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Structured Decision Making and Optimal Bird Monitoring in the Northern Gulf of Mexico

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U.S. Department of the Interior
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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Abbreviations

BCR	Bird Conservation Region
C-CAP	Coastal Change Analysis Program
CZM	Coastal Zone Management
EPA	U.S. Environmental Protection Agency
GoMAMN	Gulf of Mexico Avian Monitoring Network
NCTC	National Conservation Training Center
NFWF	National Fish and Wildlife Foundation
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NRDA	Natural Resources Damage Assessment
PIF	Partners in Flight
RESTORE	Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf States Act of 2012
SDM	Structured Decision Making
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Structured Decision Making and Optimal Bird Monitoring in the Northern Gulf of Mexico

By Auriel M.V. Fournier[1+], R. Randy Wilson[2], James E. Lyons[3], Jeffrey S. Gleason[4], Evan M. Adams[5], Laurel M. Barnhill[6], Janell M. Brush[7], Robert J. Cooper[8], Stephen J. DeMaso[9], Melanie J.L. Driscoll[10], Mitchell J. Eaton[3], Peter C. Frederick[11], Michael G. Just[12], Michael A. Seymour[13], John M. Tirpak[14], and Mark S. Woodrey[1,15]

Abstract

The avian conservation community struggles to design and implement large scale, long-term coordinated bird monitoring programs within the northern Gulf of Mexico due to the complexity of the conservation enterprise in the region; this complexity arises from the diverse stakeholders, multiple jurisdictions, complex ecological processes, myriad habitats, and over 500 species of birds using the region for at least some part of their annual cycle. In addition, long-term monitoring over large spatial scales is difficult because of the need for monitoring data to both (1) evaluate management and restoration outcomes, and (2) provide reliable information about the status and trends of bird populations over time.

To address these challenges, the Gulf of Mexico Avian Monitoring Network developed a problem statement:

"How can a cost-effective monitoring strategy for the Gulf Coast bird community and ecosystem be developed that evaluates ongoing conservation activities and chronic and acute threats; maximizes learning; and is flexible and holistic enough to detect novel ecological threats and evaluate new and emerging conservation activities?"

A structured decision-making framework was then used to articulate and quantify stakeholder values related to the problem statement. One use of the stakeholder values was to develop a regional, strategic plan for bird monitoring, which is presented elsewhere. A formal and complete decision support tool for conservation investments in monitoring and research guided by the stakeholder values is presented in this report. The technical aspects of the stakeholder value model and a portfolio analysis that could be used to guide decision making when allocating resources for monitoring activities is described. Whereas the decision analysis presented here could be useful to any decision maker faced with difficult choices about resource allocation, it is designed for decision makers who request monitoring study proposals and then determine which combination of proposals to fund. The portfolio decision support tool is designed to help funding agencies and organizations identify resource allocation strategies to maximize stated objectives.

To begin the decision analysis, an objectives hierarchy and quantitative performance metrics from the values of the Gulf of Mexico bird conservation community were created by a panel of regional stakeholders. Each fundamental objective and sub-objective in the hierarchy is composed of several performance metrics. To test the decision support tool, the authors evaluated a combination of monitoring study proposals written for the region and simulated proposals. Each proposal was scored against the performance metrics and used multi-attribute utility theory to combine the multiple objectives into a measure of total monitoring benefit. The total monitoring benefit and costs of each proposal were then used in a constrained optimization routine to identify optimal monitoring portfolios,

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that is, a combination of activities that maximizes monitoring benefits while meeting cost and other constraints of interest to stakeholders. A graphical solution based on the concept of Pareto efficiency, which is useful in situations when cost constraints and exact budgets are not known, is also provided. Finally, an evaluation of the sensitivity of the decision-making framework to the weights assigned to objectives by stakeholders is included. This decision support tool allows decision makers to identify an optimal suite of monitoring proposals with a transparent portfolio analysis that includes user-defined constraints (such as costs).

Introduction

Birds are a conspicuous natural resource in the Gulf of Mexico. Over half of all migratory bird species in North America and millions of individual birds are supported by barrier islands, beaches, marshes, estuaries, coastal forests, and the open ocean across the region (Horton and others, 2019). Collectively, birds of the Gulf of Mexico are unparalleled indicators of system health and the natural resources on which humans rely for their health, economy, and quality of life (National Academies of Sciences, Engineering, and Medicine, 2017). Today, the conservation of coastal habitats for birds is often at odds with human population growth and development, creating a dichotomy between the importance of these limited coastal areas for human needs and their conservation value for birdlife. Anthropogenic and natural stressors (such as urban and coastal development, oil spills, sea-level rise, hurricanes, etc.) can result in habitat loss and fragmentation, and reduction of habitat quality. Quantifying the scale and extent of impacts to birds and their habitats in the Gulf of Mexico will require the conservation community to work in a collaborative, proactive manner. This includes monitoring bird and habitat responses to mitigation and restoration activities.

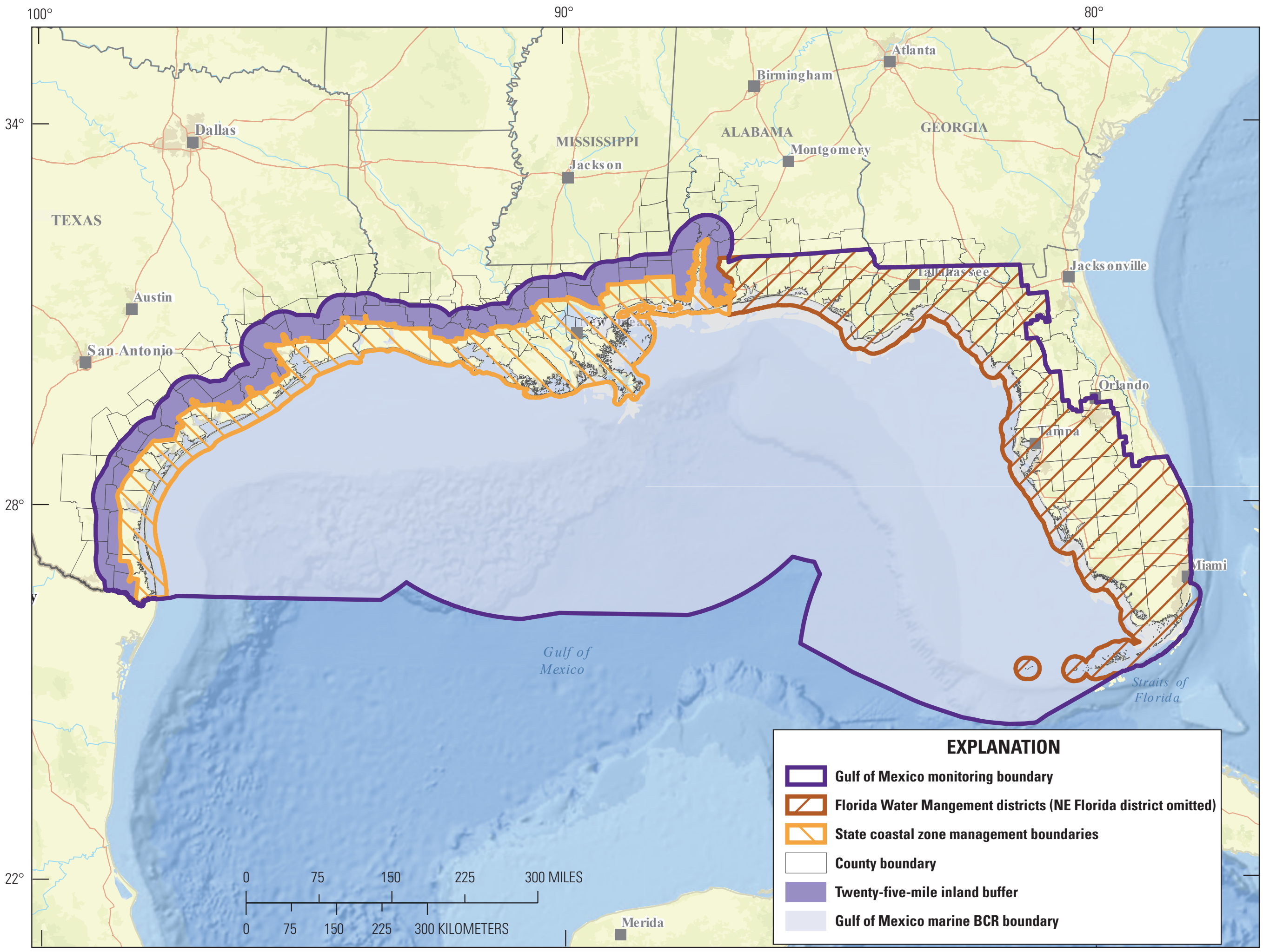
The contemporary restoration work in response to the 2010 Deepwater Horizon oil spill – conducted under the auspices of the RESTORE Act of (2012), Natural Resource Damage Assessment Trustee Council (NRDA Trustees) and the National Fish and Wildlife Foundation (NFWF; NOAA RESTORE Act Science Program Science Plan, 2015) – presents an opportunity to increase the understanding of this ecosystem by monitoring bird populations and their habitats. These entities, in addition to State, Federal, and non-governmental organizations are collectively making significant financial investments in bird conservation for the northern Gulf of Mexico region (Baldera and others 2018). To maximize environmental benefits, decision makers need information related to bird-habitat relations and strategies for evaluating restoration effectiveness.

Currently, there are no legal, regulatory, or political mandates to implement a bird monitoring strategy across the entire Gulf of Mexico. However, the Oil Pollution Act (1990) requires restoration project monitoring and the Deepwater Horizon Programmatic Damage Assessment and Restoration Plan (PDARP; Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) commits the NRDA Trustees to a robust monitoring and adaptive management framework. Additionally, several Federal and State wildlife agencies have legal requirements to protect, manage, and conserve wildlife resources (for example, trust resource responsibilities) and their habitats for the continuing benefit of the American people (Smith, 2011; Decker and others, 2014; Organ and others, 2014). As such, the success of designing and implementing a coordinated and collaborative monitoring strategy for the Gulf of Mexico will require the commitment and dedication of a wide array of conservation partners (Federal agencies, State wildlife agencies, non-governmental organizations or NGOs, Joint Venture Partnerships), all operating under different mandates and missions, often with differing objectives and priorities (U.S. North American Bird Conservation Initiative, 2007).

The larger conservation community of dedicated scientists and managers – from on-the-ground habitat managers and researchers to those making programmatic, region-wide funding allocations – have historically implemented monitoring projects in the form of short-term, site-specific projects, limited in spatial scope (Ruth and others, 2003). As such, the conservation community continues to struggle with designing and implementing large-scale, coordinated bird monitoring within the northern Gulf of Mexico region due to the complexity of the Gulf system (multiple birds of conservation concern species using different habitats, across different jurisdictions, and across different seasons).

Coordinated monitoring in such a large region is further complicated by the need for information related to system state variables (population estimates) and how state variables change with respect to management and restoration actions (Lyons and others 2008; Hutto and Belote 2013). To ensure that operational and financial decisions reflect contemporary monitoring needs, the conservation community could benefit from a structured process to identify information gaps and priorities that facilitate proactive decision making (Conroy and Peterson, 2013; Groves and Game, 2015) across the northern Gulf of Mexico region (fig. 1). In addition, the conservation community also could benefit from a transparent, quantitative means of expressing the benefit of any given monitoring project with respect to stated objectives and values.

In 2014, a group of conservation partners from a variety of agencies and organizations with interest in bird resources and conservation in the Gulf of Mexico participated in a structured decision making (SDM) workshop at the U.S. Fish and Wildlife Service's National Conservation Training Center (NCTC) in Shepherdstown, West Virginia (Wilson and others, 2014). A large scale, long-term bird monitoring strategy will require implementation and investments of time and money by multiple decision makers, stakeholders, and conservation practitioners across the region. The group of conservation partners that met at NCTC was chosen to represent as many of these decision makers as possible and the larger conservation community (such as stakeholders).



Base from Esri, GEBCO, DeLorme, NaturalVue, Esri, HERE, Garmin, FAO, NOAA, U.S. Geological Survey, U.S.Environmental Protection Agency

Figure 1. Geographical boundary for the Gulf of Mexico Avian Monitoring Network (GoMAMN). The geographic extent is bounded to the south by the southern edge of Marine Bird Conservation Region (BCR) 20 (United States, Gulf of Mexico). The northern boundary is defined by the RESTORE Act (2012; state boundaries in the Coastal Zone Management Act [1972] plus a 40.23-kilometer [25-mile] inland buffer). In Florida, the GoMAMN geographic extent is defined by the Florida Department of Environmental Protection's Water Management Districts, excluding the Northeast Florida Water Management District. For additional information regarding Marine BCR 20, Coastal Zone Management state boundaries, and the Florida Water Management District boundary, see Coastal Zone Management Act (1972), Bird Studies Canada and U.S. North American Bird Conservation Initiative (2014), and Florida Department of Environmental Protection (2018).

The purpose of this workshop was to use the principles of decision analysis to inform future bird monitoring efforts across the northern Gulf of Mexico. To that end, participants identified the following problem statement:

> *"How can a cost-effective monitoring strategy for the Gulf Coast bird community and ecosystem be developed that evaluates ongoing conservation activities and chronic and acute threats; maximizes learning; and is flexible and holistic enough to detect novel ecological threats and evaluate new and emerging conservation activities?"*

Having framed the problem in this way, the workshop participants then used the principles of decision analysis to (1) create a foundation for a comprehensive bird monitoring strategy, and (2) develop a prototype decision support tool that could be used by funding sources (RESTORE Council, NRDA Trustees, NFWF) to evaluate monitoring proposals and allocate funding to achieve the stakeholders' strategic vision.

Using the foundational work completed at NCTC, the workshop participants established a bird conservation community of practice known as the Gulf of Mexico Avian Monitoring Network (GoMAMN). The community of practice, which includes myriad conservation partners across the Southeastern

United States, met numerous times during 2014—16, including subsequent workshops at Cedar Key, FL in August 2014 and Rockport, TX in December 2014, to further refine the problem statement and the prototype portfolio selection tool. The results of those meetings describe (1) the fundamental objectives and performance metrics that biologists and managers consider important for new monitoring efforts, and (2) the decision support tool that could be used by decision makers to allocate resources in a way that maximizes monitoring benefits while meeting any constraints, such as cost (select a portfolio of monitoring investments). In this report, we describe the decision support tool which uses linear integer programming, a constrained optimization routine; simpler approaches are possible (Joseph and others, 2009), but may not maximize monitoring benefits and may not use all available funds. Constrained optimization will always identify a portfolio of monitoring projects that provides the maximum possible benefit given cost and other constraints, while simultaneously minimizing unused funds (“left on the table”).

Fundamental Objectives and Sub-Objectives

The core of Structured Decision Making (SDM) is a set of well-defined objectives and evaluation criteria. Together, they define what matters about the decision, drive the search for creative alternatives, and become the framework for comparing alternatives (Gregory and others, 2012). To clearly define and articulate fundamental objectives for bird monitoring, a “stakeholder brainstorming session” was held as part of the NCTC workshop and workshop participants were asked to list the core values and concerns underpinning bird monitoring efforts in the Gulf of Mexico. From this exercise, several key concepts repeatedly emerged: the relevance of monitoring information for decision making, understanding responses to management actions, assessing the state of the ecosystem, scientific rigor, integration, and partnerships. A restoration schematic was subsequently developed (fig. 2) linking management actions to monitoring response variables and identifying direct linkages to ongoing conservation planning efforts. This conceptual diagram allows the evaluation of fundamental

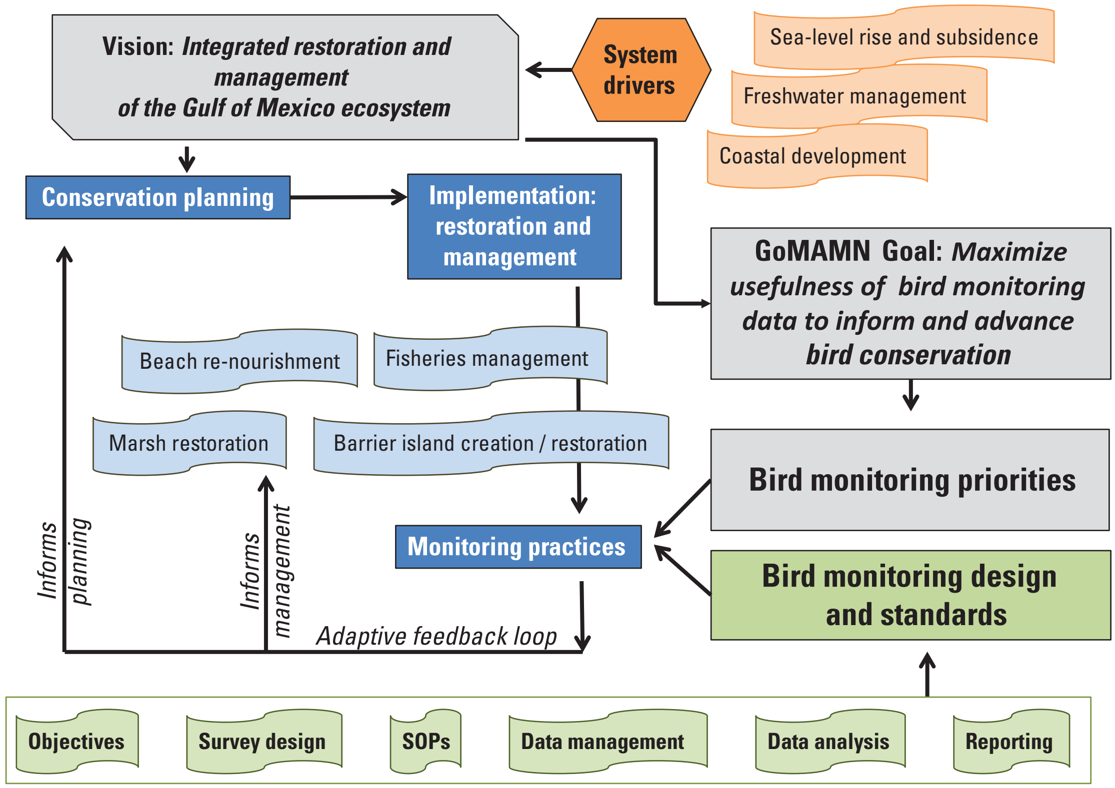


Figure 2. Restoration schematic depicting the role of the Gulf of Mexico Avian Monitoring Network (GoMAMN) within the larger context of Gulf restoration. Stakeholder values and objectives are shown in gray, the adaptive decision process in blue (with examples in wavy boxes), monitoring components in green, and system drivers in orange (with examples in wavy boxes). SOPs indicates standard operating procedures.

monitoring objectives in a new light (for example, fundamental objectives identified in the brainstorming session could be viewed as "means objectives" in an even larger, overarching vision for integrated restoration and management actions in the region).

"Process objectives" are included in the restoration schematic (fig. 2) – objectives that could be addressed in the process of developing a bird monitoring strategy – including components such as data management and reporting. The recognition of these process objectives provided additional structure, allowing the separation of components, while realizing necessary linkages where appropriate. By constructing the restoration schematic, the core values were better articulated in a hierarchical format, which begins with an over-arching strategic objective to increase the usefulness of bird monitoring data for conservation, and includes a set of three fundamental objectives (fig. 3).

On the basis of output from the brain storming session and subsequent discussions, three fundamental objectives were identified, including one with multiple sub-objectives (fig. 3), which could guide bird monitoring across the northern Gulf of Mexico (fig. 1) region:

- Fundamental Objective 1.0: Maximize the relevance of monitoring data — ensure that monitoring addresses contemporary data needs; understand the positive and negative effects of management actions on bird populations and their habitats; assess the status of bird populations and their habitats; and understand ecological processes and the associated mechanisms that impact bird populations.
  - Sub-Objective 1.1: Maximize monitoring of management effectiveness.
  - Sub-Objective 1.2: Maximize monitoring of population and habitat status (such as baseline information related to status and trends of Birds of Conservation Concern and their primary habitats in the Gulf of Mexico).
    - Sub-Objective 1.2.1: Maximize monitoring to precisely determine the population status of Birds of Conservation Concern.

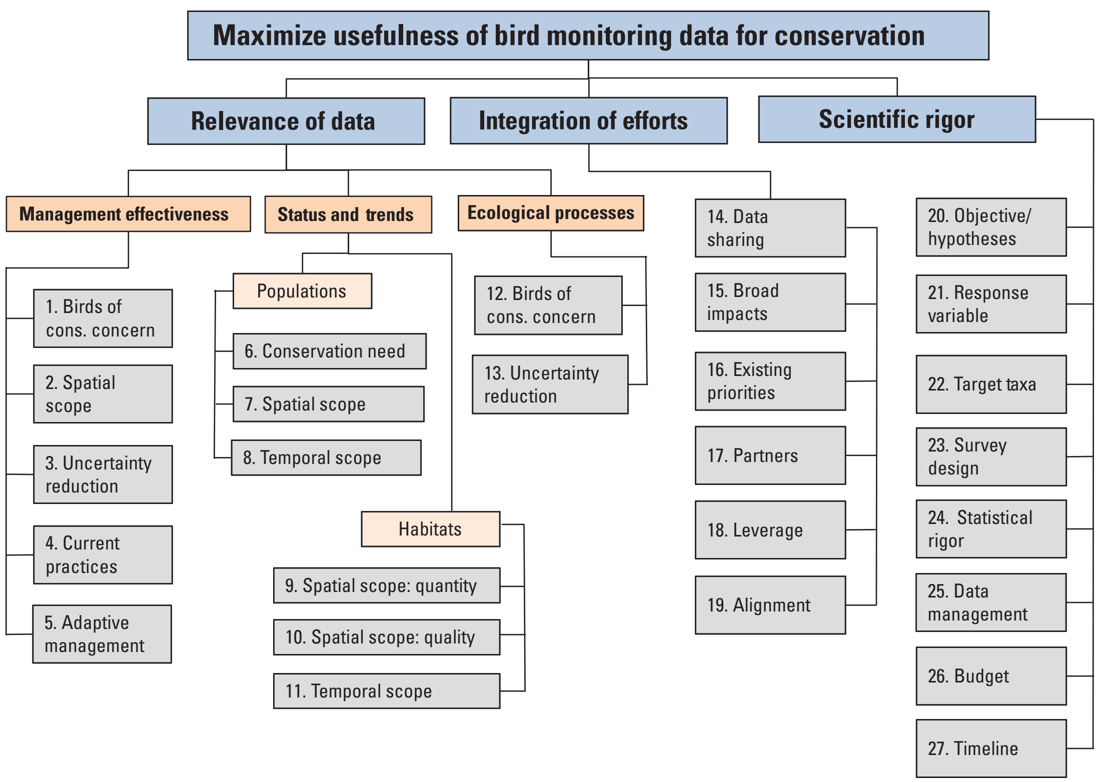


Figure 3. Objectives hierarchy showing fundamental and sub-objectives and their (numbered) performance metrics for optimal bird monitoring. "Birds of Cons. Concern" (performance metrics 1 and 12) indicates Birds of Conservation Concern. "Spatial Scope: Quantity" indicates spatial scope of habitat quantity monitoring (performance metric 9). "Spatial Scope: Quality" indicates spatial scope of habitat quality monitoring (performance metric 10).

- Sub-Objective 1.2.2: Maximize monitoring to precisely determine the habitat status of Birds of Conservation Concern.
- Sub-Objective 1.3: Maximize monitoring of ecological processes and their impacts on bird populations.
- Fundamental Objective 2.0: Maximize integration of monitoring among conservation and management organizations and entities.
- Fundamental Objective 3.0: Maximize scientific rigor of monitoring.

Relative Weights for Monitoring Objectives

Multi-criteria decision analysis requires that decision makers rank or weight multiple objectives according to their preferences (Keeney and Gregory, 2005; Clemen and Smith, 2009). To determine the relative preference for each objective, a modified Delphi method to elicit and refine objective weights was used (Clark and others, 2006). The Delphi method is a systematic process to elicit judgement from a group of experts (Dalkey and Helmer, 1963). A modified Delphi approach is an iterative, facilitated process in which the participants answer survey questions and then review, discuss, and revise their answers until consensus is reached. Participants were not required to reach a consensus, but instead statistical averages of their responses (Landeta, 2006) after multiple rounds of elicitation, review, and discussion were used.

The Delphi exercise was conducted at a workshop in December 2014 at Rockport, TX and consisted of asking 13 workshop participants, who were from a cross-section of the conservation community and represented key stakeholders, to individually and anonymously quantify their preference among the objectives. Due to the difficulty of assigning relative preferences to multiple objectives simultaneously, the exercise was completed for groups of objectives at each level of the objectives hierarchy (fig. 3). Participants were first asked to rank objectives at a given level of the hierarchy (relevance, rigor, and integration of monitoring efforts were ranked relative to each other), with the most important objective being listed as Rank 1, the second most important as Rank 2, etc. Objectives could receive the same (tied) rank. Participants were then asked to rate the objectives under the following guidelines: a rating of 100 was to be given to any objective with Rank 1, and subordinately ranked objectives were to be given a rating (number of points) that represented their preference for that objective relative to the Rank 1 objective (100 points). This process was performed at each level of the hierarchy until all objectives were ranked and rated (Goodwin and Wright, 2004).

The compiled results of these objective preferences were then reviewed with participants as a group, while maintaining the anonymity of the ranks and rates. Participants also were given a basic statistical summary of the group scores (mean, range, and variance) to understand the degree of similarity and differences among individual preferences. After this exchange, a second round of elicitations was conducted, in which experts could consider the discussions to revise their ranks and ratings if desired. The mean and range of preference weights among experts are provided in Appendix 1. Elicitation of Objective Weights.

