-246.

Lohr S. 1999. Sampling—design and analysis. Pacific Grove, CA: Duxbury Press.

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, F.S. B. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10(3):689-710.

MacKenzie DI, Kendall WL. 2002. How should detection probability be incorporated into estimates of relative abundance? Ecology 83: 2387-2393.

MacKenzie DI, Nichols JD, Hines JE, Knutson MG, Franklin AD. 2003. Estimating site occupancy, colonization and local extinction when a species is detected imperfectly. Ecology 84: 2200-2207.

MacKenzie DI, Nichols JD, Lachman GB, Droege S, Royle JA, Langtimm CA. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83: 2248-2255.

McCullagh P, Nelder JA. 1989. Generalized linear models. In: Monographs on statistics and applied probability. 2nd ed. London: Chapman and Hall.

McDonald TL. 2003. Review of environmental monitoring methods: survey designs. Environmental Monitoring and Assessment 85: 277-292.

McEneaney T. 2004. Yellowstone bird report 2003. Mammoth Hot Springs, WY: National Park Service, Yellowstone Center for Resources. Report YCR–NR–2003–01.

Meyer JL, Sale MJ, Mulholland PJ, Poff NL. 1999. Impacts of climate change on aquatic ecosystem functioning and health. Journal of the American Water Resources Association 35:1373-1386.

Mendenhall W, Ott L, Scheaffer RL. 1971. Elementary survey sampling. Belmont, CA:Wadsworth Publishing Company.

Montana Department of Environmental Quality (MTDEQ). 2002. Montana 2002 303(d) list, a compilation of impaired and threatened water bodies in need of water quality restoration. <http://nris.state.mt.us/wis/environet/2002_303dhome.html>. Accessed 2003 Oct 16.

Montana Department of Environmental Quality (MTDEQ). 2004. Water Quality Integrated Report for Montana. Helena, MT: Montana Department of Environmental Quality. 403 p.

Monteith D. 2003. Quick guide – an overview of a select few of Yellowstone's thermal attractions. <http://www.geyserstudy.org/ov_quick_guide.htm>. Accessed 2003 Aug 25.

Murphy K, Potter T, Halfpenny J, Gunther K, Jones T, Lundberg P. 2004. The presence and distribution of Canada lynx (*Lynx canadensis*) in Yellowstone National Park, Wyoming. Mammoth Hot Springs, WY: National Park Service, Yellowstone National Park. 14 p. plus appendices.

National Assessment and Synthesis Team (NAST). 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Report for the U.S. Global Change Research Program. Cambridge, UK: Cambridge University Press.

National Atmospheric Deposition Program (NADP). 2004. NADP history and overview. <http://nadp.sws.uiuc.edu/nadpoverview.asp>. Accessed 2004 Jul 15.

National Park Service (NPS). 1994a. Resources management plan, Bighorn Canyon National Recreation Area. Lovell, WY: National Park Service, Bighorn Canyon National Recreation Area.

National Park Service (NPS). 1994b. Baseline Water Quality Data Inventory and Analysis. Yellowstone National Park. Report Technical Report NPS/NRWRD/NRTR-94/22.

National Park Service (NPS). 1995. Statement for management. Moose, WY: National Park Service, Grand Teton National Park.

National Park Service (NPS). 1998. Baseline Water Quality Data Inventory and Analysis. Bighorn Canyon National Recreation Area. Technical Report NPS/NRWRD/NRTR-98/164.

National Park Service (NPS). 1999. Natural Resource Challenge: the National Park Service's action plan for preserving natural resources. Washington, DC: National Park Service. 21 p.

National Park Service (NPS). 2001a. Management policies. Washington, DC: National Park Service. Report NPS D1416. 137 p.

National Park Service (NPS). 2001b. National Park Service Strategic Plan, FY2001-FY2005. Washington, DC: National Park Service.

National Park Service (NPS). 2001c. Baseline Water Quality Data Inventory and Analysis. Grand Teton National Park. Technical Report NPS/NRWRD/NRTR-200/260.