Objective weights were calculated as the proportion of total preference within a given level of the hierarchy (a group of sub-objectives below one higher-order objective):

$$w_{i,j} = \overline{p}_{i,j} / \textstyle\sum_j \overline{p}_{i,j} \qquad (1)$$

where

$w_{i,j}$ is the weight for objective i within objective group j, and

$\overline{p}_{i,j}$ is the average preference score among experts for objective i within objective group j.

Weights sum to 1 for each group of objectives, but are then adjusted proportionally so that the weight for all objectives in the hierarchy sums to 1. This method for weighing objectives was selected because it was transparent and replicable. Swing weighting (Goodwin and Wright, 2004) is an alternative approach to determine weights, but the specific monitoring proposals that will be in the analysis must be known when weights are being elicited. In this case, the set of monitoring proposals used in the decision analysis had not been identified at the time of the elicitation with experts. Swing weights have the added benefit of accounting for the range of predicted outcomes among the (known) alternatives in a decision analysis.

The weights assigned to all objectives are presented in table 1. At the top of the hierarchy (fig. 3), the weights assigned to relevance, integration, and rigor were 0.42, 0.24, and 0.34, respectively (fig. 3, table 1). The three sub-objectives of relevance (management effectiveness, status and trends, and ecological processes) received weights of 0.16, 0.14, and 0.12 respectively (table 1).

Performance Metrics to Evaluate Monitoring Benefits

For each fundamental objective and sub-objective, a set of performance metrics and utility functions was defined by participants at a workshop in Cedar Key, FL, in August 2014, which allowed the use of multi-attribute utility theory when selecting monitoring proposals in a portfolio decision analysis. Performance metrics are the scales chosen by the decision maker as a means of measuring success toward an objective (Keeney and Gregory, 2005). Many performance measures

Table 1. Weights assigned to objectives and performance metrics in the Gulf of Mexico Avian Monitoring Network (GoMAMN) objectives hierarchy. The sums of weights for objectives and sub-objectives are shown in parentheses.

Performance metric	Weight
Relevance of data (0.42) Management effectiveness (0.16)	
1. Birds of conservation concern	0.03
2. Spatial scope (of management actions)	0.03
3. Uncertainty reduction (from monitoring management actions)	0.03
4. Current management practices	0.03
5. Adaptive management	0.04
Relevance of data (0.42) Status and trends (0.14)	
6. Conservation need	0.03
7. Spatial scope of population monitoring	0.03
8. Temporal scope of population monitoring	0.02
9. Spatial scope of habitat quantity monitoring	0.02
10. Spatial scope of habitat quantity monitoring	0.02
11. Temporal scope of habitat monitoring	0.02
Relevance of data (0.42) Ecological processes (0.12)	
12. Birds of conservation concern	0.03
13. Uncertainty reduction	0.09
Integration of efforts (0.24)	
14. Data sharing	0.04
15. Broad impacts	0.04
16. Existing priorities	0.05
17. Partners	0.05
18. Leverage	0.03
19. Alignment	0.03
Scientific rigor (0.34)	
20. Objectives/hypotheses	0.05
21. Response variable	0.04
22. Target taxa	0.04
23. Survey design	0.05
24. Statistical rigor	0.05
25. Data management	0.04
26. Budget	0.04
27. Timeline	0.03
Total	**1.00**

related to the five objectives for this decision problem (management effectiveness, status and trends, ecological processes, integration of efforts, and scientific rigor) were identified. The metrics were refined through iterative prototyping during workshops and follow-up meetings of the GoMAMN community of practice, which included additional stakeholders that were not present at the Cedar Key workshop. Performance measures that were clearly related were combined and others that were not unambiguous and operational (Keeney and Gregory, 2005) were deleted, leaving 27 performance metrics related to the five objectives (Appendix 2 Performance Metrics and Utility Functions).

The challenge in any multi-objective decision problem is combining the disparate objectives in a reasonable way that reflects overall performance across all objectives; performance measures for different objectives almost always represent “apples and oranges” so that is difficult to compare performance and make trade-offs among objectives. Multi-attribute utility theory (Keeney and Raiffa, 1976) is a framework to develop quantitative functions that transform all performance metrics to a common scale to allow an “apples to apples” comparison. The common scale is utility, which ranges between 0 and 1. To transform the performance metrics to utility, the worst outcome on each performance metric is always assigned a utility of 0 and the best possible outcome is assigned a utility of 1. In this way, any possible outcome on the performance metric is mapped to a scale between 0 and 1. Multi-attribute utility theory (Keeney and Raiffa 1976) can be used to sum (weighted) utilities across performance measures for an overall level of performance (see equation 2 in Constrained Optimization).

Utility is used to describe the decision maker’s relative preference for different levels of performance, such as the preference for different outcomes with respect to each objective. Linear or curvilinear relations between the performance measure and utility are possible. In some cases, there is a one-to-one, straight-line relation between the performance measure and utility; every increment on the performance measure provides the same increase in utility. For example, the performance measure related to uncertainty about management actions has three levels (low, medium, and high) and the change in utility is the same between low and medium as between medium and high (fig. 4A). In other cases, the utility function may be curvilinear (concave or convex). A concave utility function represents a rapid increase in the decision maker’s satisfaction at the lower end of a performance measure and diminishing returns (smaller increments in satisfaction) at the high end of the performance measure (fig. 4B). A convex utility function represents the opposite situation; satisfaction increases slowly at the lower end of the performance measure and more rapidly at the higher end of the performance measure. Finally, a utility function may be sigmoidal; utility changes more slowly at the extremes of the performance measure than in the middle of the range in performance (fig. 4C). With the performance measure related to the duration of habitat monitoring programs, the (piecewise linear) sigmoidal

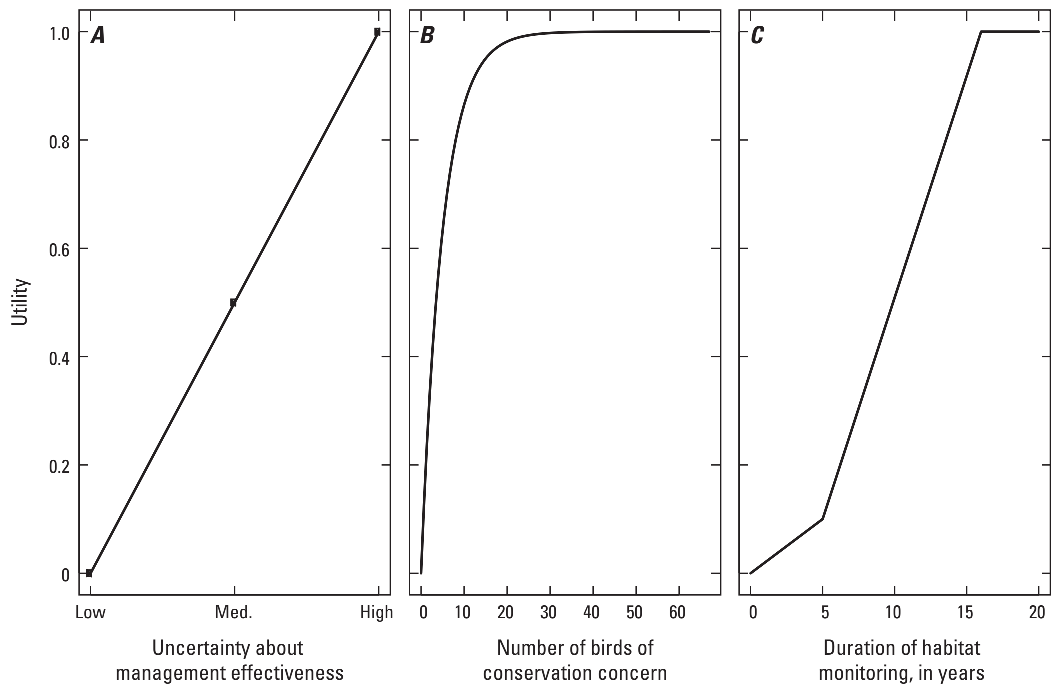


Figure 4. Example utility functions used in the portfolio decision analysis *A*, a linear utility function in which each increment on the x-axis provides the same increment in utility, *B*, a concave utility function in which utility increases rapidly for scores at the low end of the x-axis with diminishing returns at the high end of the x-axis, *C*, a sigmoidal utility function in which utility increases slowly at both the low and high end of the x-axis.

utility function reflects a strong preference for monitoring programs longer than 5 years to as much as 16 years; monitoring programs longer than 16 years provide the same level of satisfaction to decision makers.

Utility functions were elicited during an in-person workshop with a group of 18 stakeholders from the GoMAMN community of practice at Cedar Key, FL in August 2014. To prepare the stakeholders for the elicitation, multi-attribute utility theory was explained and the ways utility functions operate in decision analysis were described. Several examples of utility functions with different shapes, including linear, piecewise linear, concave, and convex, were shown and how each is interpreted to reflect how satisfaction changes with the performance measure was discussed. The group of stakeholders was then divided into four groups, each focused on a particular part of the objectives hierarchy (management effectiveness, status and trends, ecological processes, and integration of efforts and scientific rigor). Each group was given a spreadsheet with the performance measures and asked to draw a utility function representing their level of satisfaction for each performance measure. All elicited utility functions produced in the smaller groups with the entire, plenary group of stakeholders were reviewed and discussed. In some cases, utility functions were revised based on feedback and discussion during the plenary review.

Fundamental Objective 1: Maximize Relevance of Monitoring Data

The GoMAMN is designed to address contemporary and relevant information needs. Specifically, to advance bird habitat conservation and restoration, the workshop participants decided that the larger community of practice must: (1) reduce uncertainty about how management actions impact birds and their habitats and evaluate returns on investments in restoration (effectiveness); (2) better understand abundance and distribution of birds, and the quantity and quality of their habitat (status and trends); and (3) reduce uncertainty about how ecological processes affect bird populations and their habitats. Information related to these three needs will help maximize the relevance of monitoring data.

Sub-Objective 1.1: Maximize monitoring of management effectiveness

As management actions and restoration projects are implemented across the Gulf of Mexico, stakeholders in our workshops determined that the effectiveness and efficiency of those actions can be assessed, and potential trade-offs that may exist among species or actions can be evaluated. Stakeholders decided that there are at least two ways to increase the efficiency of monitoring efforts: (1) focus monitoring on the effectiveness of management and restoration practices that are commonly used in the region, and (2) focus monitoring on the effectiveness of management actions that impact Birds of Conservation Concern (Supplemental Material 1). In addition, monitoring could reduce uncertainty about management actions by targeting management and restoration practices with the greatest uncertainty and by using adaptive management frameworks wherever possible to simultaneously achieve restoration goals and learn about how these systems respond to management and restoration practices (Lyons and others 2008; Williams and others 2009; Williams and Brown, 2012). With these concerns in mind, a set of GoMAMN management actions was created (Appendix 3). Five performance metrics related to monitoring management actions were used and the group assigned nearly equal weight to each performance metric (fig. 5).

Sub-Objective 1.2: Maximize monitoring of population and habitat status and trends

Typical monitoring efforts often focus on status and trends monitoring, or tracking population numbers through time. This type of monitoring often includes monitoring habitats as well as population size. Therefore, within the status and trends part of the hierarchy, workshop participants further divided the status objective into two sub-objectives (fig. 6). The first sub-objective is populations, in which higher value is placed on species with high conservation need (for example, species with a declining trend and greater uncertainty). Proposals that have large spatial and temporal scope are also valued, because those are at the appropriate scales at which the monitoring of status and trends are the most informative. In addition, it is known that birds are mobile and many species can make large regional shifts in their distribution due to

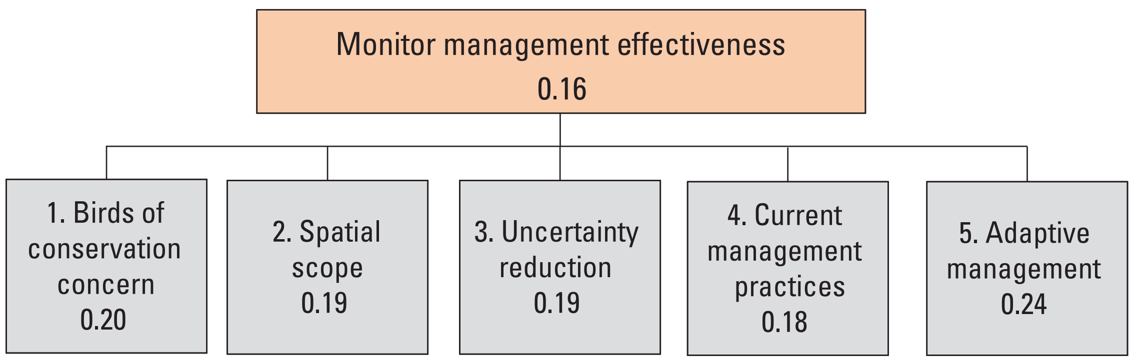


Figure 5. Objectives hierarchy for monitoring effectiveness of management actions, including restoration (sub-objective 1.1). Numbers indicate the relative weight assigned to each performance metric (absolute weights are shown in table 1).

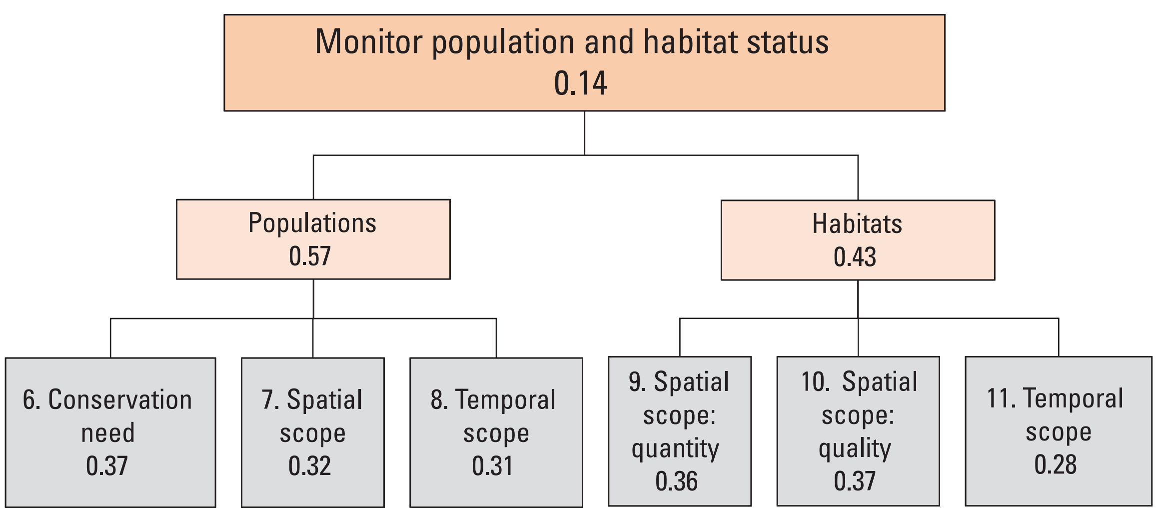


Figure 6. Objectives hierarchy for monitoring status and trends. Numbers indicate the relative weight assigned to each performance metric (absolute weights are shown in table 1). "Spatial Scope: Quantity" indicates spatial scope of habitat quantity monitoring (performance metric 9). "Spatial Scope: Quality" indicates spatial scope of habitat quality monitoring (performance metric 10).

changes in food resources or suitable habitat availability (Pavlacky and others, 2017). The second component is habitats, where the spatial and temporal scope of habitat quality and quantity monitoring is valued. For example, it is also known that suitable habitat for migratory shorebirds can vary regionally depending on annual local and regional rainfall patterns, so it is critical to monitoring habitats at broad scales to document and determine changes in species numbers due to actual population fluctuations and not sampling bias (Withers 2002; Colwell, 2010).

Sub-Objective 1.2.1: Population status assessment

With regards to population status, the primary goal is to maximize the understanding of baseline information for birds of conservation concern. The importance of precise estimates of baseline populations cannot be overstated. Not only do they provide a population estimate at a point in time, they are necessary for evaluating population trends over time through repeated estimates. Further, they also are critical for understanding natural population variability across the region due to regional differences in the effects of ecological processes that operate at different geographic scales. In addition, they provide population data necessary to quantitatively measure the additive effects of habitat restoration across the northern Gulf of Mexico (National Academies of Sciences, Engineering, and Medicine, 2017). To further the understanding of population status assessments, three performance measures were created: conservation need, spatial scope of population monitoring, and temporal scope of population monitoring (under Populations in fig. 6).

Sub-Objective 1.2.2: Habitat status assessment

Monitoring populations alone is not enough to maximize our understanding of bird populations; the monitoring of habitat quality and quantity is also necessary. Team members defined three attributes useful in evaluating habitat monitoring included in a status and trends proposal, such as the spatial and temporal scope of those habitat data (fig. 6).

Sub-Objective 1.3 Maximize monitoring of ecological processes

Bird populations are sustained by an intricate interplay of ecological processes, such as climate dynamics, patterns in primary and secondary productivity, hydrological processes, formation and maintenance of habitats, interactions between and among species, movement ecology and natural disturbances (Newton, 1998; Bennett and others, 2009). Anthropogenic effects, negative and positive, exert their influences on avian populations by affecting these ecological processes. Conserving bird populations therefore depends, in part, on understanding the effects of human-driven influences on the ecological processes, which in turn affect bird populations. A better understanding of the natural variability in populations as a result of ecological processes is needed. Such a body of knowledge is not only fundamental to long-term management of bird populations generally, it is also necessary to interpret the effects of specific management actions (Wilson and others, 2019). Monitoring to understand the ecological drivers of avian populations will often occur at much larger spatial and temporal scales than those typical of studies designed to monitor specific management actions. The separation of monitoring ecological processes that influence bird populations, and management actions that influence bird populations, is based on these general differences in scaling (Suding and others, 2004; Simenstad and others, 2006; National Academies of Sciences, Engineering, and Medicine, 2017). Stakeholders participating in the workshops decided that monitoring ecological processes has two important aspects: focus on Birds of Conservation Concern, and reduce uncertainty about ecological processes driving changes in bird populations (fig. 7).

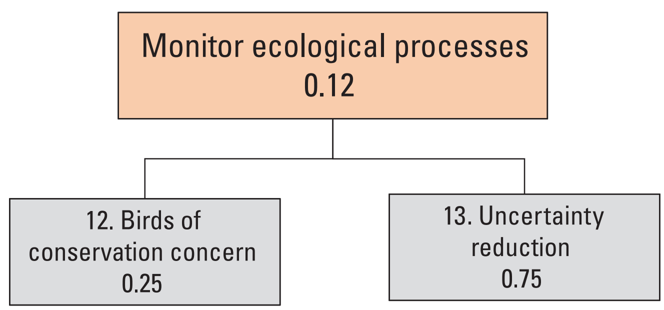


Figure 7. Objectives hierarchy for monitoring ecological processes. Numbers indicate the relative weight assigned to each performance metric (absolute weights are shown in table 1).

Fundamental Objective 2: Maximize Integration of Bird Monitoring Efforts

An overarching goal of GoMAMN is to ensure that monitoring data are collected in a standardized way within taxa, for similar management actions, or for similar ecological processes, so that they can be combined, or "rolled up," to address questions at larger spatial scales. Typically, many projects may have taken place at one or two local-scale sites with little or no attempt to use similar data-collection approaches (for example, study design, protocols, and response metrics) for evaluating the same management action(s) or similar ecological processes. Such differences create deficiencies or otherwise constrain the value of data, which in turn, limits the ability to make strong inferences at meaningful spatial and temporal scales. This section includes a description of how data could be collected, so that these data can be integrated with other datasets. Guidance is provided for data sharing (so that questions can be addressed at larger scales than for individual projects and proposals) and for a focus on the need for data used for broader impacts (such as use of data for education). In order to promote collaboration and minimize redundancy, it is then determined how a project or proposal fits into the larger picture of existing priorities from other plans, and how many partners and how much leveraging from partners are incorporated into the project or proposal. Lastly, GoMAMN data-collection methods require that the data are in alignment with other programs and the suggested protocols in the Strategic Bird Monitoring Guidelines for the Northern Gulf of Mexico (Wilson and others, 2019). Performance metrics 14-19 reflect these values related to Integration of Efforts (fig. 8).

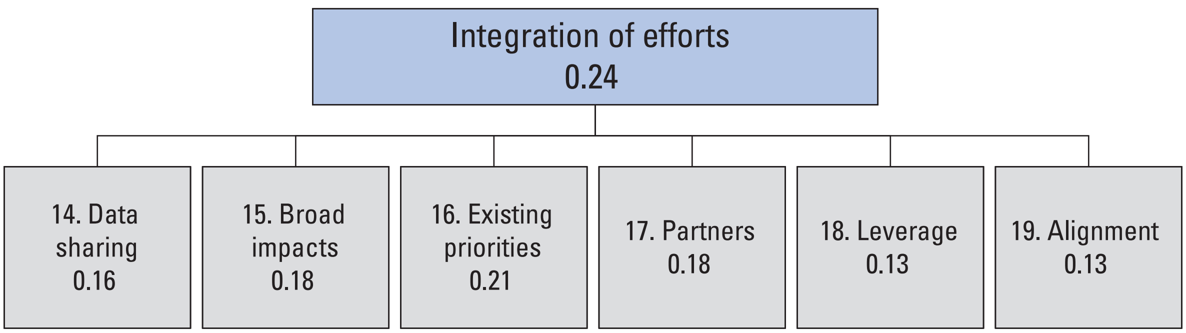


Figure 8. Objectives hierarchy for integration of monitoring efforts. Numbers indicate the relative weight assigned to each performance metric (absolute weights are shown in table 1).

Fundamental Objective 3: Maximize Scientific Rigor

This section describes how rigor is valued within a monitoring proposal, starting with an objective(s) or hypothesis(es) with appropriate variables, taxa, survey design and analyses, and data management plan, in addition to a project timeline and budget (Pavlacky and others, 2017). Without these components and processes in place, a project or proposal will likely not provide actionable results that can be used to inform conservation needs or be used to leverage results from other similar projects/proposals for different parts of the Gulf of Mexico. Performance metrics 20—27 quantify the values associated with scientific rigor (fig. 9).

Alternatives and Consequences

The essence of a decision is the choice of one option or course of action from a set of available options or alternative courses of action. To maximize the chance of a good outcome, decision makers predict the consequences of each option that is available to them (Goodwin and Wright, 2004; Gregory and others, 2012). Decision makers that will fund and implement monitoring activities in the Gulf of Mexico must decide on the appropriate allocation of resources to achieve the objectives described above, and maximize the usefulness of monitoring data for conservation. Such funding decisions are difficult given the rich diversity of living marine resources (including birds) in the region, the growing list of conservation challenges and restoration actions, and the highly competitive nature of securing funding for monitoring proposals – it's simply not possible to monitor everything (see Caughlan and Oakley, 2001; Field and others 2005, 2007). Any combination of different monitoring proposals may be considered a "monitoring portfolio." Therefore, the alternatives that are available to decision makers in the Gulf of Mexico include all the possible monitoring portfolios that could be implemented.

A challenge for decision makers in all decision contexts is to predict the consequences of the alternative actions – in this case, the consequences of choosing to invest in different monitoring portfolios.

Scoring Monitoring Proposals

The decision support tool for portfolio selection aids decision makers by comparing all possible monitoring portfolios (alternatives in the decision analysis; Kirkwood, 1997). The tool for this analysis is currently built as part of a Microsoft Excel macro-enabled workbook, with detailed instructions showing how to (1) enter the proposal scores and any constraints of interest to the decision maker, and (2) use the Solver add-in and constrained optimization to select the best portfolio of proposals given the scores and constraints (Supplemental Material 2).

To test the prototype decision support tool for portfolio selection, a set of proposals for which benefits and cost could be evaluated was necessary. Six proposals provided by the NFWF were used with permission from the proposal authors. To maintain the anonymity of the proposals, each was given a new title and the proposal budget was slightly modified. These proposals were only used as examples, and the results of this analysis did not affect any actual funding decisions. Each proposal was scored using the 27 performance metrics described above (Performance Metrics to Evaluate Monitoring Benefits).

To supplement the proposals from the NFWF, 29 additional hypothetical monitoring proposals representing bird monitoring activities that could reasonably be expected as future proposals in the Gulf region were simulated as part of this analysis. For each hypothetical proposal, scores were simulated for the 27 performance metrics using random sampling techniques implemented in R (see Supplemental Material 3 for commented R code; R Core Team, 2018, Version 3.4.4). For each performance metric, samples were collected (with replacement) from the range defined by the minimum and maximum possible scores for the metric (sample function in R); sampling probabilities were defined by a uniform probability distribution for each metric. The randomly generated proposal scores were reviewed to check for logical inconsistencies and a cost was assigned to each proposal based on the nature of monitoring activities included. Proposals were categorized by taxonomic group based on the species studied (randomly generated in this simulation) and categorized by spatial scale based on habitats involved (also randomly selected from available habitats). Each proposal was also assigned an ad hoc title to help better identify it as a status and trends, management action, ecological process, or combination proposal. Scores and other information for all proposals are presented in the Supplemental Material 4.

The proposal scores on the performance metrics were converted to utilities (see Performance Metrics to Evaluate Monitoring Benefits), and utilities were multiplied by their respective weights. Total utility (total benefit) for each monitoring proposal was the sum of weighted utilities across all performance metrics. Proposal costs and total benefits (sum of weighted utility) are provided in Appendix 4.

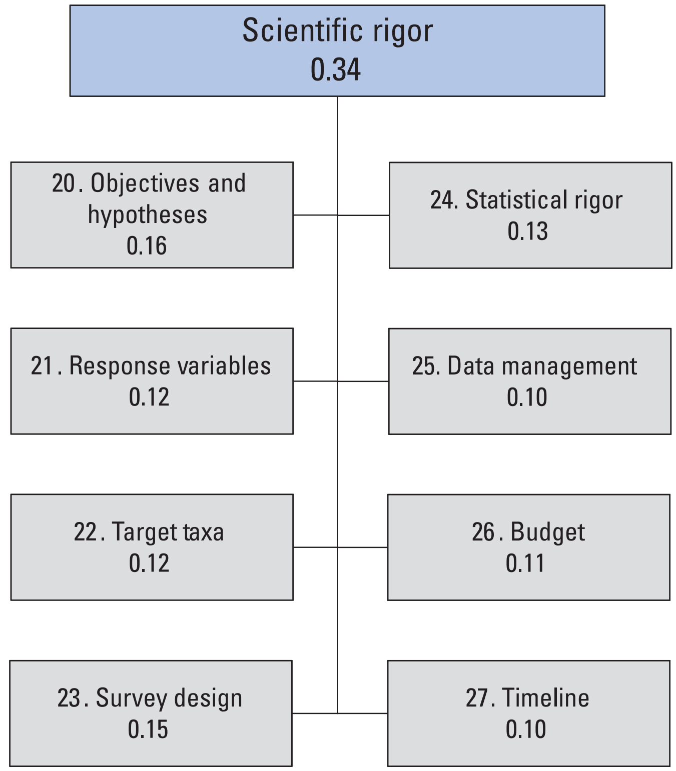


Figure 9. Objectives hierarchy for scientific rigor. Numbers indicate the relative weight assigned to each performance metric (absolute weights are shown in table 1).

Optimal Monitoring Portfolios and Trade-Offs Among Objectives

Pareto Efficiency: A Graphical Solution

A Pareto efficiency analysis (Jollands, 2006; Neckles and others, 2015) begins with a plot of monitoring portfolio costs (x-axis) compared to benefits (y-axis; fig. 10). In order to maximize portfolio benefit while minimizing costs, those in the upper left part of the plot are the most effective and efficient portfolios; the portfolios in the lower right part of the plot are of low benefit and expensive. A Pareto efficiency curve identifies the subset of portfolios for which improvement in one objective cannot occur without a loss to another, thus ensuring maximum benefit (optimality) for one objective at a given value of another. Portfolios lying below the efficiency curve are sub-optimal because improvement in one

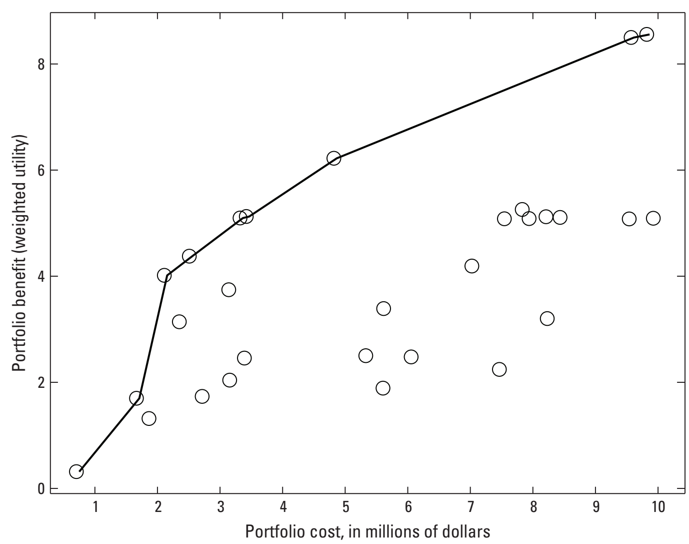


Figure 10. Pareto efficiency curve showing the curve of optimal portfolios as cost of portfolio increases. Each symbol represents a portfolio with multiple proposals. Portfolio benefit is the sum of weighted utility for all proposals in the monitoring portfolio.

objective comes at the expense of the second objective (for example, a more beneficial portfolio can be found for the same cost). As might be expected, for portfolios located on this efficiency curve, benefits initially increase as costs increase. The Pareto efficiency curve is helpful as a graphical solution that accomplishes trade-offs between costs and benefits, especially when cost constraints are unknown. If the budget for monitoring is not known, the decision maker can explore the efficiency curve and examine a variety of portfolios and budget scenarios to identify a preferred alternative. The shoulder of the Pareto efficiency curve, where benefits begin to level off with increasing investment, is a particularly interesting point on the curve and helps decision makers identify the point of diminishing returns. The Pareto efficiency curve is shown with portfolios built by the authors from combinations of actual and hypothetical proposals described above (details in R script, Supplemental Material 3).

Constrained Optimization

The total utility for each proposal, V_i, is the sum of weighted utility from all performance measures:

$$V_i = \sum_{j=1}^{J} w_j v_{ij} \tag{2}$$

where

w_j is the weight associated with performance measure j, and

v_{ij} is the utility provided by proposal i toward performance measure j.

The utility provided by each proposal was determined by the proposal's level of achievement (scores) on the performance metrics and utility functions described in Appendix 2.

To use constrained optimization to find the optimal monitoring portfolio (Kirkwood, 1997), it was assumed that there are P monitoring proposals available and that the cost of each is known. It was also assumed that it would not be possible to fund all monitoring proposals given the available budget B. A vector of binary decision variables was defined, one decision variable for each monitoring proposal; the binary decision variable d_i is equal to 1 if the monitoring proposal is included in the portfolio and 0 otherwise. The objective function is

$$max \sum_{i=1}^{P} d_i V_i \tag{3}$$

subject to the constraint

$$\sum_{i=1}^{P} d_i c_i \leq B \tag{4}$$

where

d_i is the binary decision variable for proposal i,

P is the number of monitoring proposals being considered,

V_i is utility for monitoring proposal i (sum of weighted utilities derived from all $J = 27$ performance measures),

c_i is the cost of monitoring proposal i, and

B is the total available budget.

In addition to the cost constraint, it is possible to add other types of constraints to achieve additional objectives (Kirkwood, 1997). Decision makers may be interested in additional constraints such as funding at least one proposal for each taxonomic group, one proposal in each state or region, etc. For example, a decision maker may be interested in selecting at least 2 seabird proposals and at least 11 proposals from Florida. To implement the seabird constraint, a binary indicator variable I for each proposal would be defined; the indicator variable would be equal to 1 if the proposal is a seabird proposal and 0 otherwise. The constraint is formulated as

$$\sum_{i=1}^{P} d_i I_i \geq S \tag{5}$$

where

d_i is the decision variable defined above, and

S is the desired minimum number of seabird proposals.

The constraint could also be specified as a strict equality, $\sum_{i=1}^{P} d_i I_i = S$, which would result in exactly S seabird proposals in the portfolio (or as an inequality to select no more than S seabird proposals). The constraint for a minimum number of proposals in Florida would be implemented in a similar way, with an indicator variable that was equal to 1 if the proposed monitoring occurs in Florida and 0 otherwise. In addition to the indicator variable approach demonstrated here, there are myriad ways to formulate constraints: any goal that can be written as a linear combination similar to equation 5 can be added to the analysis as a constraint. Additional constraints such as these are powerful tools to customize the portfolio to the full range of interests and concerns of the decision maker and conservation community.

For demonstration purposes, three different constraints were considered in an example analysis: maximum budget (US $4 million), minimum number of proposals from the State of Florida (11), and minimum number of seabird proposals (2). These constraints were combined in different ways and four constraint scenarios were compared:

1. Cost only (≤ US $4 million)
2. Cost (≤ US $4 million) + ≥ 11 proposals in Florida
3. Cost (≤ US $4 million) + ≥ 2 seabird proposals
4. Cost (≤ US $4 million), + ≥ 2 seabird proposals + ≥ 11 proposals in Florida.

To examine these scenarios, the raw scores (see Scoring Monitoring Proposals) and the costs for the set of proposals were entered into the Microsoft Excel-based decision support tool (Supplemental Material 2). The four scenarios above were coded and the Solver add-in was used to determine the optimal portfolio given the constraints of each scenario. The optimal portfolio had the greatest sum of weighted utility while meeting all the constraints of the scenario.

The constrained optimization resulted in a range of benefits under the four constraint scenarios (fig. 11). With only a cost constraint of US $4 million, the optimal portfolio included 15 of the 35 candidate proposals and resulted in a portfolio benefit of 6.25; the cost of these 15 proposals was US $3.955 million. When the constraint of 11 projects in Florida was added to the cost constraint, the total portfolio benefit decreased to 5.10 and the number of projects decreased to 12; the cost of these 12 projects, US $3.985 million, was again close to the budget constraint. The decrease in portfolio benefit was largely the result of decreases in two aspects of the value model: monitoring management effectiveness and scientific rigor of the projects included (fig. 11). In constraint scenario 3, the total portfolio benefit (6.23) was similar to constraint scenario 1 and included 15 proposals with a total cost of US $3.855 million. The 15 proposals in scenarios 1 and 3 were the same except for one seabird proposal selected for scenario 3 that was not included in scenario 1 because it had a slightly lower benefit to cost ratio and thus would not be included without the additional seabird constraint. This result indicated that, in this hypothetical example, the seabird constraint was easier to implement without a loss of benefit than the state-based constraint because scenario 3 is closest to scenario 1. Finally, constraint scenario 4 resulted in the smallest portfolio benefit (4.40), with 11 proposals and a cost of US $3.985; in this scenario, benefits related to monitoring management effectiveness, status and trends, and scientific rigor were sacrificed to meet the additional constraints (fig. 11).

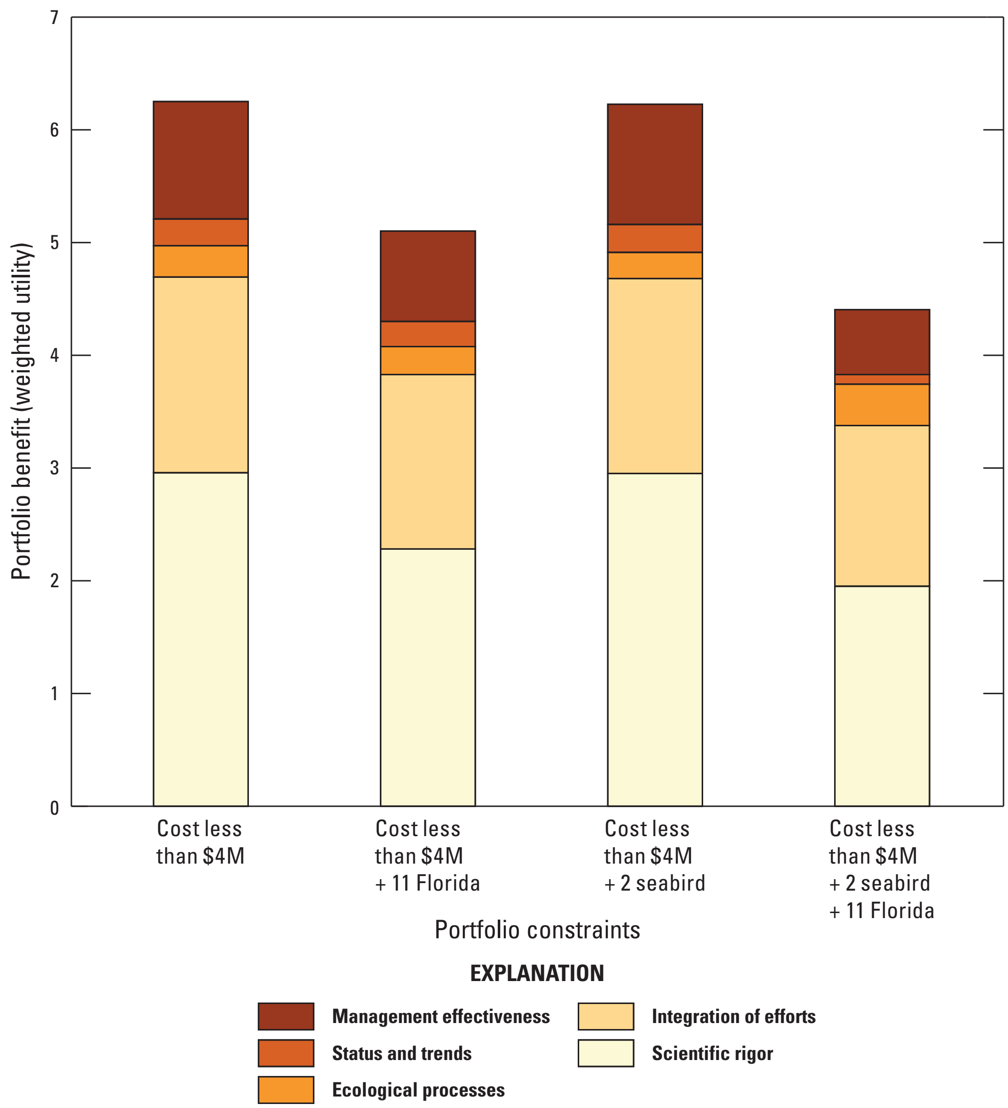


Figure 11. Portfolio benefits (multi-attribute utility; equation 2) for monitoring portfolios selected using four different sets of constraints. The height of each bar is the sum of weighted utility across all 27 performance metrics (table 1); colors within each bar show the benefits provided by five different high-level objectives (management effectiveness, status and trends, ecological processes, integration of efforts, and scientific rigor).

Interestingly, cost was similar for all four scenarios. With a large number of candidate proposals and a variety of costs and benefits, the constrained optimization successfully identifies the greatest benefit possible while meeting the cost and other constraints. As more constraints are added, the portfolio utility is expected to either decrease or remain the same; the latter if the original set of constraints also satisfied any new constraints. It is not possible for the portfolio utility to increase as additional constraints are added. Over-constraining, or having too many constraints, can preclude a solution, especially in scenarios with very few options to choose from when building a portfolio.

Sensitivity to Objective Weights

In any multi-objective decision problem, weights selected for the objectives have a strong influence on the solution. The weights assigned to the objectives and performance metrics in our decision problem (table 1, fig. 3) were determined through expert elicitation with a panel of scientists and managers from across the Gulf region (see Relative Weights for Monitoring Objectives). The panel represented a wide variety of stakeholders and perspectives. Nevertheless, given the importance of weights in multi-objective decision analysis, a sensitivity analysis was performed to better understand the implications of the weights assigned in the elicitation. A sensitivity analysis, which is typically conducted after a preferred alternative is selected but before implementation, allows the decision maker to ask, “How much would the weights assigned to the objectives have to change before the current preferred alternative is no longer the best option?” (Kirkwood, 1997; Goodwin and Wright, 2004). If the preferred alternative changes with only small changes to the weights, the solution is not robust to changes in the weights. On the other hand, if the preferred alternative remains the same, even with large changes in the weights assigned to objectives, the solution is considered robust to changes in the weights. A sensitivity analysis also provides (1) insight for the decision maker about the relative benefits within each portfolio toward specific objectives, and (2) a better understanding of overall portfolio performance.

Five monitoring portfolios, with five proposals each which were manually selected from the candidate proposals used in the constrained optimization (Appendix 5), were created. These hypothetical portfolios were created for the sensitivity analysis for demonstration purposes only; the portfolios were chosen to demonstrate how a sensitivity analysis can be used in conjunction with actual decision-making and portfolio analysis. Each of the five portfolios had a different “theme” representing potential interests of decision makers. The first two themes focused on certain taxonomic groups of birds: portfolio A contained five marsh bird monitoring proposals, whereas portfolio B contained five shorebird monitoring proposals. Portfolio C used a theme of “spatial balance across the Gulf region,” a scenario in which, for example only, a decision maker wished to identify and fund a portfolio of monitoring projects that would take place in all five U.S. Gulf states. Portfolio D contained five projects, each with a cost of less than 0.5 million USD. Portfolio E contained only projects from Texas, representing a scenario in which perhaps the focus of investment was concentrated in a particular state and moved among the Gulf states each funding cycle. These portfolios were only created to demonstrate the sensitivity analysis and were not used to make real-world inference about the subject matter they contain. As with the results of the constrained optimization, no attempt was made to infer or guide decision-making based on this analysis. Other portfolios with the same theme that contained different proposals from the list of candidate proposals are possible; the total benefits and sensitivity to weights would be different with different portfolios.

Portfolio C (“all U.S. Gulf states”) had the greatest portfolio benefit (sum of weighted utility equal to 2.38; fig. 12). Four of the five portfolios used in the sensitivity analysis had similar relative benefits for the five objectives (shaded bars in fig. 12); however, portfolio C included more monitoring benefits for understanding status and trends than the other portfolios. Since the theme for portfolio C is “all U.S. Gulf states,” this portfolio is by definition a set of proposals with a large spatial scale – a quality that is important in the status and trend monitoring values. Portfolio benefits for all five portfolios were dominated by value from integration of efforts and scientific rigor, which is not surprising given the substantial weights assigned to these two objectives by the stakeholder group. At this point, a decision maker might be ready to select portfolio C, but may want to know if this preferred alternative is robust to changes in the weights.

A sensitivity analysis could be conducted for any objective or performance metric in the decision-making framework. Rather than investigate the sensitivity to all 27 performance metrics in the objectives hierarchy individually, the analysis was restricted to five objectives in the upper levels of the hierarchy (fig. 3): management effectiveness, status and trends, ecological processes, integration of efforts, and scientific rigor. For these five objectives, the weight assigned to sub-objectives and performance measures was summed (table 1) and the sensitivity to the summed weight was evaluated by varying the summed weight from 0 to 1 in increments of 0.2. When varying the weight assigned to a particular objective, the weights for the other objectives were adjusted so that (1) the sum of all weights was equal to one, and (2) the original proportions assigned by stakeholders remained unchanged. Specifically, as the weight for each of the five objectives was varied, the weights for the four other objectives were adjusted first, and then weights were adjusted for the sub-objectives and performance measures under each of the other four. Finally, the total utility of each portfolio (equation 2) with the adjusted weights was calculated (fig. 13).

The sensitivity analysis indicated that portfolio C (all U.S. Gulf states) was the preferred option under most weight scenarios; this selection was robust to changes in the weights (fig. 13). Among the five objectives evaluated, the choice of

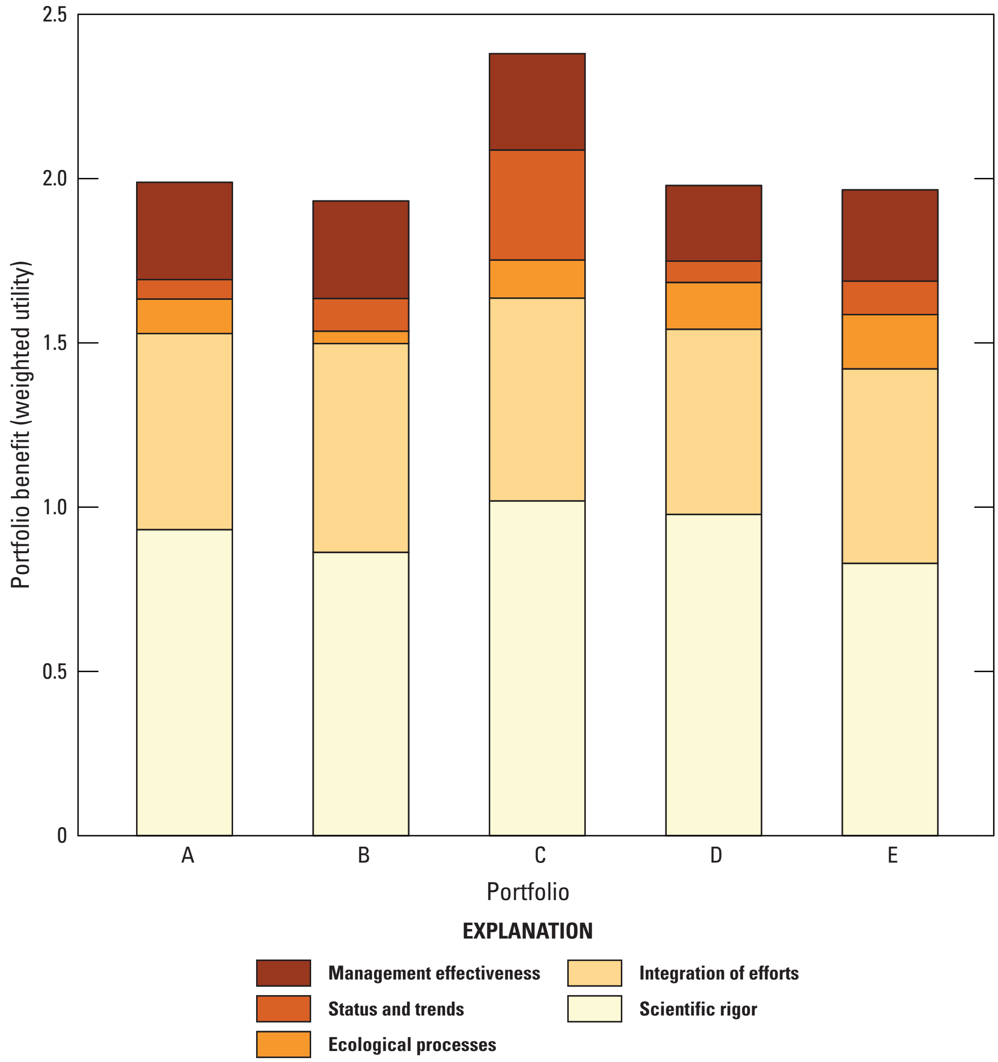


Figure 12. Summary of benefits provided by five monitoring portfolios used in the sensitivity analysis. The height of each bar is the sum of weighted utility across all 27 performance metrics (table 1); colors within each bar show the benefits provided by five different high-level objectives (management effectiveness, status and trends, ecological processes, integration of efforts, and scientific rigor). Portfolio A contains five marsh bird proposals; portfolio B, five shorebird proposals; portfolio C, five proposals that would be conducted in all five Gulf states; portfolio D, five proposals that cost less than 0.5 million USD; and portfolio E, five proposals that would occur in Texas.

portfolio C may be most sensitive to the weight assigned to monitoring ecological processes. The weight for ecological processes was set at 0.12 by the stakeholder group; if this was increased to about 0.6, portfolio E (Texas only) becomes the preferred alternative (fig. 13). Portfolio E would be the preferred alternative if the weight for ecological processes was increased to about 0.6 because this portfolio includes proposals with more monitoring of ecological processes than the other portfolios (fig. 14). Portfolio E included a proposal to monitor the effect of hurricanes on the annual survival of wintering and migrating waterfowl in the Gulf; this proposal received the highest score for reducing uncertainty about ecological processes. There are two additional reasons why portfolio E is preferred when the weight assigned to ecological processes is high. First, stakeholders valued reducing uncertainty in general (75 percent of ecological processes weight) more than a particular focus on ecological processes affecting Birds of Conservation Concern (25 percent of ecological processes weight; table 1). Therefore, any proposal that reduced uncertainty provides great benefits, and as previously noted, portfolio E is expected to reduce uncertainty about the effects of hurricanes. Second, stakeholders also chose a (piecewise linear) convex utility function for reducing uncertainty, with a large increase in utility at the upper range of this performance measure (Appendix 2, fig. 2.14). For these reasons, portfolio E was recommended if the weight for monitoring ecological

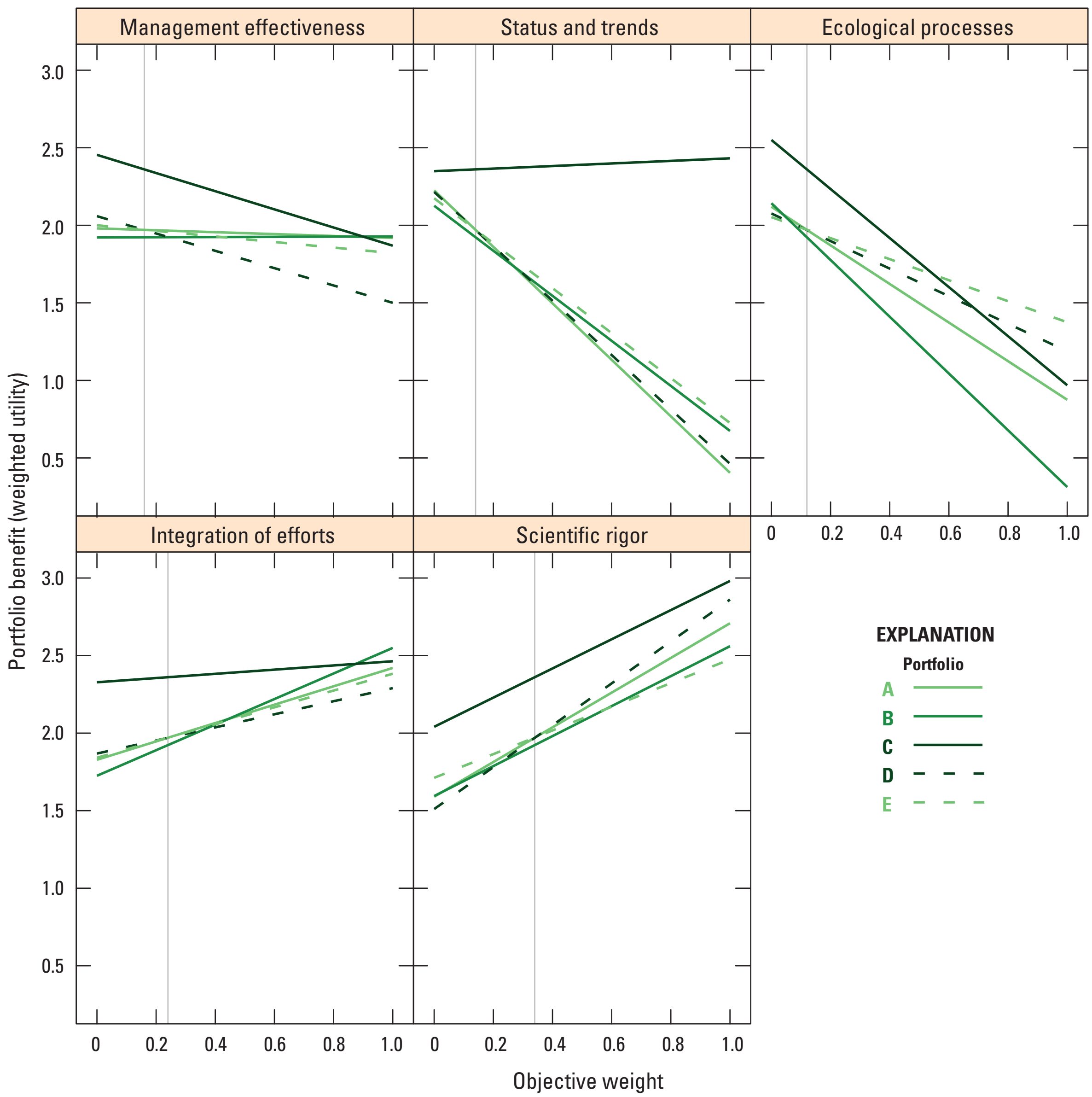


Figure 13. Results of sensitivity analysis with five different monitoring portfolios to determine the impact of weights assigned to objectives. Each line represents the total benefit for a different portfolio; the slope of the line shows how the portfolio benefit changes as the weight assigned to the objective increases from zero to one (on the x-axis). The vertical gray line represents the weight assigned to each objective by a formal elicitation process with an expert panel representing a wide variety of stakeholders in the Gulf region: 0.16, management effectiveness; 0.14, status and trends; 0.12, ecological processes; 0.24, integration of efforts; and 0.34, scientific rigor. Portfolio C is the preferred alternative in most cases, even with large changes in the weights assigned to the objectives.

processes was high. Nevertheless, it is important to note that it would require a substantial increase in the weight assigned to ecological processes (from 0.12 chosen by stakeholders to about 0.6; fig. 13) before portfolio E is preferential to portfolio C, and therefore, portfolio C was considered robust to all but large changes in the weights.