National Park Service (NPS). 2003a. Yellowstone National Park business plan, fiscal year 2002. Mammoth Hot Springs, WY: National Park Service, Yellowstone National Park.

National Park Service (NPS). 2003b. Development of monitoring programs. <http://science.nature.nps.gov/im/monitor/vsm.htm#Development>. Accessed 2003 Aug 28.

National Park Service (NPS). 2003c. Guidelines for monitoring natural resources in our national parks. <http://science.nature.nps.gov/im/monitor/vsmTG.htm>. Accessed 2003 Aug 27.

National Park Service (NPS). 2003d. Reclamation of abandoned uranium exploration sites: environmental assessment. Lovell, WY: National Park Service, Bighorn Canyon National Recreation Area. 73 p. plus appendices.

National Park Service (NPS). 2004a. Natural resource monitoring—program administration and organizational framework. <http://science.nature.nps.gov/im/monitor/vsmAdmin.htm#ProgramAdmin>. Accessed 2004 Aug 11.

National Park Service (NPS). 2004b. Grand Teton National Park facts. <http://www.nps.gov/grte/edu/factsheet.htm>. Accessed 2004 Aug 11.

National Park System Advisory Board. 2001. Rethinking the national parks for the 21st century. < http://www.nps.gov/policy/report.htm>. Accessed 2004 Aug 11.

Natural Resources Conservation Service. 2004. Pryor Mountain Wild Horse Range Survey and Assessment. Bozeman, MT. 148 p.

National Water Quality Council. 2004. <http://water.usgs.gov/wicp/acwi/monitoring>. Accessed 2004 Aug 21.

Nesser JA, Ford GL, Maynard CL, Page-Dumroese DS. 1997. Ecological units of the northern region: subsections. Ogden, UT: U.S. Forest Service, Intermountain Research Station. General Technical Report INT-GTR-369.

Newell AD, Morrison ML. 1993. Use of overlap studies to evaluate methods changes in water chemistry protocols. Water, Air and Soil Pollution 67: 433–456.

Nichols JD. 1996. Sources of variation in migratory movements of animal populations: statistical inference and a selective review of empirical results for birds. In: Rhodes OE Jr, Chesser RK, Smith MH, editors. Population Dynamics in Ecological Space and Time. Chicago: University of Chicago Press. p 147-197.

Nichols JD, Boulinier T, Hines JE, Pollock KH, Sauer JR. 1998. Inference methods for spatial variation in species richness and community composition when not all species are detected. Conservation Biology 12:1390-1398.

NOAA National Weather Service (NWS). 2005. Working Together to Save Lives. National Weather Service Strategic Plan for 2005-2010. <http://weather.gov/mission.shtml>.

Noon BR. 2003. Conceptual issues in monitoring ecological resources. In: Busch DE and Trexler JC, editors. Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Washington, DC: Island Press. p 27-72.

Oakley KL, Thomas LP, Fancy SG. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31: 1000-1002.

Olsen A (ed.), Knapp CM, Marmorek DR, Baker JP, Thornton KW, Klopatek JM, Charles DF. 1992. The indicator development strategy for the environmental monitoring and assessment program. Corvallis, OR: U.S. Environmental Protection Agency, Environmental Research Laboratory. Report EPA/600/3-91/023.

Olsen AR, Sedransk J, Edwards D, Gotway CA, Liggett W, Rathbun S, Reckhow KH, Wong LJ. 1999. Statistical issues for monitoring ecological and natural resources in the United States. Environmental Monitoring and Assessment 54: 1-45.

Omernick JM. 1987. Ecoregions of the conterminous United States. Annual Assessment of American Geography 77(1): 118-25.

O'Ney SE, McCloskey K., editors. 2004. Water quality monitoring plan, phase II report. Bozeman, MT: Greater Yellowstone Network, National Park Service. 51 p plus appendices.

O'Ney SE. 2005. Regulatory water quality monitoring protocol. Version 1.0. Bozeman, MT: Greater Yellowstone Network, National Park Service. 35 p plus appendices.