Portfolio C was especially robust to changes in the weight assigned to status and trends monitoring, and was a better option than the other portfolios whether the weight assigned to status and trends was 0 or 1, which represented the extremes (fig. 13). As noted above, portfolio C provided more benefit from status and trend monitoring than the other portfolios. The sensitivity analysis indicated that as weight assigned to status and trends monitoring increases, portfolio C maintains its benefits because it includes proposals with (1) population monitoring at large spatial scales, and (2) habitat quality monitoring, two important components of status and trends monitoring. Portfolios A, B, D, and E only include population

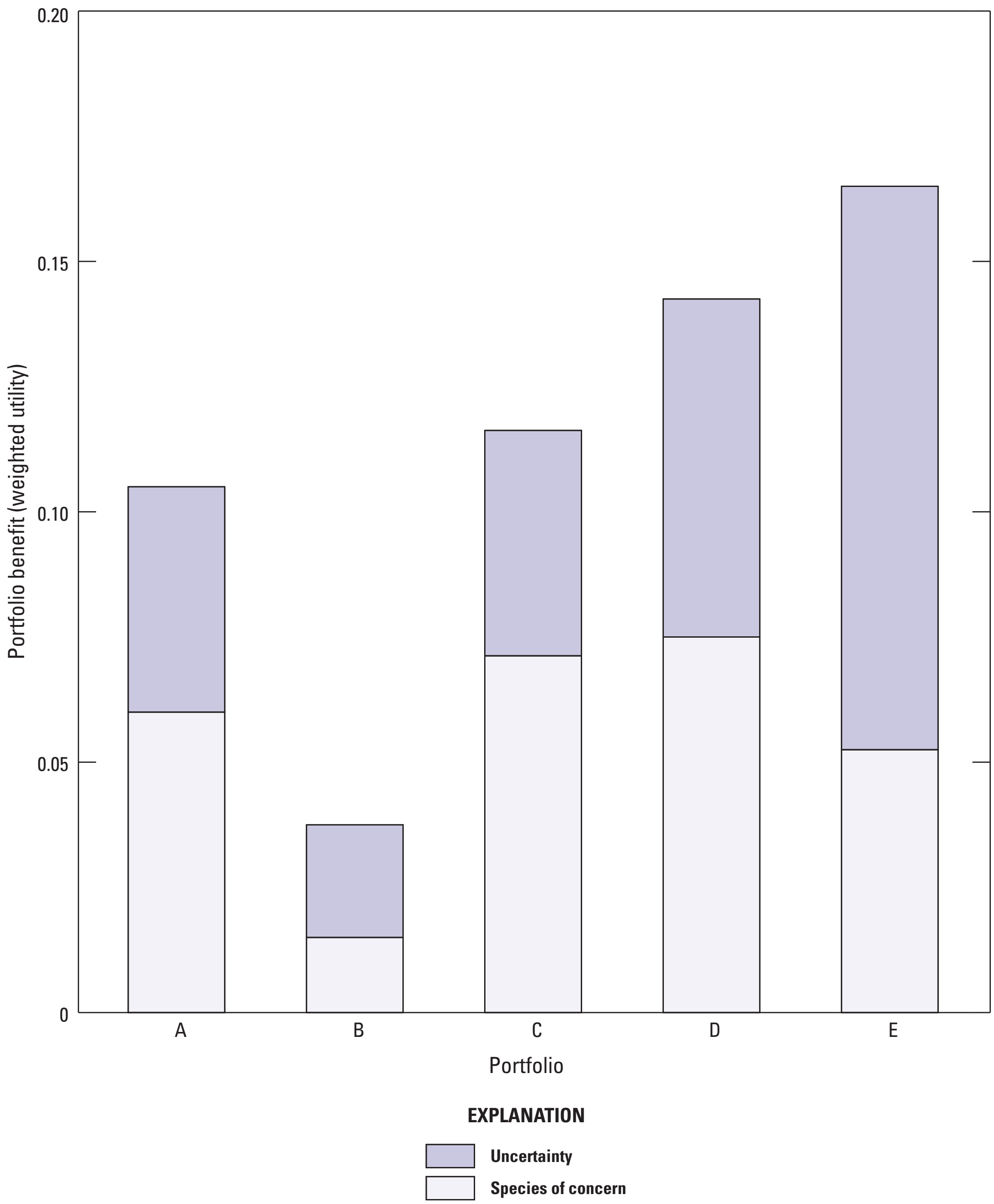


Figure 14. Relative benefits for monitoring ecological processes in five portfolios used in the sensitivity analysis. Monitoring of ecological processes includes two components, monitoring Birds of Conservation Concern (lighter shade) and monitoring to reduce uncertainty about ecological processes (darker shade). The height of the bar indicates total Portfolio benefit from monitoring ecological processes. Portfolio E provides the greatest benefits because it includes proposals that scored high for reducing uncertainty.

monitoring on smaller spatial scales or do not include as much monitoring of habitat quality; as weight assigned to status and trend monitoring increased, the benefits from these portfolios decreased (fig. 13). Conversely, as the weight assigned to scientific rigor increased, the benefits of all portfolios increased, indicating that all portfolios provided benefits related to rigor, with portfolio C maintaining its advantage (fig. 13).

Discussion

As the conservation community in the northern Gulf of Mexico delivers holistic ecosystem restoration after the Deepwater Horizon Oil Spill, they could collectively implement monitoring programs to effectively and efficiently evaluate restoration efforts in a manner that facilitates learning in an adaptive management framework. To that end, monitoring could play these distinct roles within a decision context: (1) provide information related to state variables (such as population size, occupancy, etc.); (2) evaluate management performance; and (3) facilitate improved management through learning (Nichols and Williams, 2006; Lyons and others, 2008). On the basis of these monitoring roles, the principles of structured decision making were used to identify core values underpinning bird conservation and monitoring in the northern Gulf of Mexico. More specifically, input from stakeholders representing on-the-ground practitioners, program managers, funding entities, and academia was used to identify and agree upon a suite of fundamental objectives and associated performance metrics; these objectives and metrics provide a transparent multi-criteria framework to guide decisions related to bird monitoring.

In facilitated structured decision-making workshops, the avian conservation community was able to identify and agree on three fundamental objectives to frame monitoring efforts: (1) maximize the relevance of monitoring projects; (2) maximize the integration of monitoring projects; and (3) maximize the scientific rigor of monitoring projects. The relevance of monitoring projects is determined by consistency with the three roles of monitoring within a decision context (Lyons and others, 2008). That is, stakeholders value monitoring projects that evaluate management and restoration activities, establish baselines (for example, state-dependent variables), and reduce uncertainty related to the impacts of ecological processes on avian populations and their habitat.

Whereas the identification of fundamental objectives is a good first step towards increased coordination and collaboration among stakeholders, the fundamental objectives individually and collectively lack the specificity necessary to quantify stakeholder values and evaluate trade-offs as part of a formal decision analysis. For example, what do stakeholders value about understanding management actions? To address this question, input was solicited from a wide variety of stakeholders and a suite of performance metrics was identified. These performance metrics were used in a multi-criteria decision support tool to facilitate the selection of proposals (a portfolio of monitoring projects) that maximizes stakeholder values while controlling for user-defined constraints (such as costs, geography, taxa) with a constrained optimization routine. For example, entity “x” desires to allocate “y” dollars to advance shorebird monitoring in states A, B, and C; which portfolio of projects yields the greatest return on the dollar when compared with stakeholder values? The portfolio decision tool presented here provides funding entities with a transparent means to select the combination of projects that maximizes conservation benefit in an efficient manner. Sensitivity analysis of objective weights demonstrates how to determine if recommended portfolios are robust to changes in weights.

Given the complex nature of funding decisions across and within injured resources and geographies, funding entities (such as the RESTORE Council, NRDA Trustees, NFWF) operating in the northern Gulf of Mexico are continuously searching for information and tools to facilitate their decision-making process. The multi-criteria decision support tool presented in this report provides a quantifiable means of evaluating monitoring projects against stakeholder values while allowing user-defined constraints to yield an optimal financial solution. Use of this decision support tool could increase the effectiveness of monitoring projects (selecting projects that address stakeholder values) while controlling for cost (increasing financial efficiency), thereby providing decision makers with a transparent means to inform decision-making (such as, where to invest for the greatest return on the dollar).

Bird monitoring efforts have struggled to address large-scale questions due to myriad factors (lack of agreed upon goals and objectives, different agency and organizational needs) as outlined by the U.S. North American Bird Conservation Initiative (U.S. North American Bird Conservation Initiative Monitoring Subcommittee, 2007). The performance metrics discussed in this report provide additional insight on how to establish priorities (identify core values) across political and organizational boundaries, thereby providing a means to design new monitoring programs that address key data gaps and uncertainties (Nichols and Williams, 2006) at large spatial scales (for example, across political boundaries). Due to the vast interactions and inter-relations of ecological and climatic events presumed to drive bird populations in the northern Gulf of Mexico, this agreement on large-scale data needs and *a priori* hypotheses will be imperative if the conservation community is to assess holistic Gulf restoration.

Historically, monitoring programs have not been well coordinated across large spatial scales, nor among agencies and organizations, resulting in redundancies and inefficient use of resources (U.S. North American Bird Conservation Initiative Monitoring Subcommittee, 2007). Recognition and acceptance of the fundamental objectives and performance metrics described in this report provide a firm foundation for further collaboration and integration of monitoring efforts across agencies and organizations implementing avian monitoring projects, and also provide a foundation to enable collaboration and integration among resources groups (fisheries, water quality, etc.). For example, it is beyond the scope of the GoMAMN community of practice to compile information related to the change in non-avian metrics (such as land cover and salinity) across the northern Gulf of Mexico. However, by explicitly stating the need to track changes in land-cover or ecological processes as a performance metric, GoMAMN facilitates better collaboration and integration of efforts among partners, such as the USGS, NOAA, and academia.

Summary

Monitoring data are most valuable when collected in a cost-effective and scientifically robust fashion that is relevant to stakeholder needs and values. In this report, the fundamental objectives and associated performance metrics that reflect stakeholder values of an avian monitoring program are described. Using these performance metrics, the authors developed a decision support tool for achieving optimal monitoring and cost efficiency. In addition to optimal solutions, the value model used in this report provides a means of establishing monitoring priorities using the preference weights and performance metrics. Furthermore, the value model provides a basis to evaluate historical monitoring activities (such as an information gap analysis) or to design new monitoring projects to reduce uncertainty and advance the principles of adaptive management while advocating for increased collaboration and integration of monitoring efforts. Although the application of structured decision making and the principles of decision theory were focused on birds and the northern Gulf of Mexico, a similar process could be applied to other decisions related to monitoring other living marine resources, regardless of the taxa or geography.

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Appendix 1. Elicitation of Objective Weights

Table 1.1. Results of elicitation of weights for objectives and performance measures.

[Average (Ave.) weight is the mean preference among experts participating in the elicitation exercise (n = 13 experts). Min., median, and max are the minimum, median, and maximum values among all experts. The fundamental objectives are shown at the top, with multiple levels of sub-objectives shown below each. The bars on the right show the relative magnitude of the mean weight (first column). Dash indicates no data.]

	Ave. weight	Min.	Median	Max
Fundamental objectives				
Relevance of data	0.42	0.35	0.42	0.59
Integration of efforts	0.24	0.10	0.22	0.38
Scientific rigor	0.34	0.27	0.33	0.47
Sub-objective: relevance of data				
Management effectiveness	0.37	0.12	0.36	0.58
Status and trends	0.34	0.09	0.38	0.56
Ecological processes	0.29	0.00	0.30	0.45
Sub-objective: integration of efforts				
Data sharing	0.16	0.04	0.17	0.21
Broad impacts	0.18	0.09	0.18	0.35
Existing priorities	0.21	0.17	0.20	0.36
Partners	0.18	0.15	0.19	0.22
Leverage	0.13	0.02	0.15	0.19
Alignment	0.13	0.02	0.13	0.23
Sub-objective: scientific rigor				
Objectives/hypotheses	0.16	0.13	0.15	0.25
Response variable	0.12	0.02	0.12	0.14
Target taxa	0.12	0.02	0.13	0.17
Survey design	0.15	0.13	0.14	0.22
Statistical rigor	0.13	0.10	0.13	0.21
Data management	0.10	0.05	0.11	0.14
Budget	0.11	0.09	0.11	0.14
Timeline	0.10	0.08	0.10	0.13
Sub-objective: relevance–management effectiveness				
Birds of conservation concern	0.20	0.13	0.20	0.28
Spatial scope	0.19	0.08	0.20	0.25
Uncertainty reduction	0.19	0.08	0.20	0.25
Current practices	0.18	0.12	0.18	0.31
Adaptive management	0.24	0.15	0.22	0.50
Sub-objective: relevance–status and trends				
Populations	0.57	0.50	0.53	0.80
Habitats	0.43	0.20	0.47	0.50
Sub-objective: relevance–ecological processes				
Birds of conservation concern	0.25	–	–	–
Uncertainty reduction	0.75	–	–	–

Table 1.1. Results of elicitation of weights for objectives and performance measures. —Continued

[Average (Ave.) weight is the mean preference among experts participating in the elicitation exercise (n = 13 experts). Min., median, and max are the minimum, median, and maximum values among all experts. The fundamental objectives are shown at the top, with multiple levels of sub-objectives shown below each. The bars on the right show the relative magnitude of the mean weight (first column). Dash indicates no data.]

	Ave. weight	Min.	Median	Max
Sub-objective: relevance–status and trends–populations				
Conservation needs	0.37	0.29	0.38	0.58
Population spatial scope	0.32	0.24	0.32	0.39
Population temporal scope	0.31	0.18	0.31	0.36
Sub-objective: relevance–status and trends–habitats				
Habitat spatial scope	0.36	0.31	0.34	0.44
Habitat quality	0.37	0.27	0.37	0.44
Habitat temporal scope	0.28	0.20	0.29	0.35

Appendix 2. Performance Metrics and Utility Functions

The performance metrics and utility functions were defined at an August 2014 workshop at Cedar Key, Florida by the GoMAMN community of practice (18 individuals representing stakeholders and decision makers from across the northern Gulf of Mexico). The performance metrics and utility functions were further refined and modified by additional stakeholders in subsequent meetings of the GoMAMN community of practice in 2015 and 2016.

Performance Metric 1: Birds of Conservation Concern

Because it is not possible to monitor the effects of management actions on all birds across the entire region, it is necessary to focus monitoring efforts on the Gulf of Mexico Avian Monitoring Network (GoMAMN) Birds of Conservation Concern. To understand the number of Birds of Conservation Concern affected by different management actions, every management action on the Gulf of Mexico Management Actions List (Appendix 3, table 3.1) was associated with a specific land-cover type, such as "Dredge spoil island creation--Beach/Dune". In other words, each management action is land cover-specific. Using knowledge of bird-habitat associations in the region, the potential for each management action to affect Birds of Conservation Concern was then determined based on the habitats these birds occupy (Supplemental Material 5). The score on performance metric 1 for any management action is the sum of the number of Birds of Conservation Concern that could benefit from the action. The lowest possible score on performance metric 1 is 0 species benefitting and the maximum possible score is 67 species benefitting (the total number of species on the Birds of Conservation Concern list; Supplemental Material 1). The utility function (fig. 2.1) is concave and reaches approximately 80 percent utility when 10 Birds of Conservation Concern are monitored.

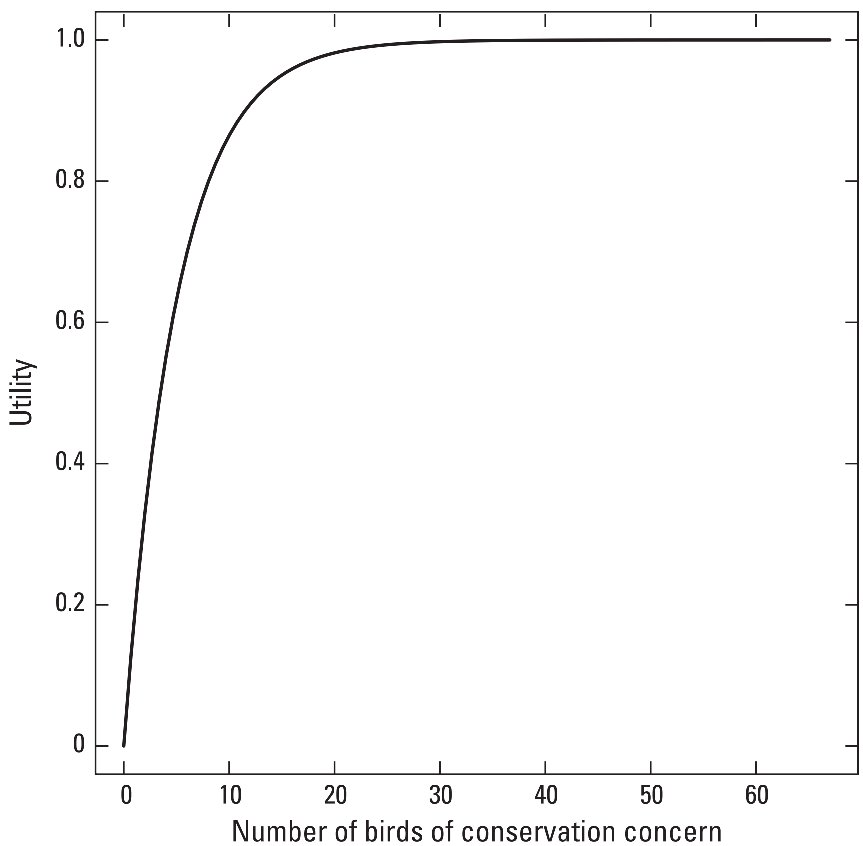

Figure 2.1. Utility function for number of Birds of Conservation Concern being monitored (performance metric 1).

Performance Metric 2: Spatial Scope (of Management Actions)

To maximize the ability to evaluate management effectiveness, one aspect of the approach that was used was monitoring management actions with a large spatial footprint. Based on the stakeholder value model, management actions that could be applied in a large proportion of the region are more beneficial to monitor because of their scope. Conversely, there may be little benefit in monitoring management actions that can only be applied in a very small part of the region. To estimate the area over which the management actions could be applied, each management action was associated with one or more land-cover classes (Appendix 3, table 3.1). Next, the geospatial extent of the associated land-cover class(es) as a proxy for the potential spatial footprint of the management actions was mapped. The land-cover nomenclature used by the National Oceanic and Atmospheric Administration's (NOAA's) Coastal Change Analysis Program (C-CAP) for land-cover mapping (Dobson and others 1995) was adopted and modified to add marine classifications using the Coastal and Marine Ecological Classification Standard (Federal Geographic Data Committee, Marine and Coastal Spatial Data Subcommittee, 2012). Monitoring proposals could be scored for "spatial scope" based on the land-cover mapping (see Appendix 2, table 2.1 to determine the extent of each C-CAP land-cover class and its associated utility). Because the marine types are so extensive, and would have dominated any area calculations, marine ecosystems were excluded first and the proportion of each non-marine land cover in the region was calculated. Of the non-marine land-cover types, Palustrine Forested Wetland was the most extensive land-cover type (16 percent of the non-marine area). The utility function is concave and reaches full utility at 16 percent of the region (fig. 2.2). By use of this method, marine ecosystems with the most extensive non-marine land-cover type (Palustrine Forested Wetland) were equated. If a proposal covered multiple land-cover classes, the utility for associated land-cover types was summed to determine the total utility for performance metric 2.

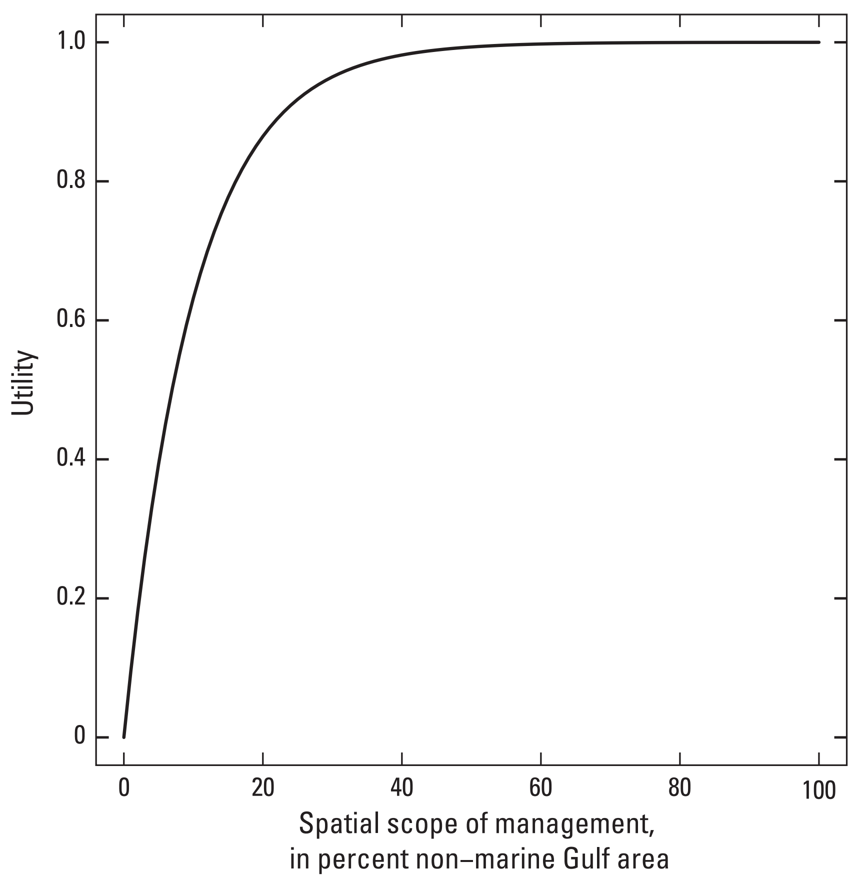

Figure 2.2. Utility function for spatial scope of management actions (performance metric 2).

Table 2.1. Acreage and percentage of the Gulf of Mexico for each National Oceanic and Atmospheric Administration Coastal Change Analysis Program (NOAA C-CAP) land-cover class.

[See description of performance metric 2 above for treatment of all marine classes. Utility is based on the utility function for performance Metric 2 (fig. 2.2).]

C-CAP class	Hectares	Percent non-marine area	Utility
Developed, high intensity	196,178	0.82	0.46
Developed, medium intensity	506,955	2.12	0.80
Developed, low intensity	1,036,203	4.34	0.96
Developed, open space	601,171	2.52	0.85
Cultivated crops	2,794,552	11.70	1.00
Pasture/hay	2,453,196	10.27	1.00
Grassland/herbaceous	1,153,401	4.83	0.98
Deciduous forest	251,758	1.05	0.57
Evergreen forest	2,624,152	10.98	1.00
Mixed forest	348,037	1.46	0.69
Scrub/shrub	2,428,713	10.16	1.00
Palustrine forested wetland	3,820,827	15.99	1.00
Palustrine scrub/shrub wetland	1,028,488	4.30	0.97
Palustrine emergent wetland	1,955,682	8.18	1.00
Estuarine forested wetland	181,450	0.76	0.46
Estuarine scrub/shrub wetland	79,373	0.33	0.21
Estuarine emergent wetland	1,050,293	4.40	0.97
Unconsolidated shore	129,479	0.54	0.32
Bare land	137,828	0.58	0.37
Open water	1,058,920	4.43	0.97
Palustrine aquatic bed	27,355	0.11	0.07
Estuarine aquatic bed	30,882	0.13	0.07
Marine nearshore	16,519,357	15.99	1.00
Marine offshore	17,418,487	15.99	1.00
Marine oceanic	36,804,070	15.99	1.00

Performance Metric 3: Uncertainty Reduction (from Monitoring Management Actions)

To maximize management efficiency and effectiveness, the goal was to reduce uncertainty about how bird populations respond to management actions. Monitoring management actions with uncertain outcomes was valued (for example, management actions for which resulting changes in vital rates [survival or productivity] are not well understood). The degree of uncertainty was measured using the Google Scholar search engine (as of June 2015) to determine the number of peer-reviewed and gray literature articles (Appendix 6) devoted to understanding each management action (Appendix 3, table 3.1). Uncertainty about management actions is characterized using a constructed scale (Low Uncertainty = >1,000 total hits and >200 relevant hits; Medium Uncertainty = 100–1,000 total hits, and 50–200 relevant hits; High Uncertainty = <100 total hits and <50 relevant hits), where relevant hits are defined as being specific to survival, productivity and (or) the Gulf of Mexico. The utility function is linear, reaching full value when a monitoring project addresses management action(s) with high uncertainty (fig. 2.3).

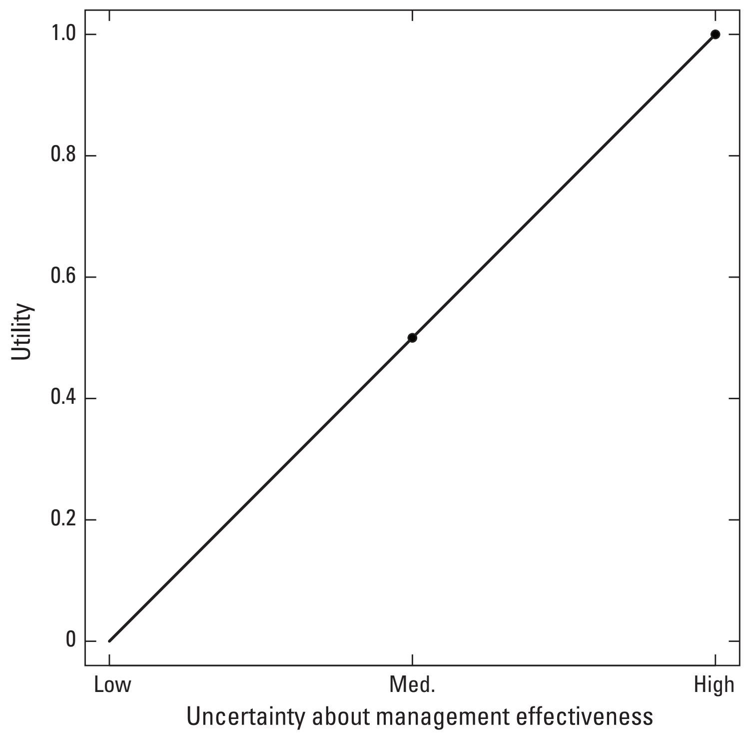

Figure 2.3. Utility function for uncertainty reduction from monitoring management actions (performance metric 3).

Table 2.2. Scoring criteria for uncertainty reduction from monitoring management actions (performance metric 3).

[>, greater than; <, less than]

Score	Description	Number of hits	Number of citations for top five relevant hits
Low	Many articles on this management action, with a large number of citations for the top five relevant hits; includes articles that evaluate impacts on reproduction and survival; one or more review papers; at least some articles are from the Gulf of Mexico region.	>1,000	>200
Medium	Moderate number of articles, but no review papers; some articles evaluate numerical response to management actions but few investigations of impacts on reproduction and survival; little information specific to Gulf of Mexico region.	100–1,000	50–200
High	Very few articles on this management action, or highly conflicting articles; articles do not evaluate impacts on reproduction and survival; no articles from Gulf of Mexico.	<100	<50

Performance Metric 4: Current Management Practices

There are myriad management practices being implemented across the northern Gulf of Mexico; the goal is to maximize the understanding of the management actions that are routinely applied (fig. 2.4). Emphasis is placed on monitoring bird response to the most frequently applied management actions. Whereas the exact number of management projects being implemented is unknown, the Deepwater Horizon Project Tracker (Ducks Unlimited and others, 2016) serves as a proxy. The score for this performance metric is determined by the number of times a management action occurs in the Deepwater Horizon Project Tracker database. The frequency of occurrence is characterized on a categorical scale (Low = <50 occurrences; Medium = 50–100 occurrences; and High = >100 occurrences) based on the number of times a management action occurs within the database. To determine a score for this performance metric, go to http://www.dwhprojecttracker.org/, and click on downloads, download the most recent “Excel Spreadsheet with Definitions” (assessed January 14, 2015) and use it as the input in the code provided as Supplemental Material 6. The code will summarize the management actions in the database at the time of the query, match them with the management actions used by the Gulf of Mexico Avian Monitoring Network (GoMAMN) (Appendix 3), and provide a count of the actions. Because the management actions in the Deepwater Horizon Project Tracker are characterized at a high level (erosion prevention and control, species restoration), each of the finer-resolution GoMAMN management actions was assigned the same count when deemed best characterized by a higher resolution management action identified within the Deepwater Horizon Project Tracker (table 2.3).

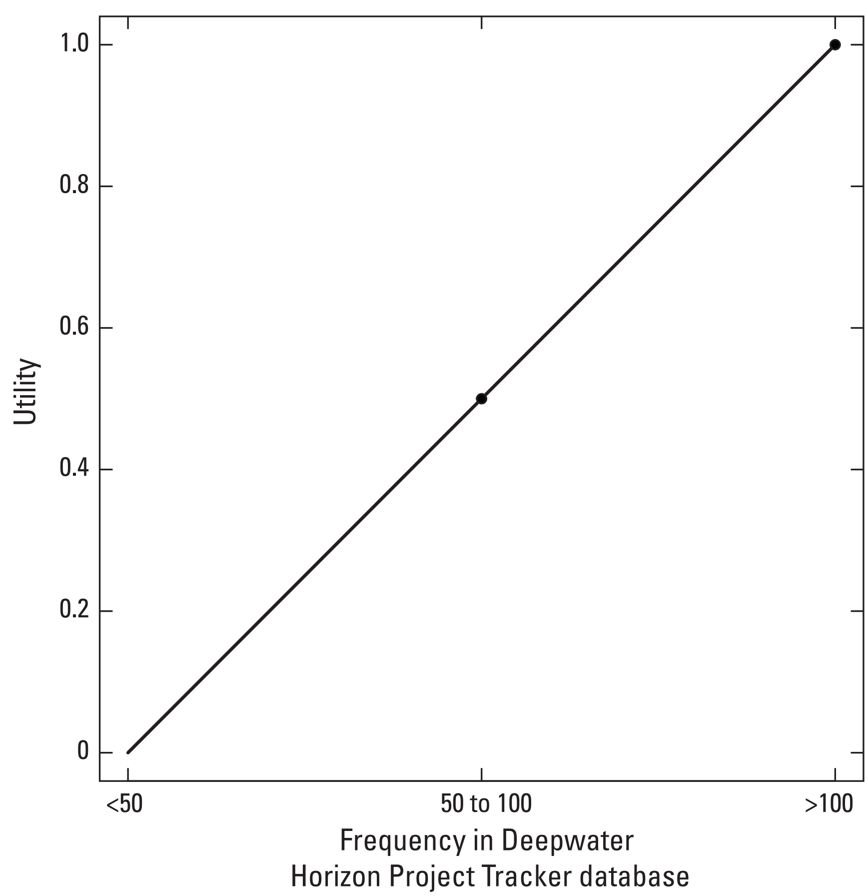

Figure 2.4. Utility function for current management practices (performance metric 4).

Table 2.3. Scoring criteria for current management practices (performance metric 4).

[DWH, Deepwater Horizon Project Tracker; GoMAMN, Gulf of Mexico Avian Monitoring Network; <, less than; >, greater than]

DWH project tracker action	Count of projects	GoMAMN management action	Category
Erosion prevention or control	20	Barrier island creation	<50 projects
Erosion prevention or control	20	Dredge spoil island creation	<50 projects
Water-quality restoration and maintenance	41	Wastewater management	<50 projects
Species restoration	67	Artificial nest construction	50–100 projects
Species restoration	67	Disease/pathogen/parasite management	50–100 projects
Species restoration	67	Fisheries management	50–100 projects
Species restoration	67	Harvest management for game species	50–100 projects
Species restoration	67	Reduce disturbance to beach-nesting birds	50–100 projects
Species restoration	67	Reduce disturbance to nesting raptors	50–100 projects
Species restoration	67	Reduce disturbance to waterbirds	50–100 projects
Habitat restoration and enhancement	171	Ecosystem restoration	>100 projects
Habitat restoration and enhancement	171	Prescribed fire	>100 projects
Habitat restoration and enhancement	171	Removal of invasive species	>100 projects
Habitat restoration and enhancement	171	Sustainable agriculture	>100 projects
Habitat restoration and enhancement	171	Sustainable aquaculture	>100 projects
Habitat restoration and enhancement	171	Sustainable forestry	>100 projects

Performance Metric 5: Adaptive Management

Monitoring management actions conducted in the context of adaptive management (Williams and others 2009; Williams and Brown 2012) facilitates learning about the bird response to management actions (fig. 2.5). For monitoring to be consistent with the principles of adaptive management, several conditions must be met (Williams and others 2009): (1) the management action is associated with an iterative decision, which provides an opportunity to apply what is learned to future decisions; (2) monitoring is linked to explicit management objective(s) and a set of potential management actions to achieve the stated management objective(s); (3) decision-makers and other stakeholders have identified a key uncertainty that impedes decision-making (if there is no uncertainty about management actions, there is no need for adaptive management); (4) monitoring is associated with a conceptual model or set of hypotheses of the system that can be used to predict consequences of the management actions; and (5) there is an explicit process for updating model (hypothesis) weights. The utility function is linear and reflects the binary classification (yes or no) for consistency with the U.S. Department of the Interior definition of adaptive management (Williams and others 2009).

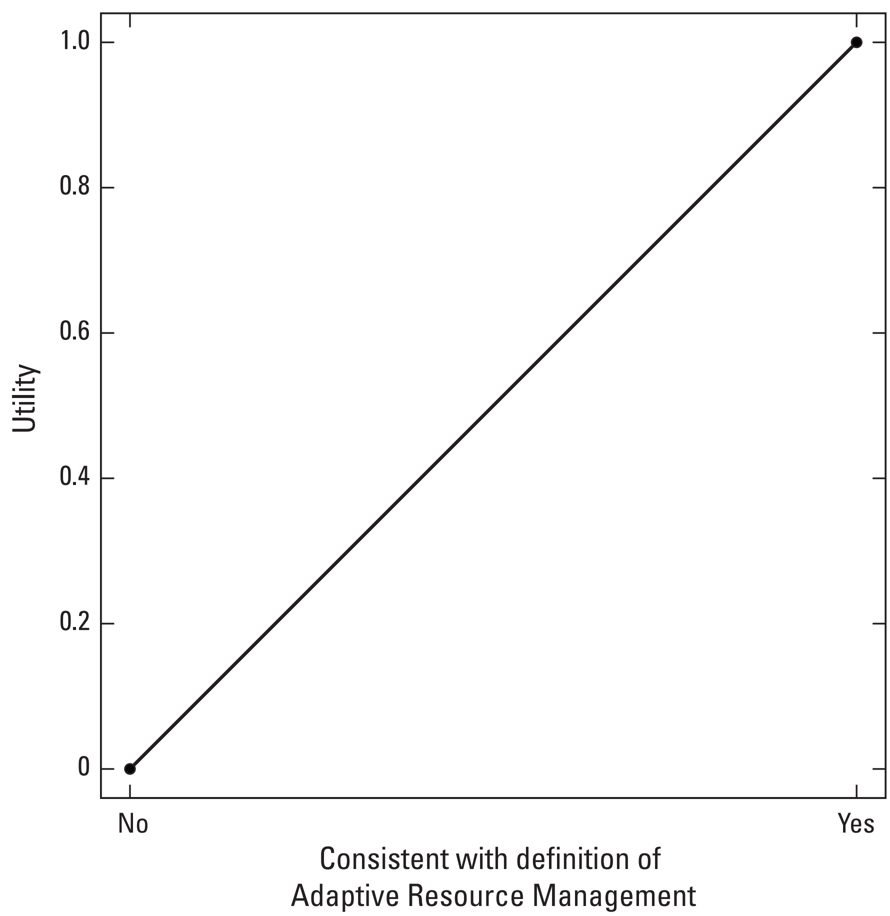

Figure 2.5. Utility function for Adaptive Management (performance metric 5). (Performance metric reflects agreement of proposed methods with the stated definition of Adaptive Resource Management from Williams and others [2009]).

Performance Metric 6: Conservation Need

The northern Gulf of Mexico is home to more than 500 species of birds at some point during their annual life cycle. Unfortunately, many of these species are undergoing population declines (Withers, 2002; Wilson and others, 2019). This performance metric emphasizes monitoring species with decreasing population trends and high uncertainty about the magnitude of their population trend (for example, monitor birds of high conservation need, figs. 2.6–2.7). To identify these species, the authors of this report used the Trend and Concern scores from the Partners in Flight (PIF) Avian Conservation Database (Partners in Flight, 2017). Trend and Concern scores for all Gulf of Mexico Avian Monitoring Network (GoMAMN) Birds of Conservation Concern are provided in the Supplemental Material 1. Overall utility for status and trend monitoring of GoMAMN Birds of Conservation Concern is determined in three steps. First, all the PIF Trend scores for monitored species are summed, and utility is determined from the trend utility function (fig. 2.6). Second, all the PIF Concern scores for monitored species are summed, and utility is determined using the concern utility function (fig. 2.7). Finally, trend utility and concern utility are summed to determine the overall utility for performance metric 6. For example, if a proposed project monitored the status and trends of Black Skimmer, Royal Tern, and Gull-Billed Tern, the sum of trend scores for each species (5, 2, and 4, respectively) is 11. Using the trend utility function, the utility of trend sum = 11 is 0.0506. The sum of concern scores (14, 11, and 13, respectively) is 38, which has a utility of 0.0459. The sum of the two utility scores (0.0506 + 0.0459 = 0.0965) determines overall utility for performance metric 6.

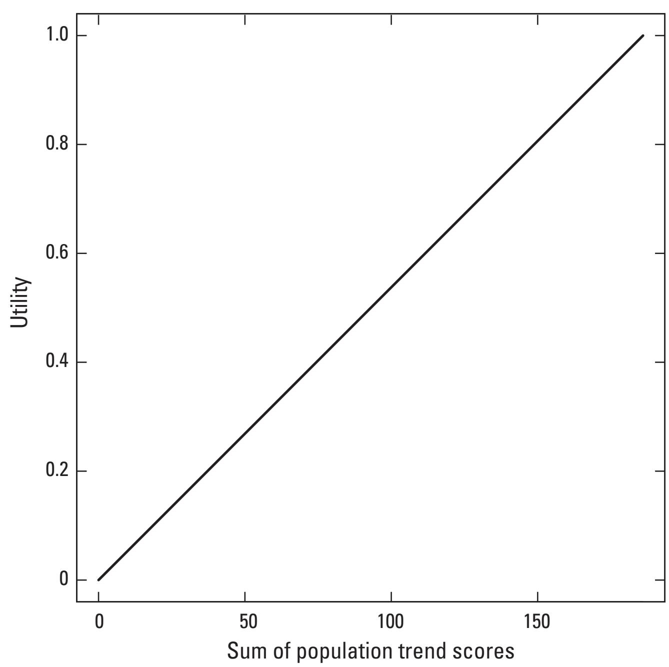

Figure 2.6. Utility function for Conservation Need (performance metric 6, part A), sum of Partners in Flight Trend scores (Partners in Flight, 2017) for species included in a proposal.

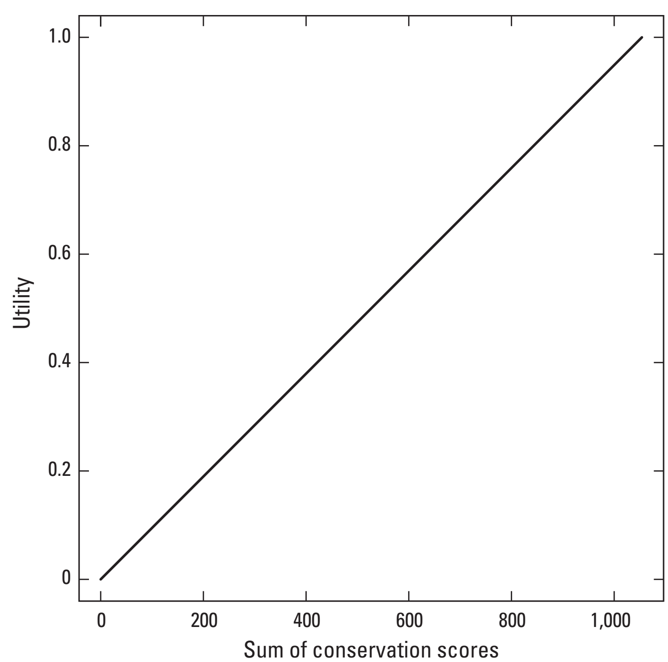

Figure 2.7. Utility function for Conservation Need (performance metric 6, part B), the sum of Partners in Flight Conservation Concern scores (Partners in Flight, 2017) for species included in a proposal.

Performance Metric 7: Spatial Scope of Population Monitoring

Projects that incorporate a large percentage of the geographic range during a life-cycle period (such as breeding, wintering, or migration) are highly valued (fig. 2.8). For example, little value is given to surveys that cover less than 25 percent of a species range, whereas the utility score increases rapidly thereafter up to 80 percent of the range, where it reaches maximum value. If more than one Bird of Conservation Concern (Supplemental Material 1) is surveyed, then the average percentage of the species' range is used to determine the utility score.

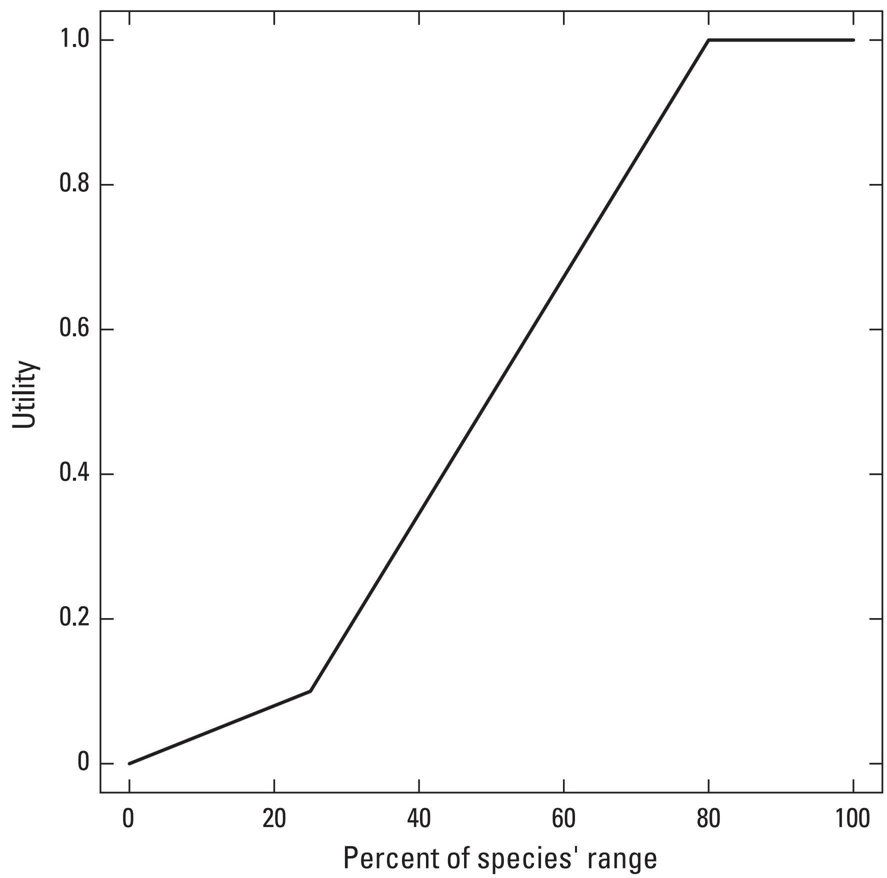

Figure 2.8. Utility function for spatial scope of population monitoring (performance metric 7).

Performance Metric 8: Temporal Scope of Population Monitoring

Surveys that generate data over many years are highly valued (fig. 2.9). For example, little value is given to a survey that spans less than 5 years, whereas the utility score increases rapidly thereafter up to 16 years, where it reaches maximum value. This does not mean locations must be surveyed every year, but the survey design should address repeated counts at specified time intervals.

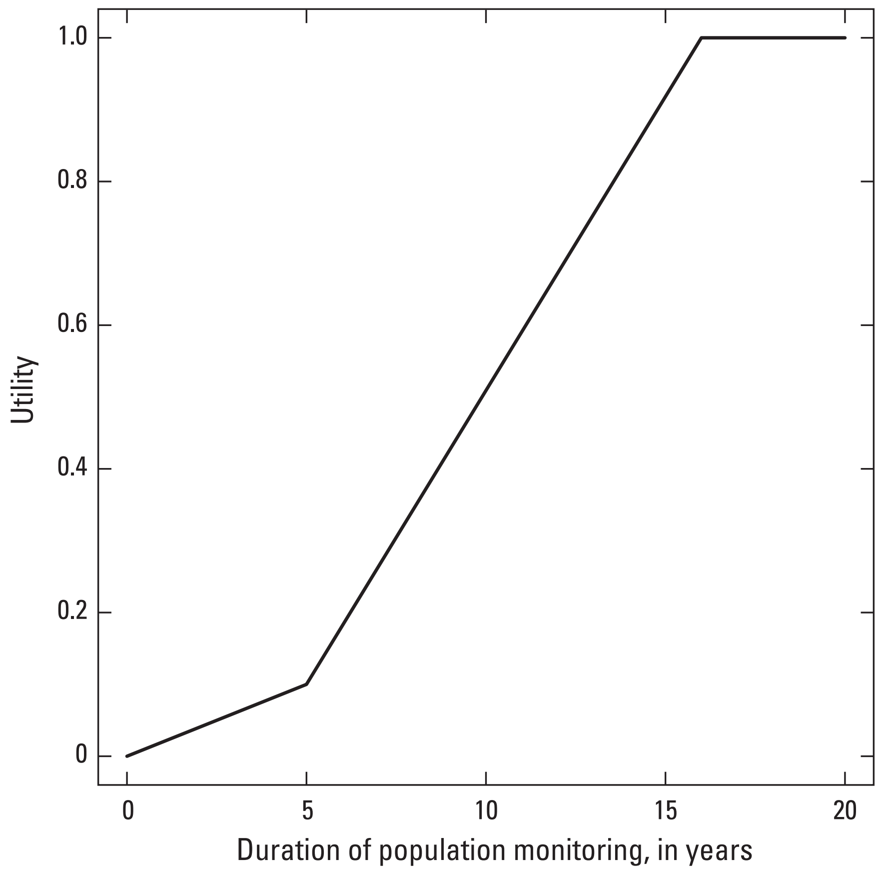

Figure 2.9. Utility function for temporal scope of population monitoring (performance metric 8).

Performance Metric 9: Spatial Scope of Habitat Quantity Monitoring

This metric seeks to maximize the spatial scope of habitat quantity assessments (fig. 2.10). Proposals that include/recommend the collection of habitat quantity data (acreage, distribution, number of patches, patch size, juxtaposition, etc.) and incorporate the full extent of the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (C-CAP) habitat classes are highly valued. To calculate a proportion of habitat monitored, the acreage that the proposal will cover within a particular C-CAP habitat class is determined and divided by the total area available for that C-CAP habitat class (table 2.1). The percentage of C-CAP class for the proposal determines the utility with respect to the spatial scope of habitat monitoring (fig. 2.10). For proposals that cover multiple C-CAP habitat classes, the utilities are summed for total utility with respect to the spatial scope of habitat monitoring. If the sum of utilities is less than 1, the utility is set to 1 for that proposal.