Palmer CJ. 2003. Approaches to quality assurance and information management for regional ecological monitoring programs. In: Busch DE and Trexler JC. Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Washington, DC: Island Press. p 211-225.

Patten D, Schmitz D. 2002. Ecosystem Conceptual Models for Bighorn Canyon National Recreation Area, Grand Teton National Park and Yellowstone National Park. Bozeman, MT: Big Sky Institute, Montana State University.

Plumb GP. 2002. Really useful conceptual models: metaphors, censorship and negotiated knowledge. Presented at the 2002 NPS Tucson conference.

Powell DS. 2000. A "white paper" for the Washington Office Ecosystem Management Corporate Team and Interregional Ecosystem Management Coordinating Group. Washington, DC: US Forest Service.

Ramsey FL, Scott JM. 1979. Estimating population density for variable circular plot surveys. In: Cormack RM, Patil GP, Robson DS, editors. Sampling biological populations. Fairland, MD: International Cooperative Publishing House. p 155-181.

Rasker R. 1991. Rural development, conservation, and public policy in the Greater Yellowstone Ecosystem. Society and Natural Resources 6:109-126.

Rexstad EA, Miller D, Flather C, Anderson E, Hupp J, Anderson DR. 1988. Questionable multivariate statistical inference in wildlife and community studies. Journal of Wildlife Management 52: 794-798.

Richardson RE. 1925. Illinois River bottom fauna in 1923. Bulletin of the Illinois Natural History Survey 15: 391-422.

Richardson RE. 1929. The bottom fauna of the Middle Illinois River 1913-1925: its distribution, abundance, valuation and index value in the study of stream pollution. Bulletin of the Illinois Natural History Survey 17: 387-475.

Rocky Mountains Cooperative Ecosystem Studies Unit (RM-CESU). 2004. Mission and Vision statement. <http://www.forestry.umt.edu/research/CESU/default.htm>. Accessed 2004 November 15.

Schaeffer RL, Mendenhall W, Ott L. 1990. Elementary Survey Sampling. Boston, MA: Publishing Company.

Schlesinger WH. 1997. Biogeochemistry: An Analysis of Global Change. San Diego: Academic Press.

Schwartz CC, Moody D. 2004. Introduction. In: Schwartz CC, Haroldson MA, editors. Yellowstone grizzly bear investigations: annual report of the Interagency Grizzly Bear Study Team, 2003. Bozeman, MT: U.S. Geological Survey. p 1-2.

Schwartz CJ. 1998. Studies of uncontrolled events. In: Sit V, Taylor B, editors. Statistical methods for adaptive management studies. Victoria, BC: British Columbia Ministry of Forestry. Handbook 42. p 19-40.

Shelton LR. 1994. Field guide for collecting and processing stream-water samples for the National Water Quality Assessment Program. US Geological Survey Open-File Report 94-455. Sacramento, CA.

Smith VH. 1998. Cultural eutrophication of inland, estuarine, and coastal waters. In: Groffman PM, Pace ML, editors. Success, limitations, and frontiers in ecosystem science. New York: Springer. pp 7-49.

Smith DW, Stahler DR, Guernsey DS. 2003. Yellowstone wolf project: annual report, 2002. Mammoth Hot Springs, WY: National Park Service, Yellowstone Center for Resources. Report YCR-NR-2003-04.

Soballe DM, Fischer J. 2001. Long Term Resource Monitoring Program Procedures: Water Quality Monitoring. Upper Midwest, U.S. Geological Survey.

Soil Survey Staff. 2003. Keys to Soil Taxonomy, Ninth Edition. Washington, D.C.: USDA Natural Resources Conservation Service. 331 p.

Spellerberg IF. 1991. Monitoring ecological change. Cambridge, UK: Cambridge Press.

Spendelow JA, Nichols JD, Nisbet ICT, Hays H, Cormons GD, Burger J, Safina C, Hines JE, Gochfeld M. 1995. Estimating annual survival and movement rates of adults within a metapopulation of Roseate terns. Ecology 76: 2415-2428.

Stapp P, Hayward GD. 2002. Estimates of predator consumption of Yellowstone cutthroat trout (Oncorhynchus clarki bouveri) in Yellowstone Lake. Journal of Freshwater Ecology 17:319-329.

Stauffer DF, Garton EO, Steinhorst RK. 1985. A comparison of principal components from real and random data. Ecology 66: 1693-1698.

Stevens DL Jr, Olsen AR. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association. 99: 262-278.

Stoddard JL, Driscoll CT, Kahl JS, Kellogg JH. 1998. Can site-specific trends be extrapolated to a region? An acidification example for the Northeast. Ecological Applications 8: 288-299.

Stuart SN, Chanson JS, Cox NA, Young BE, Rodrigues ASL, Fischman DL, Waller RW. 2004. Status and Trends of Amphibian Declines and Extinctions Worldwide. Science 306: 1783-1786.

Thomas L, Laake JL, Strindberg S., Marques FFC, Buckland ST, Borchers DL, Anderson DR, Burnham KP, Hedley SL, Pollard JH, Bishop JRB. 2004. Distance 5.0. Release "Beta 5"1. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

Thompson SK. 2002. Sampling. 2nd ed. New York: J. Wiley and Sons.

Thompson SK, Seber GAF. 1996. Adaptive sampling. New York: J. Wiley and Sons.

University of Wyoming. 2004. The University of Wyoming – National Park Service Research Center. <http://uwadmnweb.uwyo.edu/Zoology/UWNPSRS/UWNPSRS.htm>. Accessed 2004 Nov 15.

US Department of Agriculture (USDA). 1999. The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan U.S. Portland, Oregon: US Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-437.

U.S. Department of Agriculture (USDA). 2005. Interior West – Forest Inventory & Analysis. <http://www.fs.fed.us/rm/ogden/index.html>. Accessed 2005 August 27.

US Fish and Wildlife Service (USFWS). 1993. Grizzly bear recovery plan. Missoula, MT: US Fish and Wildlife Service. 181 p.

US Fish and Wildlife Service (USFWS). 1994. Final rule: endangered and threatened wildlife and plants; establishment of a nonessential experimental population of gray wolves in Yellowstone National Park in Wyoming, Idaho and Montana. 50 CFR Part 17 RIN 1018-AC86. <https://ecos.fws.gov/docs/frdocs/1994/94-28746.html>. Accessed 2003 Aug 27.

U.S. Fish and Wildlife Service (USFWS). 1999. The bald eagle is back! President Clinton announces proposal to remove our national symbol from endangered species list. <http://news.fws.gov/NewsReleases/R9/A11C3CEE-AC20-11D4-A179009027B6B5D3.html>. Accessed 2004 Jun 7.

U.S. Fish and Wildlife Service (USFWS). 2000. Endangered and threatened wildlife and plants; determination of threatened status for the contiguous U.S. distinct population segment of the Canada lynx and related rule. Federal Register 2000: 16052-16086.

U.S. Fish and Wildlife Service (USFWS). 2003. U.S. Fish and Wildlife Service finds that Canada lynx should remain listed as threatened in lower 48. <http://news.fws.gov/NewsReleases/R6/560B1008-2E34-4321-B5E1508B05545815.html>. Accessed 2003 Aug 27.

U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service and USDA Wildlife Services. 2004. Rocky Mountain Wolf Recovery 2003 Annual Report. Meier T, editor. Helena, MT: US Fish and Wildlife Service. 65 p.

U.S. Geological Survey (USGS). 1999. The National Hydrography Dataset. Fact Sheet 106-99.

U.S. Geological Survey (USGS). 2001. The National Water – Quality Assessment Program – Entering a new decade of investigations. USGS Fact Sheet 071-01.

U.S. Geological Survey (USGS). 2004. Northern Rocky Mountain Science Center. <http://www.nrmsc.usgs.gov/default.htm>. Accessed 2004 Nov 15.