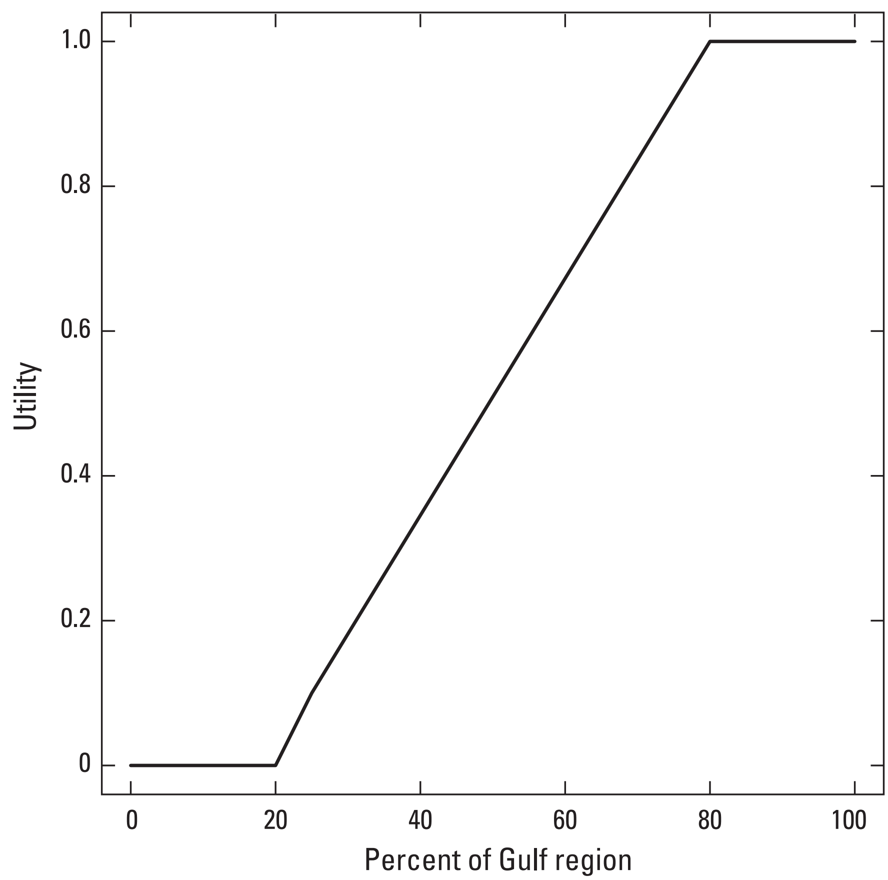

Figure 2.10. Utility function for spatial scope of habitat quantity monitoring (performance metric 9).

Performance Metric 10: Spatial Scope of Habitat Quality Monitoring

This performance metric seeks to maximize the spatial scope of habitat quality assessments (fig. 2.11). Proposals that include/recommend the collection of habitat quality data (vegetative structure, water-quality parameters, etc.) and incorporate the full range of the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (C-CAP) habitat classes have the greatest utility. The scoring procedure is similar to performance metric 9 for the spatial scope of habitat monitoring (quantity). To calculate the utility with respect to habitat quality, one of the four scoring classifications that best describes the proposal is determined (table 2.4), and the values are summed for vegetation score and water score. For example, a proposal with a 30-percent vegetation spatial scope and 15-percent water spatial scope receives a score of 2 for vegetation and 1 for water (total score equal to 3). This score is used to determine utility (y-axis, fig. 2.11).

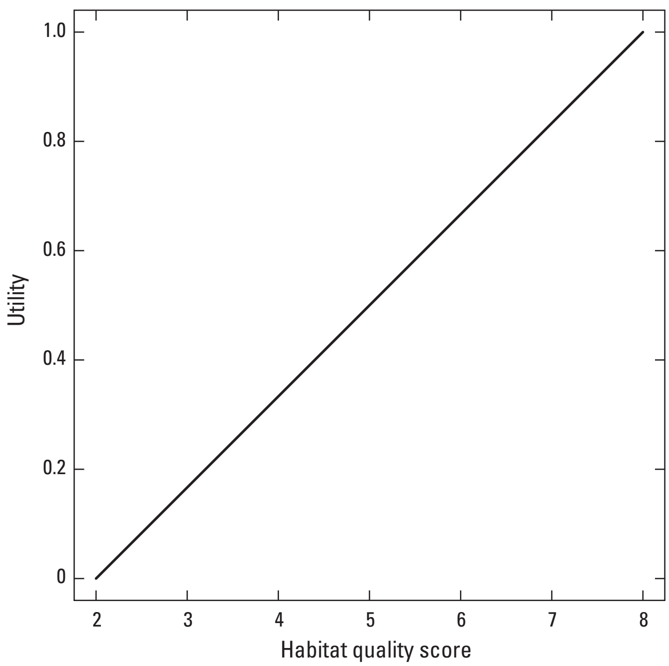

Figure 2.11. Utility function for spatial scope of habitat quality monitoring (performance metric 10).

Table 2.4. Scoring criteria for spatial scope of habitat quality monitoring (performance metric 10).

[<, less than; >, greater than]

Spatial Scope of assessment	Vegetation score	Water score
<25 percent	1	1
25–50 percent	2	2
51–75 percent	3	3
>75 percent	4	4

Performance Metric 11: Temporal Scope of Habitat Monitoring

This performance metric seeks to maximize the temporal scope of proposals to monitor habitat (fig. 2.12). Proposals that generate data over many years have the greatest utility. Note: locations do not need to be surveyed every year, but the survey design should address repeated counts at specified time intervals.

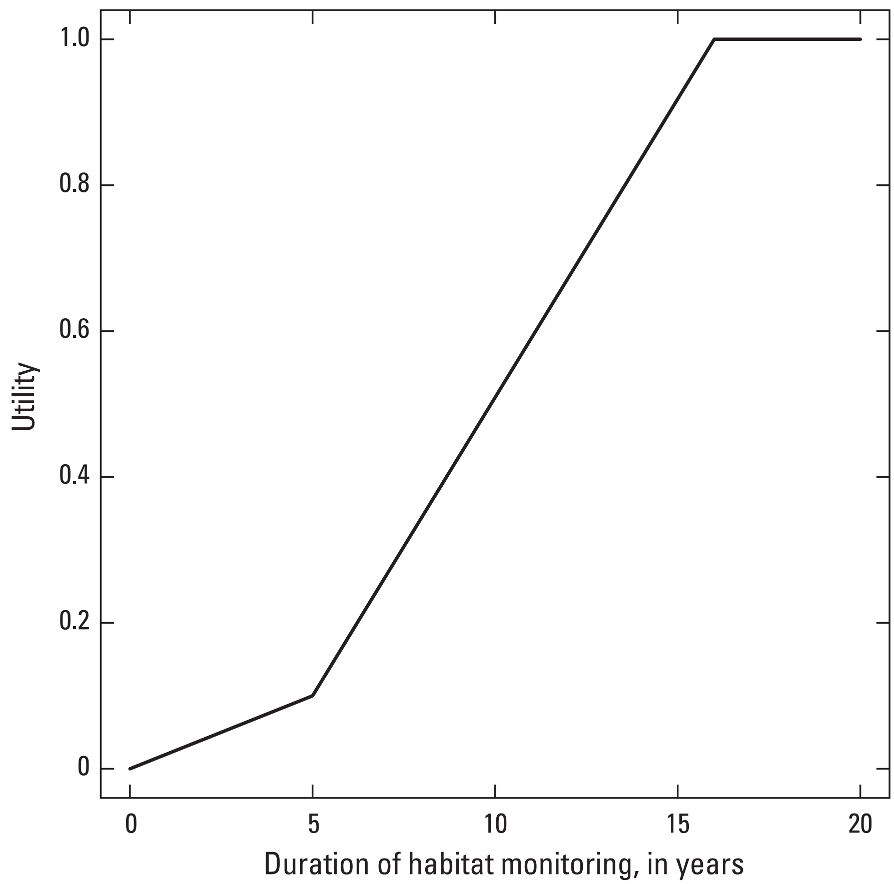

Figure 2.12. Utility function for temporal scope of habitat monitoring (performance metric 11).

Performance Metric 12: Birds of Conservation Concern (Ecological Processes)

Proposals that monitor multiple Birds of Conservation Concern (Supplemental Material 1) representing multiple taxonomic groups will maximize the understanding of how ecological processes influence population dynamics. This metric is the sum of two constructed scales, one for the number of species and one for the number of taxonomic groups represented by those species (table 2.5). For example, a proposed survey including two species representing two taxonomic groups would be scored as 1+2 = 3. Taxonomic groups were included as a scoring criterion to reduce the potential dominance of any one taxa group made up of many species (such as seabirds, land birds, etc.). This utility function achieves full value for a proposed survey that incorporates more than 12 species and more than 3 taxonomic groups (fig 2.13).

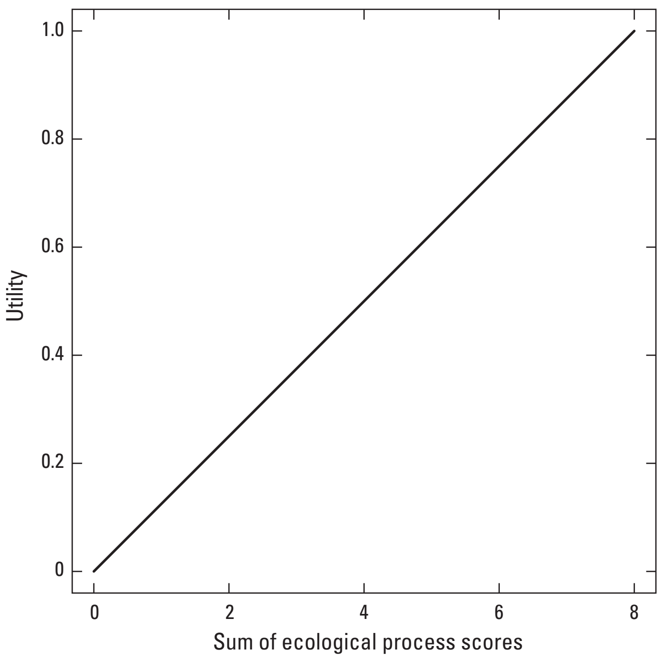

Figure 2.13. Utility function for Birds of Conservation Concern when monitoring ecological processes (performance metric 12).

Table 2.5. Scoring criteria for Birds of Conservation Concern when monitoring ecological processes (performance metric 12).

[>, greater than]

Score	Number of species	Number of taxonomic groups
0	0	0
1	1–3	1
2	4–8	2
3	9–12	3
4	>12	>3

Performance Metric 13: Uncertainty Reduction (from Monitoring Ecological Processes)

Across the northern Gulf of Mexico, there are a variety of ecological processes (such as climatic processes, interactions with other species, hydrological processes, etc.) influencing the population dynamics of avian populations. Unfortunately, there is substantial uncertainty about how these ecological processes work independently or collectively to influence population dynamics. As such, this metric emphasizes the reduction of uncertainty to inform decision making (fig. 2.14). This performance metric is calculated using a constructed scale (table 2.6).

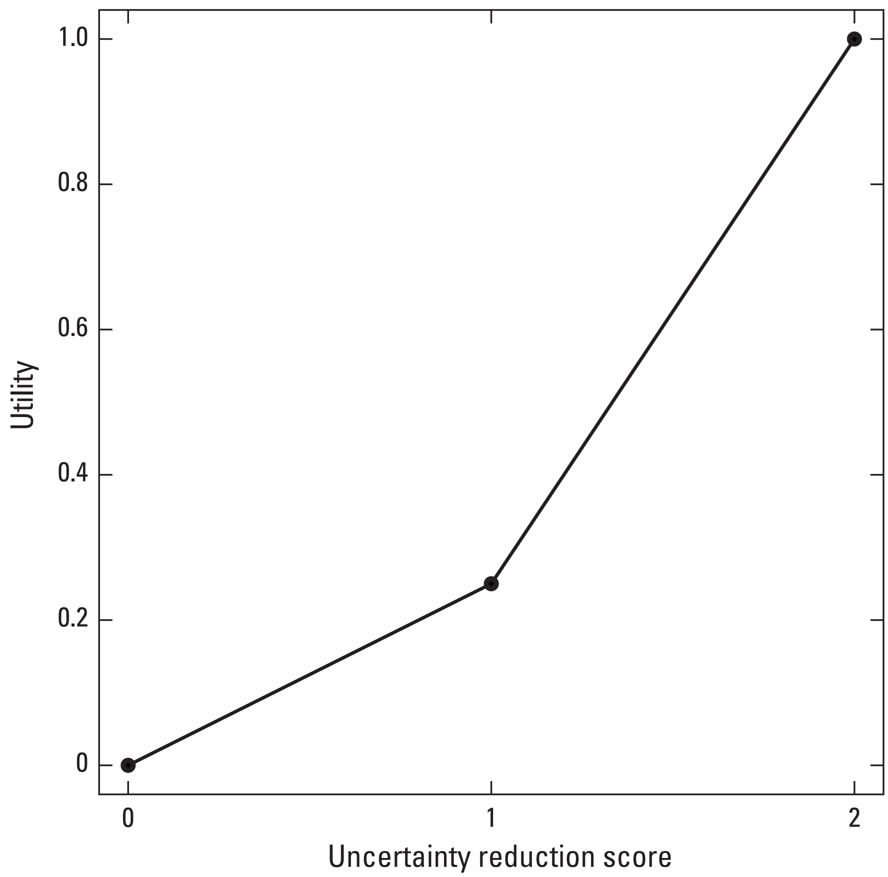

Figure 2.14. Utility function uncertainty reduction from monitoring ecological processes (performance metric 13).

Table 2.6. Scoring criteria for uncertainty reduction from monitoring ecological processes (performance metric 13).

[>, greater than]

Score	Description
0	All processes monitored have low uncertainty
1	Addresses ecological processes with a mixture of high and low uncertainty, with >50 percent monitored processes being low uncertainty processes
2	Addresses >50 percent high uncertainty ecological processes

Performance Metric 14: Data Sharing

With an increasing demand and need to share and make data publicly available, this metric emphasizes the need to publicly share data as broadly and quickly as possible (fig. 2.15). The utility function is linear and reaches full value when data is released within 1 year after completion of the project. The utility score is calculated from a constructed scale (table 2.7) based on the type of data: restricted data (such as endangered species or data containing personally identifiable information), and unrestricted data (such as non-sensitive data).

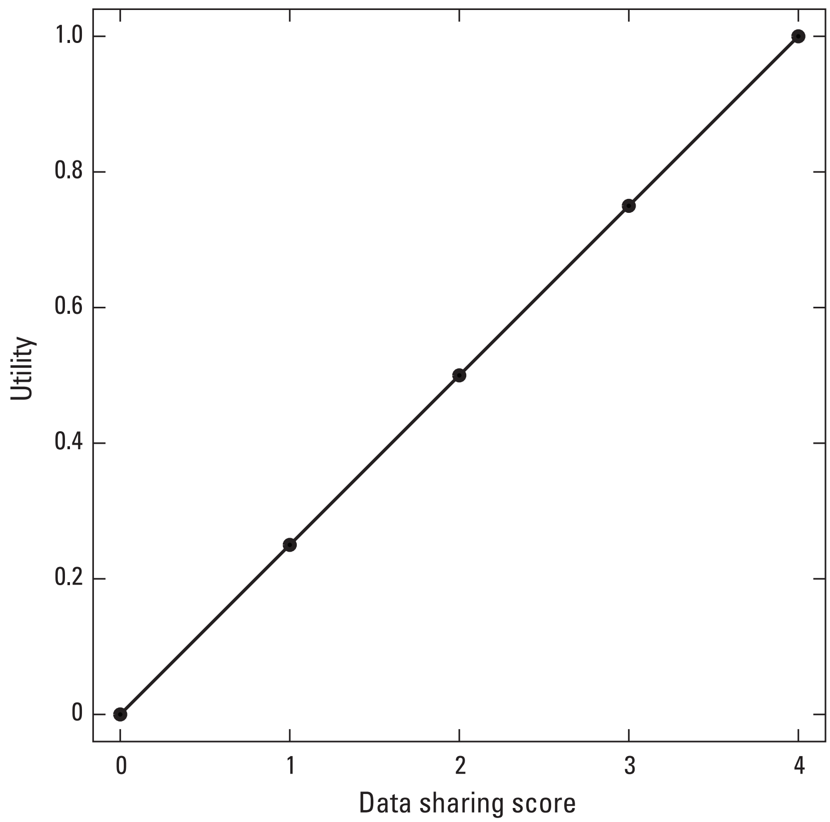

Figure 2.15. Utility function for data sharing (performance metric 14).

Table 2.7. Scoring criteria for data sharing (performance metric 14).

Score	For unrestricted data	For restricted data (such as endangered species)
0	No data sharing policy; or only vague reference to sharing data at some point in future	No data sharing policy; or only vague reference to sharing data at some point in future
1	Open access to data within 8 years of project completion (for example, end date of funding agreement), whether or not included in a central repository	Depositing data into an appropriate restricted access central repository within 8 years of project completion (for example, end date of funding agreement)
2	Open access to data within 5 years of project completion, whether or not included in a central repository	Depositing data into an appropriate restricted access central repository within 5 years of project completion
3	Open access to data in a central repository within 2 years of project completion	Depositing data into an appropriate restricted access central repository within 5 years of project completion
4	Data are entered directly into a central repository, with open access within 1 year of project completion	Data are entered directly into an appropriate restricted access central repository or within 1 year of project completion

Performance Metric 15: Broad Impacts

This metric seeks to maximize the applicability of data beyond bird monitoring (environmental compliance, curriculum development, non-bird monitoring efforts, etc.). Additional applications of the data, such as informing compliance decisions, creating curriculums, etc. (fig. 2.16) result in greater utility. The performance metric is scored using a constructed scale depicting a range of alternative uses and reaches full value when monitoring data are specifically stated as having multiple uses (table 2.8).

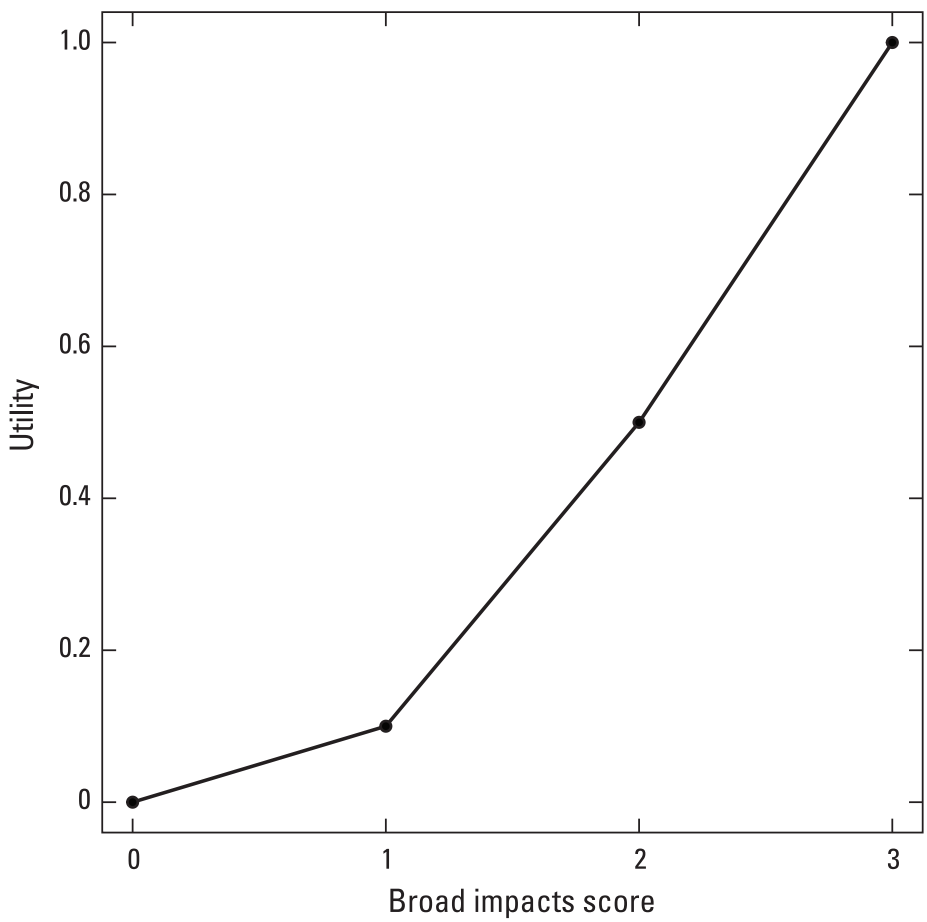

Figure 2.16. Utility function for broad impacts of monitoring (performance metric 15).

Table 2.8. Scoring criteria for broad impacts of monitoring (performance metric 15).

Score	Description
0	No reference to other use of data or information
1	Alternative uses of information are stated generally
2	Alternative uses of information are stated clearly but are multiple steps away from intended application (for example, inclusion in broader scale analyses, pilot study), or intended uses are not realistic or specific
3	Data and (or) research products are clearly stated as being relevant for purposes other than the primary objective in ways that are realistic and specific (such as environmental compliance, curriculum development, project evaluation)

Performance Metric 16: Existing Priorities

New monitoring efforts are often developed and designed with little consideration for existing, established priorities. This performance metric emphasizes the need to incorporate pre-existing priorities and data needs into future monitoring efforts. The metric is scored using a constructed scale (table 2.9) and reaches full value when a proposed project specifically incorporates one or more pre-existing, established monitoring priorities identified within a conservation plan (such as a State Wildlife Action Plan).

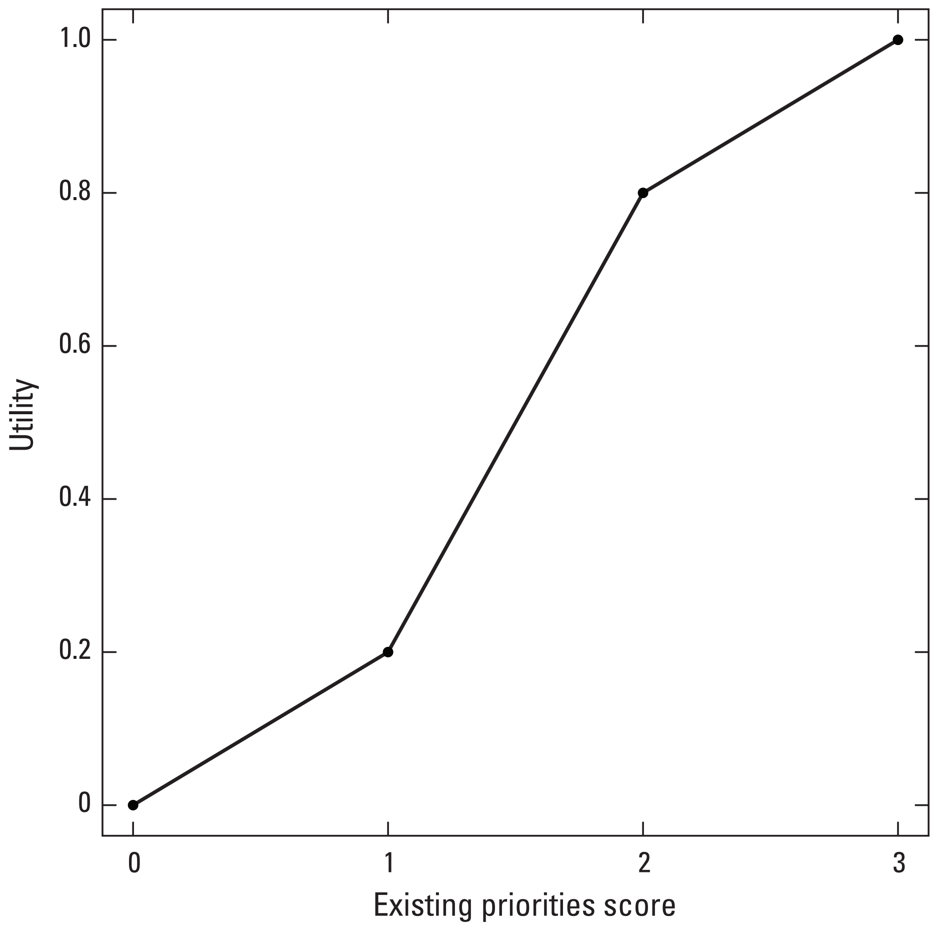

Figure 2.17. Utility function for addressing existing priorities (performance metric 16).

Table 2.9. Scoring criteria for addressing existing priorities (performance metric 16).

Score	Description
0	No reference to existing plans
1	Reference to general support of existing plans (for example, supports State Wildlife Action Plan)
2	Specific reference to existing plan used to support general priority action (supports monitoring, a priority within the State Wildlife Action Plan)
3	Specific reference to multiple existing plans used to support specific priority action (such as supporting monitoring of Seaside Sparrows, as identified as a priority need in State Wildlife Action Plan and Joint Venture Plan)

Performance Metric 17: Partners

In keeping with the fundamental objective of maximizing the integration of efforts, this metric emphasizes the need to incorporate multiple partners in future monitoring efforts. The metric seeks to maximize the number of partners (any collaborators, regardless of funding support) involved in a proposal (fig. 2.18), and relies on a constructed scale (table 2.10) for partner involvement. The utility function is linear and reaches full value when there are more than five partners included in the proposal.

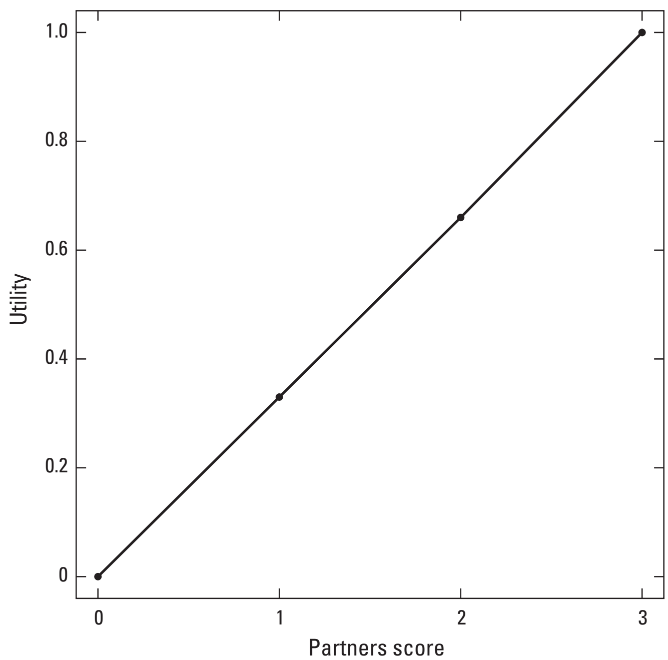

Figure 2.18. Utility function Partners score (performance metric 17).