Urquhart NS, Kincaid TM. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural and Biological Environmental Statistics 4(4): 404–414.

Urquhart NS, Paulsen SG, Larsen DP. 1998. Monitoring for policy relevant regional trends over time. Ecological Applications 8: 246-257.

Wagner FH, editor. 2003. Rocky Mountain/Great Basin Regional Climate Change Assessment. A Report of the Rocky Mountain/Great Basin Regional Assessment Team for the U.S. Global Change Research Program. Logan, UT: Utah State University.

Walker LR, Smith SD. 1997. Impacts of invasive plants on community and ecosystem properties. In: Luken JO, Thieret JW, editors. Assessment and Management of Plant Invasions. New York: Springer-Verlag.

Walker B, Steffen W. 1997. An overview of the implications of global change for natural and managed terrestrial ecosystems. Conservation Ecology 1(2). <http://www.ecologyandsociety.org/vol1/iss2/art2/index.html>. Accessed 2004 Oct 29.

Walters CJ. 1986. Adaptive management of renewable resources. New York: Macmillan Publishing Company.

Western Regional Climate Center. 2004. Western U.S. historical climate summaries. <http://www.wrcc.dri.edu/climsum.html>. Accessed 2004 Oct 29.

White GC, Burnham KP. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement:120-138.

Williams BK, Nichols JD, Conroy MJ. 2002. Analysis and management of animal populations. San Diego: Academic Press.

Williams MW, Baron JS, Caine N, Sommerfeld R, Sanford R. 1996. Nitrogen saturation in the Rocky Mountains. Environmental Science and Technology 30:640-646.

Wolfe AP, Baron JS, Cornett RJ. 2001. Anthropogenic nitrogen deposition induces rapid ecological changes in alpine lakes of the Colorado Front Range (USA). Journal of Paleolimnology 25:1-7.

Wolff S. 2003. Bald eagle and sage grouse inventory update 2001-2003. Moose, WY: National Park Service, Grand Teton National Park. 4 p.

Woods SW, Corbin J. 2003a. Vital signs water quality monitoring for the Greater Yellowstone Network: Bighorn Canyon National Recreation Area: Final Technical Report, July 2003. Bozeman, MT: National Park Service, Greater Yellowstone Network.

Woods SW, Corbin J. 2003b. Vital signs water quality monitoring for the Greater Yellowstone Network: Grand Teton National Park: Final Technical Report, August 2003. Bozeman, MT: National Park Service, Greater Yellowstone Network.

Woods SW, Corbin J. 2003c. Vital signs water quality monitoring for the Greater Yellowstone Network: Yellowstone National Park: Final Technical Report, September 2003. Bozeman, MT: National Park Service, Greater Yellowstone Network.

Wyoming Department of Environmental Quality (WYDEQ). 2001. Wyoming surface water classification list, June 21, 2001.

Wyoming Department of Environmental Quality (WYDEQ). 2002. Wyoming's 2002 303(d) list of waters requiring TMDLs. <http://deq.state.wy.us/wqd/watershed/Downloads/TMDL/2-2227-doc.pdf>. Accessed 2003 Oct 16.

Wyoming Department of Environmental Quality (WYDEQ). 2004. Wyoming's 2004 305(b) State Water Quality Assessment Report and 2004 303(d) List of Waters Requiring TMDLs. 91 p.

Yates F. 1951. The influence of 'Statistical Methods for Research Workers' on the development of the science of statistics. Journal of the American Statistical Association 46: 19-34.

Yoccoz NG. 1991. Use, overuse and misuse of significance tests in evolutionary biology and ecology. Bulletin of the Ecological Society of America 72: 106–111.

Yoccoz NG, Nichols JD, Boulinier T. 2001. Monitoring of biological diversity in space and time. Trends in Ecology and Evolution 16: 446-453.

Yellowstone National Park (YELL). 2004a. Yellowstone resources and issues 2004. Mammoth Hot Springs, WY: National Park Service, Yellowstone National Park. 191 p.