Table 2.10. Scoring criteria for incorporation of partners (performance metric 17).

[>, greater than]

Score	Description
0	An individual submission
1	1 collaborating agency, organization, or institution
2	2–5 collaborating agencies, organizations, or institutions
3	>5 collaborating agencies, organizations, or institutions

Performance Metric 18: Leverage

In addition to the number of partners (performance metric 17), another means to achieve the fundamental objective of maximizing integration is to maximize the amount of in-kind (such as equipment, housing, etc.) or financial support leveraged (financial match, salaries, etc.). This performance metric seeks to maximize the matching in-kind and financial support for a proposed monitoring project (fig. 2.19). Proposals that leverage additional resources have the greatest utility, which reaches full value when the proposal exceeds 150 percent in match (table 2.11).

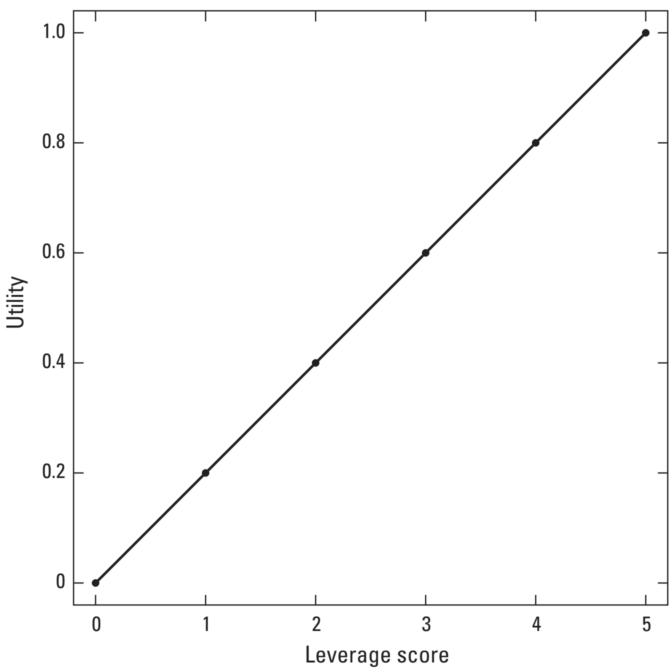

Figure 2.19. Utility function for leverage of in-kind or financial support (performance metric 18).

Table 2.11. Scoring criteria for amount of leveraged in-kind or financial support (performance metric 18).

[>, greater than]

Score	Description
0	No match
1	0–25 percent
2	26–50 percent
3	51–100 percent
4	101–150 percent
5	>151 percent

Performance Metric 19: Alignment

Given the complexity of interactions between ecological processes and management actions, it is imperative that bird monitoring projects align themselves to increase efficiency. More specifically, understanding patterns and trends in bird response will require an understanding of food resource availability, changes in habitat, and (or) changes in climatic-related events, all of which will require alignment and partnering with other monitoring communities of practice (for example, fisheries, water quality, etc.). Monitoring efforts that are aligned with other existing or proposed monitoring programs that allow for data integration across programs, spatial scales, objectives, or hypotheses have the greatest utility (fig. 2.20). The utility function is scored on a constructed scale and reaches full value when proposed projects explicitly address alignment with other monitoring efforts (table 2.12).

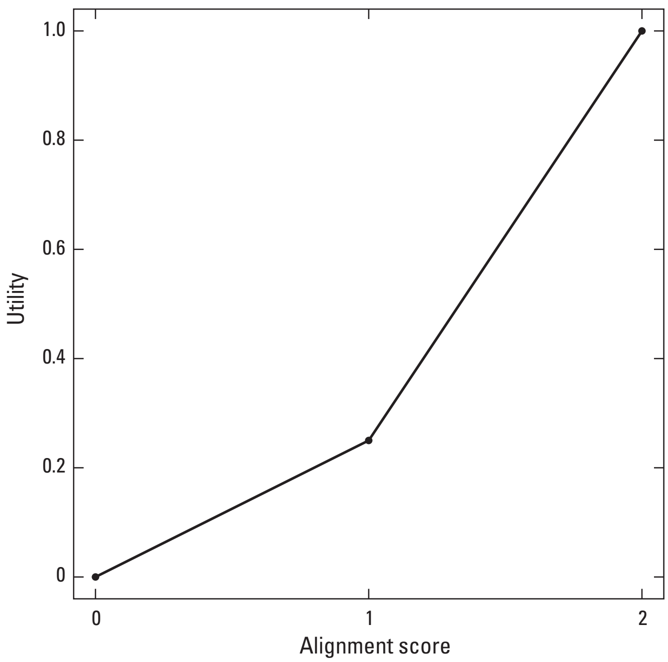

Figure 2.20. Utility function for alignment of monitoring efforts (performance metric 19).

Table 2.12. Scoring criteria of alignment of monitoring efforts (performance metric 19).

Score	Description
0	No alignment
1	Benefits of monitoring program alignment stated generally
2	Benefits of monitoring program alignment stated explicitly

Performance Metric 20: Objective and Hypotheses

For monitoring projects to effectively answer a question or inform a decision, the survey must have an explicitly stated objective or hypothesis(es) (fig. 2.21). Scores on this metric are determined using a constructed scale that reaches full value when a monitoring proposal clearly states the objective or hypothesis(es) along with any assumptions and supportive material (table 2.13).

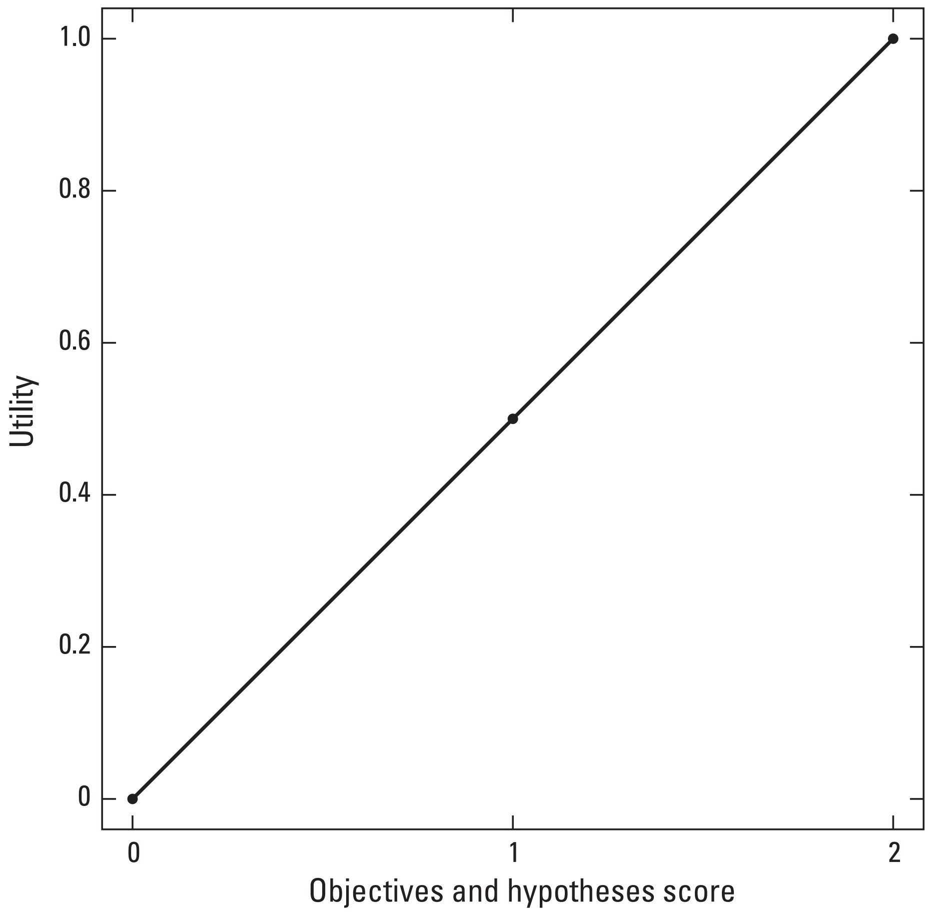

Figure 2.21. Utility function for stated objectives and hypotheses (performance metric 20).

Table 2.13. Scoring criteria for stated objectives and hypotheses (performance metric 20).

Score	Description
0	No objectives and (or) hypotheses clearly stated, or objectives are inappropriate to answer research questions
1	Objectives and (or) hypotheses stated generally, and objectives appropriate to answer research questions
2	Specific objectives and (or) hypotheses stated explicitly with documentation of assumptions, and objectives appropriate to answer research question

Performance Metric 21: Response Variable

In addition to clear objectives or hypotheses to guide monitoring efforts (performance metric 20), an appropriate response variable to best address an objective or hypothesis also is critical. For example, in some cases, density estimates corrected for observer bias are preferred over the use of relative abundance to answer a specific question. This performance metric emphasizes the use of the most appropriate response variable(s) to address proposal objectives and hypotheses (fig. 2.22). Utility is calculated using a constructed scale and reaches full utility when projects clearly identify the most appropriate response variable to answer the stated question (table 2.14).

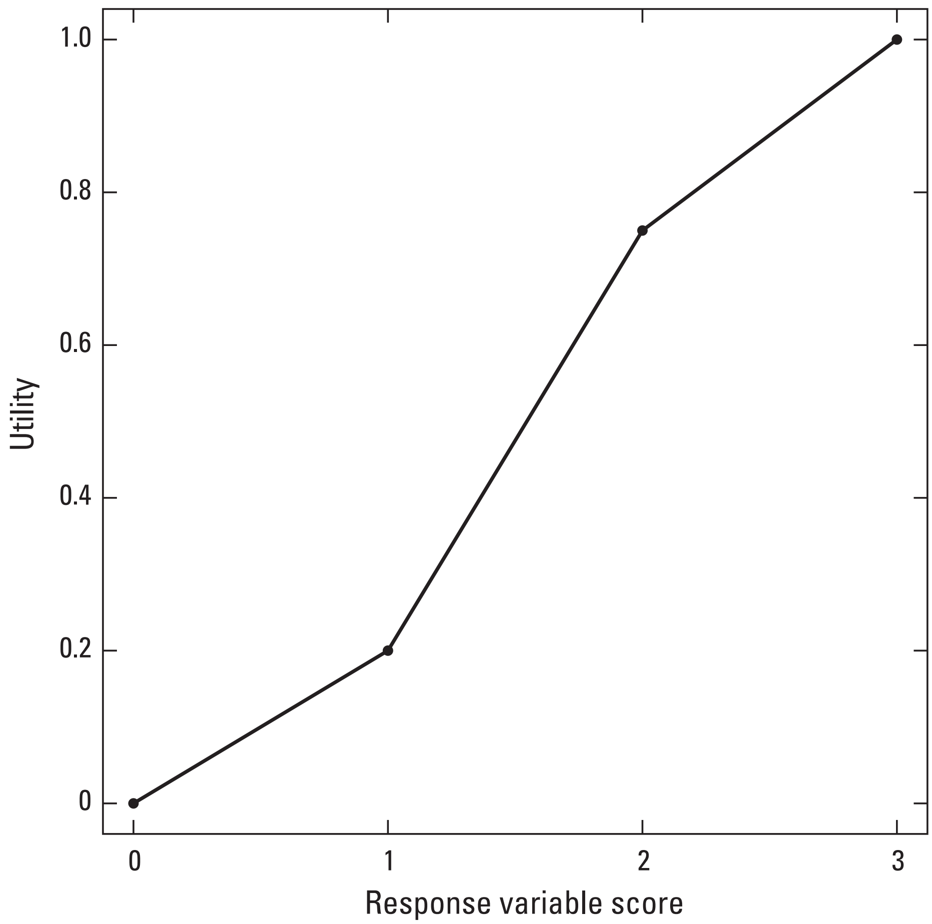

Figure 2.22. Utility function for selection of the appropriate response variable (performance metric 21).

Table 2.14. Scoring criteria for selection of the appropriate response variable (performance metric 21).

Score	Description
0	No response variable identified or clearly inappropriate to address monitoring effort's objectives and (or) hypotheses
1	Appropriateness of response variable for evaluating monitoring effort's objectives and hypotheses uncertain or possibly inappropriate
2	Response variable appropriate but not best suited for addressing monitoring effort's objectives and (or) hypotheses
3	Response variable clearly appropriate and best suited for addressing monitoring effort's objectives and (or) hypotheses

Performance Metric 22: Target Taxa

Another means of increasing the scientific rigor of a monitoring project is the selection of the appropriate taxa, which allows a full and thorough understanding of the stated objective or hypotheses (see performance metric 20). For example, to fully understand the impacts of a rare or small population of birds, it may be more appropriate to select another, more abundant species with similar life history traits as the target taxa. As such, this performance metric places an emphasis on using the most appropriate target species for evaluating objectives and hypotheses (fig. 2.23). The performance metric is calculated from a constructed scale (table 2.15) and reaches full utility when the proposed project selects the most appropriate taxa for addressing the objective(s) or hypothesis(es).

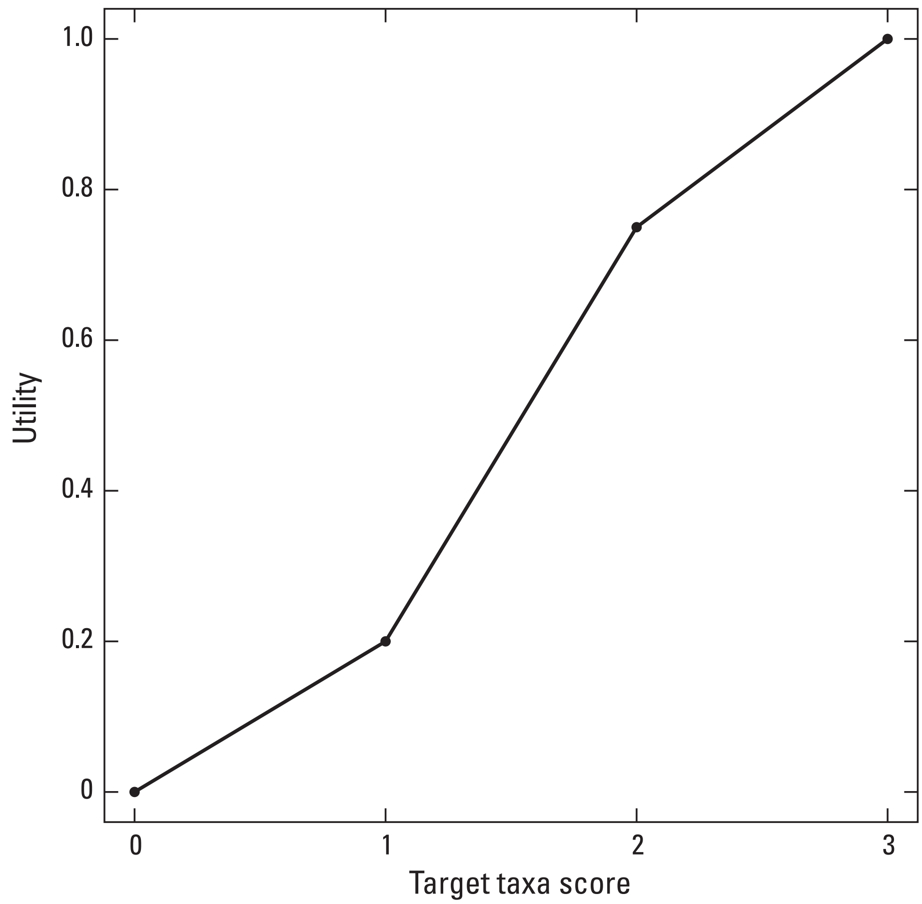

Figure 2.23. Utility function for selecting the appropriate target taxa (performance metric 22).

Table 2.15. Scoring criteria for selection of the appropriate target taxa (performance metric 22).

Score	Description
0	Target species not identified or are clearly inappropriate for evaluating monitoring effort's objectives and (or) hypotheses
1	Appropriateness of target species for evaluating monitoring effort's objectives and hypotheses uncertain or possibly inappropriate
2	Target species will address monitoring effort's objectives and hypotheses - but are not most appropriate (for example, other species would offer greater insights due to some life history characteristic)
3	Target species are most appropriate species for evaluating the monitoring effort's objectives and hypotheses

Performance Metric 23: Survey Design

Unfortunately, many surveys are being implemented with little thought about survey design (for example when, where, and how sampling is conducted). As such, these surveys often struggle or fail to provide sufficient information to answer the proposed objectives. This performance metric places an emphasis on projects with sampling designs that are clearly appropriate to achieve the proposed objectives in a scientifically robust manner (fig. 2.24). The performance metric is calculated from a constructed scale (table 2.16) and reaches full utility when the proposed project utilizes the most appropriate survey design determined by a formal power analysis.

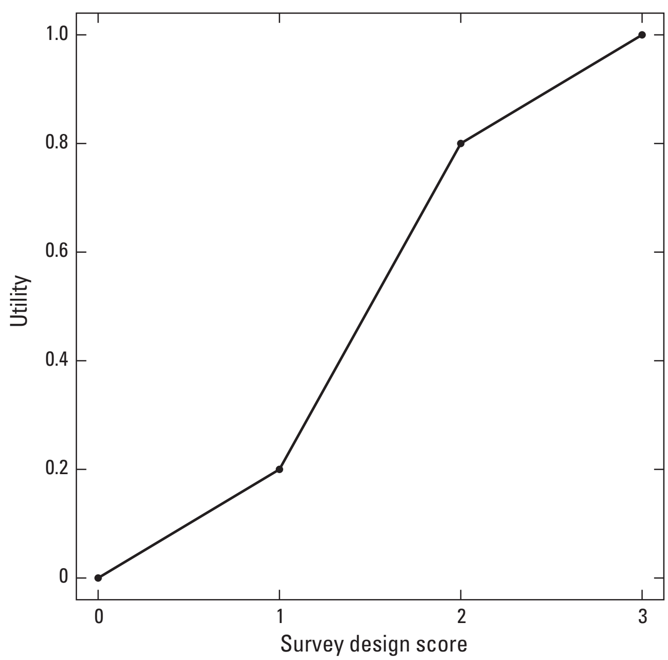

Figure 2.24. Utility function for selecting the appropriate survey design (performance metric 23).

Table 2.16. Scoring criteria for selecting the appropriate survey design (performance metric 23).

Score	Description
0	No reference to survey and sampling design or clearly inappropriate
1	Survey and sampling design(s) present but incomplete
2	Survey and sampling design(s) present but not detailed
3	Survey and sampling design(s) clearly appropriate to achieve objectives; formal power analysis conducted

Performance Metric 24: Statistical Rigor

Proposed monitoring projects should consider the types of statistical analyses planned. This performance metric emphasizes the use of statistical methods that are well described and appropriate for answering the proposed objective (fig. 2.25). The performance metric is calculated from a constructed scale (table 2.17) and reaches full utility when the proposal uses well-documented and proven analytical methods deemed most appropriate to achieve the stated objectives.

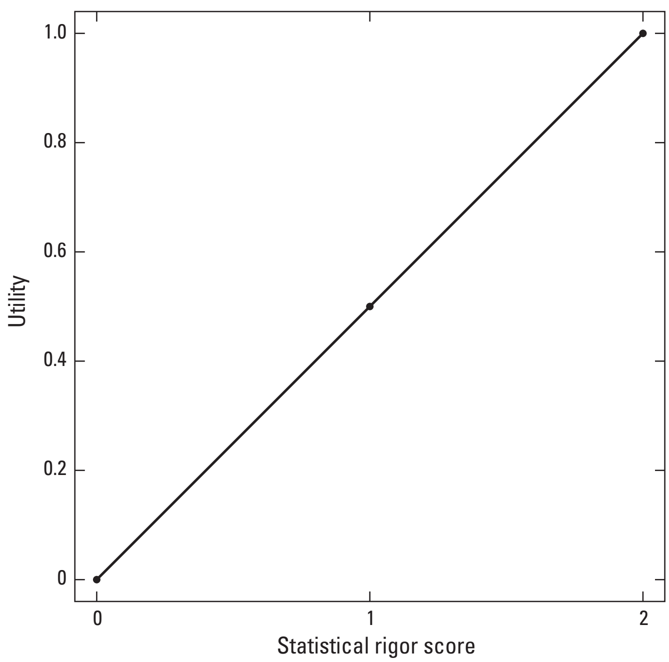

Figure 2.25. Utility function for increasing statistical rigor (performance metric 24).

Table 2.17. Scoring criteria for increasing statistical rigor (performance metric 24).

Score	Description
0	No reference to statistical analysis or analysis is clearly inappropriate
1	Statistical analysis section present, but incomplete
2	Statistical analysis clearly appropriate to achieve objectives (widely used, well-documented, proven)

Performance Metric 25: Data Management Plans

One often overlooked aspect of statistical rigor is data management. This performance metric places an emphasis on projects that develop and adhere to well-articulated data management plans (fig 2.26). The performance metric uses a constructed scale (table 2.18) and reaches full utility when data management plans in a monitoring proposal address data acquisition, development, storage, and transfer.

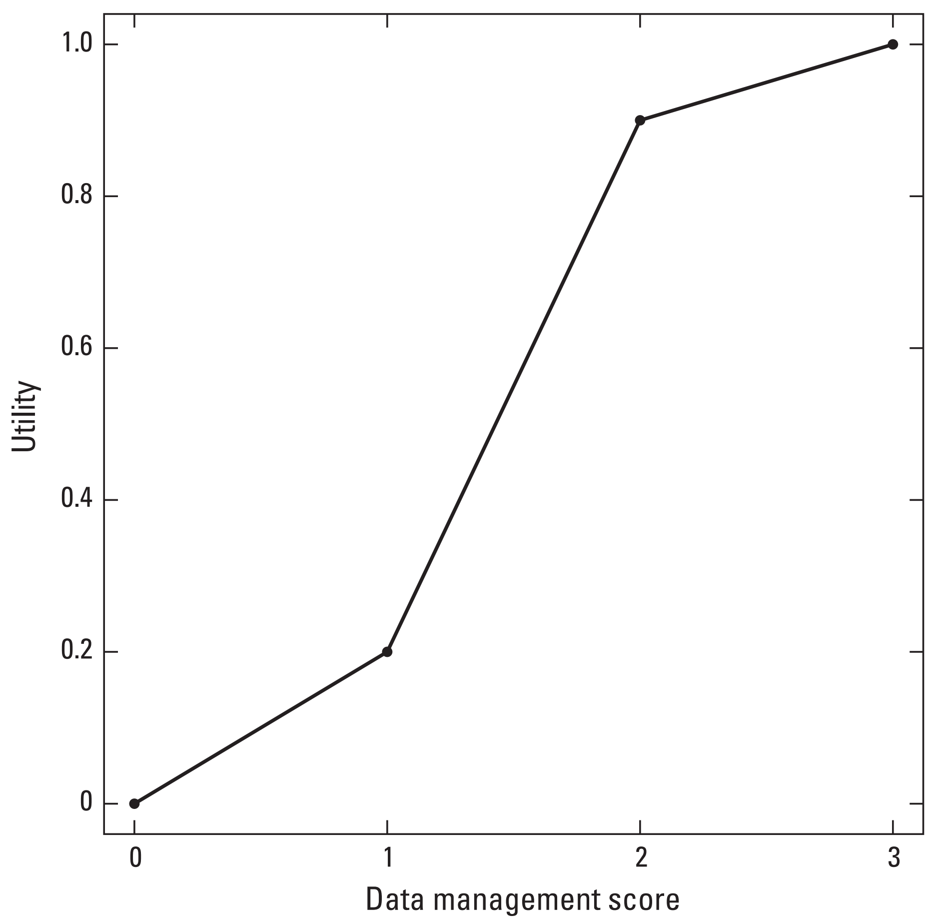

Figure 2.26. Utility function for development of data management plan (performance metric 25).

Table 2.18. Scoring criteria for data management plans (performance metric 25).

Score	Description
0	No reference to data management plan
1	Data management plan incomplete
2	Data management plan incomplete but adheres to metadata standards
3	Data management plan completed; addresses acquisition, development, storage, and transfer of data; adheres to metadata standards

Performance Metric 26: Budget

One of the overarching goals of the Gulf of Mexico Avian Monitoring Network (GoMAMN) is to facilitate the development and implementation of cost-efficient monitoring strategies. Other metrics seek to maximize the number of partners (performance metric 17) and leveraged resources (performance metric 18). Another way to increase efficiency is to ensure that proposed projects do not request more funding than is warranted. Conversely, and equally vital to project success, it is important to ensure that proposed projects have not significantly underestimated the budget. This performance metric emphasizes the need for an appropriate and reasonable budget to address the stated objective (fig. 2.27), and uses a constructed scale (table 2.19) that reaches full utility when the proposed budget is appropriate and reasonable.