Yellowstone National Park (YELL). 2004b. Fact sheet. <http://www.nps.gov/yell/technical/yellfact.htm>. Accessed 2004 Nov 5.

ACRONYMS

Acronym	Definition
AIC	Akaike's Information Criterion
ARD	Air Resources Division (NPS)
ARMI	Amphibian Research and Monitoring Initiative (USGS)
BICA	Bighorn Canyon National Recreation Area
BOD	Board of Directors
BRD	Biological Resources Division (BRD)
BSI	Big Sky Institute
CASTNET	Clean Air Status and Trends Network
CWA	Clean Water Act
CSDGM	Content Standard for Digital Geospatial Metadata
DOI	Department of Interior
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute, Inc.
FGDC	Federal Geographic Data Committee
FHM	Forest Health Monitoring (USFS)
FTP	File Transfer Protocol
GIS	Geographic Information System
GPRA	Government Performance and Results Act
GPS	Global Positioning System
GRD	Geologic Resources Division (NPS)
GRTS	Generalized Random-Tessellation Stratified Design
GRTE	Grand Teton National Park
GRYN	Greater Yellowstone Network
GSA	General Services Administration
GYCC	Greater Yellowstone Coordinating Committee
GYE	Greater Yellowstone Ecosystem
HUC	Hydrologic Unit Code
I&M	Inventory and Monitoring
IDF&G	Idaho Fish and Game
IGBST	Interagency Grizzly Bear Study Team

Acronym	Definition
IMPROVE	Interagency Monitoring of Protected Visual Environments
IMR	Intermountain Region Office (NPS I&M)
IT/IS	Information Technology/Information Services
JODR	John D. Rockefeller, Jr. Memorial Parkway
LTER	Long-Term Ecological Research
MSU	Montana State University
MTDEQ	Montana Department of Environmental Quality
MTFWP	Montana Fish, Wildlife and Parks
NADP/MDN	National Atmospheric Deposition Program/Mercury Deposition Network
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NAS	Network Attached Storage
NAWQA	National Water Quality Assessment Program
NBII	National Biological Information Infrastructure
NFM	National Field Manual (USGS)
NGO	Non-governmental Organization
NHD	National Hydrography Dataset
NOAA/NCDC	National Oceanic and Atmospheric Administration/National Climatic Data Center
NOAA/NWS	National Oceanic and Atmospheric Administration/National Weather Service
NPS	National Park Service
NR-GIS	Natural Resources-Geographic Information System
NVCS	National Vegetation Classification Standards
QA/QC	Quality Assurance/Quality Control
SD	Standard Deviation
SE	Standard Error
SOP	Standard Operating Procedure
TC	Technical Committee
USFS	US Forest Service
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey
UW-NPS	University of Wyoming-National Park Service Research Center
WASO	Washington Office (NPS)
WCS	Wildlife Conservation Society
WPEF	Whitebark Pine Ecosystem Foundation
WRD	Water Resources Division (NPS)
WYDEQ	Wyoming Department of Environmental Quality
WYG&F	Wyoming Game and Fish
YELL	Yellowstone National Park
YVO	Yellowstone Volcano Observatory

GLOSSARY

Area Frame: A sampling frame that is designated by geographical boundaries within which the sampling units are defined as subareas.

Aridisol: A soil characterized by an aridic moisture regime (the soil is dry in all parts for more than half of the cumulative days per year when the soil temperature at a depth of 50 cm from the soil surface is above 5°C; and the soil is moist in some or all parts for less than 90 consecutive days when the soil temperature at a depth of 50 cm is above 8°C) (Soil Survey Staff 2003).

Adaptive Management: A systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form—"active" adaptive management—employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed.

Adaptive Sampling: A sampling process that entails the selection of units that may be influenced by the value or type of unit selected (Thompson and Seber 1996).

Bayesian Statistics: Statistics that incorporate prior knowledge and accumulated experience into probability calculations; statistics that use subjective probability as a starting point for assessing a subsequent probability.