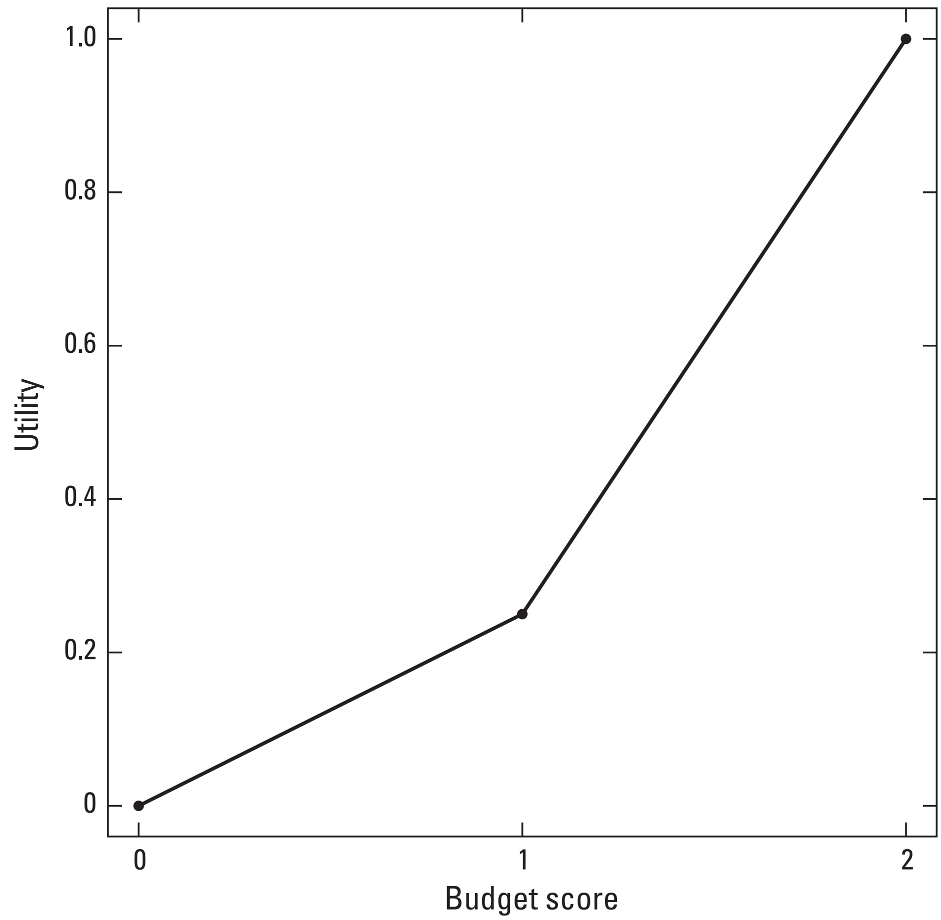

Figure 2.27. Utility function for selection of appropriate budget (performance metric 26).

Table 2.19. Scoring criteria of selection of appropriate budget (performance metric 26)

[>, greater than]

Score	Description
0	No budget or completely unreasonable budget; orders of magnitude off
1	Budget seems unreasonable to address stated objectives and (or) hypotheses; >50 percent off from what reviewer thinks work should cost
2	Budget appropriate and reasonable to address stated objectives and (or) hypotheses
3	Survey and sampling design(s) clearly appropriate to achieve objectives; formal power analysis conducted

Performance Metric 27: Timeline

Similar to performance metric 26 (selecting an appropriate budget), this performance metric addresses the need for an appropriate timeline to complete the stated proposal objective. For example, if the proposed objective is to evaluate the effects of a marsh restoration technique using an adaptive management framework, a 2–year study is not appropriate; it will likely require several years to implement and evaluate the technique, and apply the technique again using knowledge learned. Hence, the greatest utility is from proposals that have an appropriate and reasonable timeline to address the stated objectives (fig. 2.28). Scores on this performance metric are from a constructed scale (table 2.20) and reach full utility value when the proposed project selects a specific, appropriate, and reasonable timeline necessary to address the stated objective.

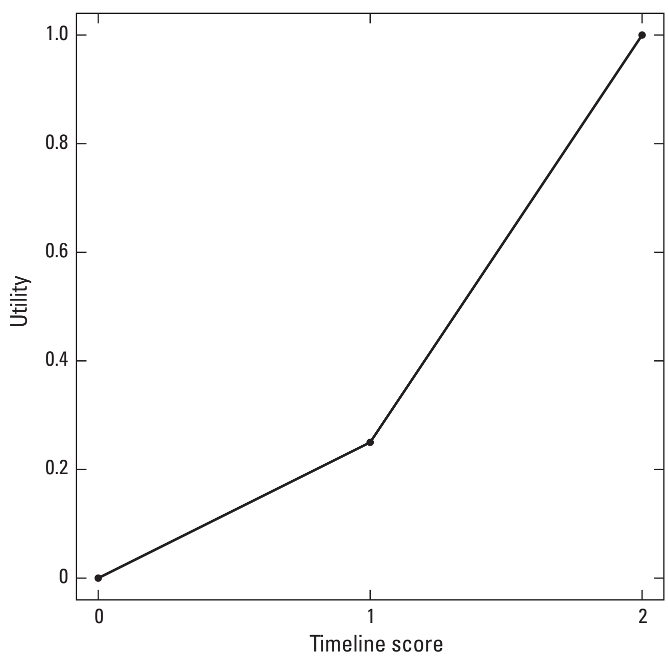

Figure 2.28. Utility function for selecting the appropriate project timeline (performance metric 27).

Table 2.20. Scoring criteria for selecting appropriate project timeline (performance metric 27).

Score	Description
0	No timeline or unreasonable timeline
1	Timeline generally outlined
2	Timeline specific, appropriate, and reasonable

Appendix 3. Management Actions

Table 3.1. Management actions of the Gulf of Mexico Avian Monitoring Network (GoMAMN).

[Classification of management actions is adapted from Salafsky and others (2008), which is based on the Open Standards for the Practice of Conservation. Level 1 categories are shown in the column spanner and level 2 categories are shown in the first column. Enumeration of level 1 and level 2 categories in this table (such as “2. Land/Water Management”) is taken from Salafsky and others (2008). GoMAMN uses habitat-specific management actions to facilitate mapping and measuring the potential spatial footprint based on the extent of each habitat (National Oceanic and Atmospheric Administration Coastal Change Analysis Program land cover; Dobson and others, 1995) in the region.]

Open standards classification	Management action
2. Land/water management	
2.1 Site/area management	Reduce disturbance to beach-nesting birds–beach/dune
	Reduce disturbance to beach-nesting birds–estuarine emergent wetland
	Reduce disturbance to nesting raptors–deciduous forest
	Reduce disturbance to nesting raptors–evergreen forest
	Reduce disturbance to nesting raptors–palustrine forested wetland
	Reduce disturbance to waterbirds–beach/dune
	Reduce disturbance to waterbirds–estuarine emergent wetland
	Reduce disturbance to waterbirds–estuarine forested wetland
	Reduce disturbance to waterbirds–open water
	Reduce disturbance to waterbirds–palustrine forested wetland
	Sustainable agriculture–cultivated crops
	Sustainable agriculture–pasture/hay
	Sustainable aquaculture–estuarine emergent wetland
	Sustainable aquaculture–estuarine forested wetland
	Sustainable aquaculture–open water
	Sustainable aquaculture–oyster reefs
	Sustainable aquaculture–palustrine emergent wetland
	Sustainable aquaculture–palustrine forested wetland
	Sustainable forestry–deciduous forest
	Sustainable forestry–evergreen forest
	Sustainable forestry–grassland
	Sustainable forestry–palustrine forested wetland
	Vegetation removal (pines, etc.) from roosting and nesting sites–beach/dune
	Vegetation removal (pines, etc.) from roosting and nesting sites–estuarine emergent wetland
	Wastewater management–estuarine emergent wetland
	Wastewater management–estuarine forested wetland
	Wastewater management–open water
	Wastewater management–palustrine emergent wetland
	Wastewater management–palustrine forested wetland
2.2 Invasive/problematic species control	Integrated predator control for beach-nesting birds–beach/dune
	Integrated predator control for beach-nesting birds–estuarine emergent wetland
	Integrated predator control for beach-nesting birds–open water
	Removal of invasive species–beach/dune
	Removal of invasive species–deciduous forest
	Removal of invasive species–estuarine emergent wetland

Table 3.1. Management actions of the Gulf of Mexico Avian Monitoring Network (GoMAMN).—Continued

[Classification of management actions is adapted from Salafsky and others (2008), which is based on the Open Standards for the Practice of Conservation. Level 1 categories are shown in the column spanner and level 2 categories are shown in the first column. Enumeration of level 1 and level 2 categories in this table (such as “2. Land/Water Management”) is taken from Salafsky and others (2008). GoMAMN uses habitat-specific management actions to facilitate mapping and measuring the potential spatial footprint based on the extent of each habitat (National Oceanic and Atmospheric Administration Coastal Change Analysis Program land cover; Dobson and others, 1995) in the region.]

Open standards classification	Management action
	Removal of invasive species–estuarine forested wetland
	Removal of invasive species–evergreen forest
	Removal of invasive species–grassland/herbaceous
	Removal of invasive species–mixed forest
	Removal of invasive species–open water
	Removal of invasive species–palustrine emergent wetland
	Removal of invasive species–palustrine forested wetland
	Removal of invasive species–scrub/shrub
2.3 Habitat and natural process restoration	Barrier island creation–beach/dune
	Dredge spoil island creation–beach/dune
	Ecosystem restoration–beach/dune
	Ecosystem restoration–deciduous forest
	Ecosystem restoration–estuarine emergent wetland
	Ecosystem restoration–estuarine forested wetland
	Ecosystem restoration–evergreen forest
	Ecosystem restoration–grassland
	Ecosystem restoration–mixed forest
	Ecosystem restoration–open water
	Ecosystem restoration–palustrine emergent wetland
	Ecosystem restoration–palustrine forested wetland
	Ecosystem restoration–scrub/shrub
	Nest habitat creation (dredge)–estuarine emergent wetland
	Prescribed fire–deciduous forest
	Prescribed fire–estuarine emergent wetland
	Prescribed fire–evergreen forest
	Prescribed fire–grassland/herbaceous
	Prescribed fire–mixed forest
3. Species management	
3.1 Species management	Artificial nest construction–beach/dune
	Artificial nest construction–cultivated crops
	Artificial nest construction–estuarine emergent wetland
	Artificial nest construction–estuarine forested wetland
	Artificial nest construction–grassland/herbaceous
	Artificial nest construction–open water
	Artificial nest construction–palustrine emergent wetland
	Artificial nest construction–palustrine forested wetland
	Artificial nest construction–pasture/hay
	Fisheries management–beach/dune
	Fisheries management–estuarine emergent wetland

Table 3.1. Management actions of the Gulf of Mexico Avian Monitoring Network (GoMAMN).—Continued

[Classification of management actions is adapted from Salafsky and others (2008), which is based on the Open Standards for the Practice of Conservation. Level 1 categories are shown in the column spanner and level 2 categories are shown in the first column. Enumeration of level 1 and level 2 categories in this table (such as "2. Land/Water Management") is taken from Salafsky and others (2008). GoMAMN uses habitat-specific management actions to facilitate mapping and measuring the potential spatial footprint based on the extent of each habitat (National Oceanic and Atmospheric Administration Coastal Change Analysis Program land cover; Dobson and others, 1995) in the region.]

Open standards classification	Management action
	Fisheries management–estuarine forested wetland
	Fisheries management–open water
	Fisheries management–palustrine emergent wetland
	Fisheries management–palustrine forested wetland
	Harvest management for game species–beach/dune
	Harvest management for game species–cultivated crops
	Harvest management for game species–deciduous forest
	Harvest management for game species–estuarine emergent wetland
	Harvest management for game species–estuarine forested wetland
	Harvest management for game species–evergreen forest
	Harvest management for game species–grassland
	Harvest management for game species–mixed forest
	Harvest management for game species–open water
	Harvest management for game species–palustrine emergent wetland
	Harvest management for game species–palustrine forested wetland
	Harvest management for game species–pasture/hay
	Harvest management for game species–scrub/shrub
3.2 Species recovery	Disease/pathogen/parasite management–beach/dune
	Disease/pathogen/parasite management–cultivated crops
	Disease/pathogen/parasite management–deciduous forest
	Disease/pathogen/parasite management–estuarine emergent wetland
	Disease/pathogen/parasite management–estuarine forested wetland
	Disease/pathogen/parasite management–evergreen forest
	Disease/pathogen/parasite management–grassland/herbaceous
	Disease/pathogen/parasite management–mixed forest
	Disease/pathogen/parasite management–open water
	Disease/pathogen/parasite management–palustrine emergent wetland
	Disease/pathogen/parasite management–palustrine forested wetland
	Disease/pathogen/parasite management–pasture/hay
	Disease/pathogen/parasite management–scrub/shrub

Appendix 4. Costs and Benefits of Monitoring Proposals

Table 4.1. Costs and benefits (total utility) of proposals used in the constrained optimization and Pareto analysis (Jollands, 2006; Neckles and others 2015).

[Benefit is the sum of the weighted utility for 27 different performance metrics. Proposals 1–6 are based on actual proposals provided by the National Fish and Wildlife Foundation; the remainder were simulated for demonstration purposes.]

Proposal name	Cost (USD)	Benefit (utility)	Benefit-cost ratio
Project 1	$700,000.00	0.629	0.090
Project 2	$5,400,000.00	0.534	0.010
Project 3	$250,000.00	0.459	0.184
Project 4	$150,000.00	0.377	0.252
Project 5	$220,000.00	0.374	0.170
Project 6	$110,000.00	0.218	0.198
Project 7	$1,000,000.00	0.559	0.056
Project 8	$5,000,000.00	0.527	0.011
Project 9	$25,000.00	0.458	1.834
Project 10	$900,000.00	0.421	0.047
Project 11	$1,500,000.00	0.488	0.033
Project 12	$100,000.00	0.382	0.382
Project 13	$250,000.00	0.305	0.122
Project 14	$500,000.00	0.431	0.086
Project 15	$800,000.00	0.610	0.076
Project 16	$2,000,000.00	0.543	0.027
Project 17	$500,000.00	0.402	0.080
Project 18	$300,000.00	0.439	0.146
Project 19	$750,000.00	0.415	0.055
Project 20	$1,500,000.00	0.559	0.037
Project 21	$900,000.00	0.422	0.047
Project 22	$750,000.00	0.444	0.059
Project 23	$1,000,000.00	0.379	0.038
Project 24	$150,000.00	0.379	0.253
Project 25	$250,000.00	0.533	0.213
Project 26	$500,000.00	0.429	0.086
Project 27	$1,200,000.00	0.341	0.028
Project 28	$500,000.00	0.494	0.099
Project 29	$2,000,000.00	0.445	0.022
Project 30	$250,000.00	0.283	0.113
Project 31	$650,000.00	0.357	0.055
Project 32	$200,000.00	0.491	0.245
Project 33	$400,000.00	0.407	0.102
Project 34	$900,000.00	0.477	0.053
Project 35	$900,000.00	0.453	0.050

Appendix 5. Monitoring Portfolios for Sensitivity Analysis

Table 5.1. Five portfolios used in the sensitivity analysis, including which proposals were selected for each portfolio (indicated with “1”), portfolio cost, and portfolio benefit (sum of weighted utility). The five Gulf States are Texas, Louisiana, Mississippi, Alabama, and Florida.

[<, less than]

	Portfolio				
	Marsh birds	**Shorebirds**	**In all 5 U.S. gulf states**	**<0.5 million USD**	**All Texas**
Cost (USD)	1,550,000	2,380,000	4,700,000	1,420,000	3,910,000
Benefit (utility)	1.994	1.938	2.380	1.984	1.973
Project 1	0	1	0	0	0
Project 2	0	0	0	0	0
Project 3	0	0	0	1	0
Project 4	0	1	0	0	0
Project 5	0	1	0	1	0
Project 6	0	1	0	0	1
Project 7	0	0	1	0	0
Project 8	0	0	0	0	0
Project 9	0	0	0	0	0
Project 10	0	0	0	0	1
Project 11	0	0	1	0	0
Project 12	1	0	0	0	0
Project 13	0	0	0	1	0
Project 14	0	0	0	0	0
Project 15	0	0	0	0	0
Project 16	0	0	0	0	0
Project 17	0	0	0	0	0
Project 18	1	0	0	1	0
Project 19	0	0	0	0	0
Project 20	0	0	0	0	0
Project 21	0	0	0	0	0
Project 22	0	0	0	0	0
Project 23	0	0	0	0	0
Project 24	0	0	0	0	0
Project 25	1	0	0	0	1
Project 26	0	0	0	0	0
Project 27	0	1	0	0	0
Project 28	0	0	0	0	0
Project 29	0	0	0	0	1
Project 30	1	0	0	0	0
Project 31	1	0	0	0	1
Project 32	0	0	0	0	0
Project 33	0	0	1	1	0
Project 34	0	0	1	0	0
Project 35	0	0	1	0	0

Appendix 6. Assessing Uncertainty About Management Actions

Table 6.1. Results from Google scholar search in June 2015 to determine the uncertainty of management actions and scoring performance metric 3, Uncertainty Reduction (from Monitoring Management Actions), by National Oceanic and Atmospheric Administration Coastal Change Analysis Program, or C-CAP, land-cover classes (Dobson and others, 1995). Uncertainty Scores (low, medium, and high) are based on performance metric 3. Dash indicates no data.

Management action	Habitat (C-CAP classes)	Number of hits	Number of citations for top five (relevant) hits	Uncertainty score
Artificial nest/nestbox/nest platform construction	Beach/dune	879	37	High
Artificial nest/nestbox/nest platform construction	Cultivated crops	4,230	117	Medium
Artificial nest/nestbox/nest platform construction	Estuarine emergent wetland	456	28	High
Artificial nest/nestbox/nest platform construction	Estuarine forested wetland	730	54	High
Artificial nest/nestbox/nest platform construction	Grassland/herbaceous	378	23	High
Artificial nest/nestbox/nest platform construction	Open water	6,370	100	Medium
Artificial nest/nestbox/nest platform construction	Palustrine emergent wetland	57	6	High
Artificial nest/nestbox/nest platform construction	Palustrine forested wetland	66	0	High
Artificial nest/nestbox/nest platform construction	Pasture/hay	719	0	High
Barrier island creation	Beach/dune	5,790	185	High
Disease/pathogen/parasite management	Beach/dune	508	46	High
Disease/pathogen/parasite management	Cultivated crops	4,910	2,287	High
Disease/pathogen/parasite management	Deciduous forest	1,880	724	Low
Disease/pathogen/parasite management	Estuarine emergent wetland	607	113	Medium
Disease/pathogen/parasite management	Estuarine forested wetland	959	156	Medium
Disease/pathogen/parasite management	Evergreen forest	948	182	Medium
Disease/pathogen/parasite management	Grassland/herbaceous	835	90	Medium
Disease/pathogen/parasite management	Mixed forest	5,170	492	Low
Disease/pathogen/parasite management	Open water	7,020	142	Medium
Disease/pathogen/parasite management	Palustrine emergent wetland	55	0	High
Disease/pathogen/parasite management	Palustrine forested wetland	61	0	High
Disease/pathogen/parasite management	Pasture/hay	742	41	Medium
Disease/pathogen/parasite management	Scrub/shrub	1,140	110	Medium
Dredge spoil island creation	Beach/dune	889	33	High
Ecosystem restoration	Beach/dune	3,700	468	Low
Ecosystem restoration	Deciduous forest	17,200	761	Medium
Ecosystem restoration	Estuarine emergent wetland	3,410	702	Low
Ecosystem restoration	Estuarine forested wetland	5,600	654	Low
Ecosystem restoration	Evergreen forest	3,740	445	Medium
Ecosystem restoration	Grassland	14,500	568	Medium
Ecosystem restoration	Mixed forest	17,000	357	High
Ecosystem restoration	Open water	–	–	–
Ecosystem restoration	Palustrine emergent wetland	602	299	Medium
Ecosystem restoration	Palustrine forested wetland	610	694	Medium
Ecosystem restoration	Scrub/shrub	5,900	448	High
Fisheries management	Beach/dune	4,930	817	High
Fisheries management	Estuarine emergent wetland	2,440	1,040	Medium

Table 6.1. Results from Google scholar search in June 2015 to determine the uncertainty of management actions and scoring performance metric 3, Uncertainty Reduction (from Monitoring Management Actions), by National Oceanic and Atmospheric Administration Coastal Change Analysis Program, or C-CAP, land-cover classes (Dobson and others, 1995). Uncertainty Scores (low, medium, and high) are based on performance metric 3. Dash indicates no data. —Continued

Management action	Habitat (C-CAP classes)	Number of hits	Number of citations for top five (relevant) hits	Uncertainty score
Fisheries management	Estuarine forested wetland	6,540	1,217	High
Fisheries management	Open water	5,310	1,075	Medium
Fisheries management	Palustrine emergent wetland	598	962	High
Fisheries management	Palustrine forested wetland	746	1,375	High
Harvest management for game species	Beach/dune	14,200	320	Medium
Harvest management for game species	Cultivated crops	15,100	2,070	Low
Harvest management for game species	Deciduous forest	9,080	800	Low
Harvest management for game species	Estuarine emergent wetland	15,100	424	Low
Harvest management for game species	Estuarine forested wetland	9,080	800	Low
Harvest management for game species	Evergreen forest	16,400	591	Low
Harvest management for game species	Grassland	1,310	1,846	Low
Harvest management for game species	Mixed forest	9,080	800	Low
Harvest management for game species	Open water	14,200	320	Medium
Harvest management for game species	Palustrine emergent wetland	15,100	424	Low
Harvest management for game species	Palustrine forested wetland	9,080	800	Low
Harvest management for game species	Pasture/hay	15,100	2,070	Low
Harvest management for game species	Scrub/shrub	5,200	324	Low
Integrated predator control for beach-nesting birds	Beach/dune	13,300	367	High
Integrated predator control for beach-nesting birds	Estuarine emergent wetland	13,300	367	High
Integrated predator control for beach-nesting birds	Open water	13,300	367	High
Prescribed fire	Deciduous forest	2,460	790	Medium
Prescribed fire	Estuarine emergent wetland	1,100	539	Medium
Prescribed fire	Evergreen forest	1,440	506	Medium
Prescribed fire	Grassland/herbaceous	4,420	1,064	Medium
Prescribed fire	Mixed forest	7,370	1,316	Low
Reduce disturbance to beach-nesting birds	Beach/dune	229	299	Medium
Reduce disturbance to beach-nesting birds	Estuarine emergent wetland	114	11	High
Reduce disturbance to nesting raptors	Deciduous forest	2,220	89	Medium
Reduce disturbance to nesting raptors	Evergreen forest	898	111	Medium
Reduce disturbance to nesting raptors	Palustrine forested wetland	156	0	High
Reduce disturbance to waterbirds	Beach/dune	1,130	314	Low
Reduce disturbance to waterbirds	Estuarine emergent wetland	1,210	3	High
Reduce disturbance to waterbirds	Open water	8,710	80	Medium
Reduce disturbance to waterbirds	Palustrine forested wetland	5,390	249	Low
Removal of invasive species	Beach/dune	5,380	110	High
Removal of invasive species	Deciduous forest	10,500	1,022	High
Removal of invasive species	Estuarine emergent wetland	3,510	113	High
Removal of invasive species	Estuarine forested wetland	5,650	45	High
Removal of invasive species	Evergreen forest	5,780	901	High

Table 6.1. Results from Google scholar search in June 2015 to determine the uncertainty of management actions and scoring performance metric 3, Uncertainty Reduction (from Monitoring Management Actions), by National Oceanic and Atmospheric Administration Coastal Change Analysis Program, or C-CAP, land-cover classes (Dobson and others, 1995). Uncertainty Scores (low, medium, and high) are based on performance metric 3. Dash indicates no data. —Continued

Management action	Habitat (C-CAP classes)	Number of hits	Number of citations for top five (relevant) hits	Uncertainty score
Removal of invasive species	Grassland/herbaceous	5,200	708	High
Removal of invasive species	Mixed forest	18,000	921	High
Removal of invasive species	Open water	20,200	0	High
Removal of invasive species	Palustrine emergent wetland	503	23	High
Removal of invasive species	Palustrine forested wetland	558	4	High
Removal of invasive species	Scrub/shrub	9,530	259	High
Sustainable agriculture	Cultivated crops	9,240	1,057	Low
Sustainable agriculture	Pasture/hay	8,190	2,232	Low
Sustainable aquaculture	Estuarine emergent wetland	757	23	High
Sustainable aquaculture	Estuarine forested wetland	1,410	17	High
Sustainable aquaculture	Open water	3,220	38	High
Sustainable aquaculture	Oyster reefs	762	0	High
Sustainable aquaculture	Palustrine emergent wetland	71	6	High
Sustainable aquaculture	Palustrine forested wetland	95	5	High
Sustainable forestry	Deciduous forest	13,200	1,149	Low
Sustainable forestry	Evergreen forest	14,000	623	Low
Sustainable forestry	Grassland	1,900	243	Low
Sustainable forestry	Palustrine forested wetland	3,710	243	Low
Wastewater management	Estuarine emergent wetland	1,090	25	High
Wastewater management	Estuarine forested wetland	1,850	26	High
Wastewater management	Open water	5,000	168	Low
Wastewater management	Palustrine emergent wetland	212	27	High
Wastewater management	Palustrine forested wetland	236	0	High

Supplemental Material

Available at https://doi.org/10.3133/ofr20201122

1. Birds of Conservation Concern Spreadsheet

2. Portfolio Analysis Spreadsheet (Constrained Optimization with Solver Add-in)

Microsoft Excel workbook (sdm_tool_excel_version_2019_12_22.xlsm) with instructions to use Solver add-in program to find the optimal monitoring portfolio by use of constrained optimization.

3. R Code to Simulate Monitoring Proposals

R code to simulate hypothetical monitoring proposals and scores for 27 performance metrics.

4. All Test Projects and Portfolios

Microsoft Excel workbook with test projects, portfolios, and constraint scenarios used in analysis.

5. Matrix of Management Actions and Bird Species Affected

6. R Code for Using Deepwater Horizon Project Tracker Database

R code to determine the number of occurrences in the Deepwater Horizon Project Tracker database of Gulf of Mexico Avian Monitoring Network (GoMAMN) management actions. This code is used to determine the score for performance metric 3 (uncertainty reduction from monitoring management actions).

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Or visit our website at:
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