Bias: The difference between the expectation of the sample estimator and the true population value, depriving a statistical result of representativeness by systematically distorting it.

Biological Significance: An important finding from a biological point of view that may or may not pass a test of statistical significance.

Cluster Sample: An approach whereby selection is made of groups or clusters of units, called primary units, within which all of the secondary units are sampled (Levy and Lemeshow 1999).

Control Conceptual Model: A model that represents key processes, interactions and feedbacks (Gross 2003).

Convenience Sampling: Generally based on factors such as ease of access with no assurance that samples collected in this manner will be representative of the target population.

Data Dictionary: Describes a set of database system tables that contain the data definitions of database objects.

Database Application: A specific database designed and built for a specific data management and storage purpose using a database program.

Design-based Inference: Uses probability sampling to derive estimates of state variables and/or rates of change (Hansen et al.1983).

Driver: The major external driving forces that have large-scale influences on natural systems. Drivers can be natural forces or anthropogenic.

Dual Frame Sampling Design: A sampling design that incorporates both a list frame and an area frame.

Element: Sometimes referred to as an observational unit; consists of any item for which measurement is made or information is recorded (Schaeffer et al. 1990, Lohr 1999).

Endangered: Any species that is in danger of becoming extinct throughout all or a significant portion of its range.

Entisol: A soil that lacks any developmental horizons because the material comprising the soil has only recently accumulated (Soil Survey Staff 2003).

Hypothesis Testing: Making a decision between rejecting or not rejecting a null hypothesis, on the basis of a set of observations.

Inference: Extension of sample results to a population of interest.

Inventory: An extensive point-in-time survey to determine the presence/absence, location or condition of a biotic or abiotic resource.

Judgment Sampling: Employs expert knowledge in the selection of sampling units. Studies have shown that selection bias is common when judgment sampling is used (Edwards 1998, Stoddard et al. 1998, Olsen et al. 1999).

List Frame: A sampling frame that is a list of the potential sampling units along with their descriptive attributes.

Management Objective: An objective that focuses on the desired state or condition of the resource.

Metadata: Data about data. Metadata describes the content, quality, condition and other characteristics of data. Its purpose is to help organize and maintain a organization's internal investment in spatial data, provide information about an organization's data holdings to data catalogues, clearinghouses, and brokerages, and provide information to process and interpret data received through a transfer from an external source (Federal Geographic Data Committee 1997).

Metrics (Measurements): Specific measures used to quantify the indicators. Analysis of this information will assess how well the indicator is responding to the ecological effect.

Model-based Inference: Enables incorporation of hypothesized relationships, which can better lead to predictive capabilities (Olsen et al. 1999).

Monitoring: The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective.

Monitoring Objective: An objective that focuses on the measurement of the state or condition of the resource

Multi-stage Cluster Sample: An extension of cluster sampling where a subset of the units within the primary units are sampled.

Monitoring Protocol: A detailed study plan that explains how data are to be collected, managed, analyzed and reported and are a key component of quality assurance for natural resource monitoring programs (Oakley et al. 2003).

NatureBib: The national master database for natural resource bibliographic references that merges a number of previously separate databases such as NRBib, GeoBib, and others.

NPS Dataset Catalog: A tool for keeping an inventory and providing abbreviated metadata or "metadata light" about a variety of natural resource data sets, from physical files and photographs to digital scientific and spatial data. Each I&M Network has a Dataset Catalog to house metadata about natural resource datasets pertaining to that Network's park units.

NPS Natural Resources Metadata and Data Store: A Web-based NPS system designed to integrate data dissemination and metadata maintenance for Natural Resource, GIS and other NPS data sets, digital documents and appropriate digital photos.

NPS Protocol Clearinghouse: A Website containing links to monitoring protocol documents that have been developed by various NPS I&M Networks throughout the U.S. The web link is http://science.nature.nps.gov/im/monitor/protocoldb.cfm.

NPSpecies: The NPS database to store, manage and disseminate scientific information on the biodiversity of all organisms in all National Park units throughout the United States and its territories.

Null Hypothesis: In hypothesis testing, this is the hypothesis we wish to falsify on the basis of the data. The null hypothesis is typically that something is not present, that there is no effect or trend.

Observational Unit: Sometimes referred to as an *element*; consists of any item for which measurement is made or information is recorded (Schaeffer et al. 1990, Lohr 1999).

Outcome: Ecological attributes that result from effects within which specific processes or factors may become vital signs.

Panel: A group of sample units that are sampled during the same sampling occasion.

Parameter Estimation: The process of using a sample to estimate features of a population.

Precision: A statistical measurement of repeatability that is usually expressed as a variance or standard deviation.

Probability-based Sampling: A sampling method that applies sampling theory and some form of randomization in sample unit selection (EPA 2002). This randomization ensures a reduction in potential bias from judgment or convenience sampling, thus increasing the validity of extending inference from a sample to the population of interest.

Response Variables: Physical, chemical and biological responses to drivers and stressors.

Revisit Design: A sampling design that incorporates a scheme for revisiting sample sites.

Sample Frame: A complete collection of the possible sample units from which the sample can be drawn. Sample frame types are list frames and area frames.

Sample Units: All of the individual units contained within the sample frame that are actually sampled.

Sample Population: The actual population from which a given sample is drawn.

Simple Random Sample: A sample in which units are selected from a population of size (N) via a random process, such that every sample unit has the same probability of being included in the sample.

Standard Operating Procedure (SOP): A detailed description of how all aspects of the components describe in the monitoring protocol will be carried out (Oakley et al. 2003).

Statistical Power: The probabililty of not making a Type II error. Estimating power enables the determination of the sample size needed in order to detect a trend of a given magnitude with reasonable confidence.

Statistical Significance: A result that is probably not due to chance. The level of significance is chosen by the statistician or researcher.

Stratified Random Sample: A sampling method in which the sampling frame is divided into mutually exclusive and exhaustive subpopulations called strata, from which *n* samples are randomly selected (Levy and Lemeshow 1999).

STORET/NPSTORET: A database application maintained by the U.S. Environmental Protection Agency that contains raw biological, chemical and physical data on surface and ground water collected by federal, state and local agencies, Indian Tribes, volunteer groups, academics, and others. All 50 states, and jurisdictions of the U.S. are represented in these systems. NPSTORET is the NPS version of this database used for data entry by NPS staff. Data from NPSTORET are subsequently transferred to STORET.

Stressor: Physical, chemical or biological agents that cause significant changes in the ecological components, patterns and relationships in natural systems. The effects of stressors on park resources can be positive or negative. ***The difference between a Driver and a Stressor is in some cases a matter of scale. For example, exotic species invasions, land-use change and fire suppression can be a driver in cases where they have a national or regional effect, but at a more localized scale, they may be stressors.*

Stressor Conceptual Model: Models tuat identify the relationships between stressors (or drivers), ecosystem components and effects.

Systematic Sample: A sampling method in which one sample unit is typically selected at random and subsequent units are selected according to a systematic pattern. A common form of systematic sampling is randomly selecting one unit from the first k units in the sampling frame and every k^{th} unit thereafter (Mendenhall et al. 1971).

Target Population: The set of all of the units or elements for which inference is intended and should directly reflect the monitoring objectives.

Threatened: A species that is likely to become endangered in the foreseeable future.

Type I Error: Erroneously rejecting a null hypothesis that is true or finding a trend when none exists.

Type II Error: Erroneously failing to reject a null hypothesis that is false or not detecting a trend when one exists.

Validity/Standard Error: The estimated standard deviation of a statistic.

Vertisol: A soil containing a 25 cm or more thick horizon (within 100 cm from the soil surface) that has such a very high concentration of clay or that has such a high clay content in the soil generally that the soil cracks temporarily when dry (Soil Survey Staff 2003).

Vital Signs: Vital signs are a subset of physical, chemical and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system) or functional (referring to ecological processes).