Application of Structured Decision Making to Assess Multiple Scale Monitoring Needs for Waterbird Management

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Decision Problem

Integrated management and conservation of waterbirds comprises decisions at multiple geographic scales, including local management units, ecoregions, and flyways. While decision-makers at all three spatial scales formulate objectives and attempt to maximize success with a particular spatial scale in mind, there is growing recognition that successful conservation requires integrated objectives, management, and monitoring across scales. At the local level, wetland managers and field biologists choose management actions to best achieve objectives with respect to a particular management unit or wetland complex, but often strive to contribute to ecoregional objectives whenever possible. Depending on management context, ecoregions may be variously defined as Bird Conservation Regions (NABCI 2008), United States Fish and Wildlife Service (USFWS) Regions, planning regions outlined in national conservation plans (e.g., Brown et al. 2001), etc. A primary decision of managers at the regional scale is a spatial allocation of resources and funds among sites within the region of interest. Similarly, decision makers at the flyway scale often decide on spatial allocation of resources, but from a broader perspective and often with additional considerations related to maintaining connections between breeding and wintering areas. Our case study addresses decisions at all three spatial scales, from implementation of wetland management actions to allocation of resources within regions and across flyways. The geographic scope includes both the Atlantic and Mississippi Flyways of North America (USFWS Regions 3, 4, and 5). It is critical that management decisions at all three spatial scales are supported by targeted monitoring (Nichols and Williams 2006). Our case study describes a program for integrated management and monitoring of waterbirds by a widely distributed network of collaborators, one that presents many logistical and administrative

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challenges. Coordinated and targeted monitoring of waterbirds and wetland habitats, as well as modern data management systems, are essential to maintaining productive collaborations and improving decisions at all spatial scales.

Background

Waterbirds (**defined here as migrating and wintering waterfowl, shorebirds, and wading birds**) are the most common bird group monitored on managed wetlands (e.g., National Wildlife Refuges (NWR), state wildlife management areas, etc.). This likely results from the high proportion of NWR and state lands comprised of wetlands that have been set aside for waterbirds, extensive management actions undertaken to enhance wetland habitats, and the recreational value of many of these waterbird species.

At the local scale, federal, state and private land managers make annual decisions about how and when to implement habitat manipulations, management actions to reduce disturbance, acquisition and protection of additional lands, and other actions that may impact the quality, availability, and amount of waterbird habitats provided during migration and wintering periods. Historically, traditional management actions have been employed, with little formal evaluation of progress toward population objectives or effectiveness and efficiency of waterbird habitat delivery. More recently however, many managers have identified the need to evaluate the performance of wetland management actions relative to waterbird population objectives in an adaptive management framework (e.g., IAFWA 2004, Nichols and Williams 2006).

Within the NWR System, the majority of refuges that monitor waterbirds have independently designed their monitoring programs with little emphasis on standardization or sharing of data to complement waterbird management decisions at larger spatial scales. Additionally, many refuge monitoring efforts lack clear objectives and a framework for incorporating monitoring data into management decisions, thus decreasing the value of monitoring. More recently, a growing number of land managers have identified as a high priority the need to use monitoring data to evaluate the effectiveness of their habitat management and to contribute their monitoring information to help inform larger-scale management decisions.

The USFWS, under the authority of the Migratory Bird Treaty Act, is responsible for management of migratory bird populations. The NWR System is charged with protecting and managing NWR habitats for many migratory bird species. Likewise, states, joint ventures and several non-governmental organizations have responsibilities or missions to conserve migratory birds and their habitats. Presently, there is much coordination among state and federal agencies to manage waterfowl populations for recreational hunting. Joint ventures are attempting to coordinate the delivery of optimum habitat quantity and quality for waterbirds at multiple scales in an adaptive management framework.

Waterbird migration and wintering strategies require that sufficient high quality wetland habitats be provided to meet their needs during these periods of their annual life cycle. Joint ventures are currently coordinating efforts to determine if habitat requirements are being met to support established waterbird population objectives (Runge et al. 2006). Due to fact that the location of

NWRs and state wildlife management areas are biased towards high quality wetland habitats, these areas may contribute significantly to meeting the habitat needs of some waterbird species. However, this contribution has never been quantified. Additionally, present wetland management actions are not coordinated among management areas. Although untested, coordinating habitat manipulations and their timing across these collection of lands to match waterbird migration chronologies may result in greater efficiency in waterbird conservation.

Decision Structure

The decision structure incorporates objectives, action alternatives, and predictive models at all three spatial scales (local, regional, and flyway) important to integrated wetland management and monitoring. To create a rapid prototype of the decision structure we identified hypothetical decision makers at each spatial scale. The geographic scope and complexity of the integrated management program prohibited us from developing all aspects of all possible management decisions. It was necessary to simplify the decision structure and identify common scenarios to begin to structure the decision analysis. Our prototype decision maker for the local scale is a state or federal biologist deciding which management action to implement; for the regional scale, a USFWS Regional Refuge Chief deciding how to allocate funds among refuges in a particular region; and for the flyway scale, a joint venture coordinator deciding how to allocate resources among sites distributed across the flyway. We recognize that there are additional decision makers representing various stakeholders and agencies; additional decision makers at all geographic scales will be included in future versions of the prototype. We chose these prototype decision makers as a means to develop a working decision model in the time available. Furthermore, we chose to concentrate most of our available time on the regional funding allocation decision; the other geographic scales remain largely undeveloped in this prototype. Local and flyway level decisions will require additional effort structured in a similar manner to complete the integrated wetland management and monitoring prototype.

Alternatives

1. Local scale: Managers choose among habitat manipulations (water level manipulations, chemical treatments, mechanical treatments, burning etc.), actions to control disturbance for each management unit, and acquisition of additional lands.

2. Regional scale: Alternatives include all the possible ways that available resources may be distributed among management units in the region. One alternative is equal allocation to all refuges; another alternative is allocation proportional to refuge wetland area. Allocation of resources is a continuum from equal allocation to all resources being assigned to one management unit or refuge. Status quo management provides annual operating funds to land managers based upon criteria other than potential for efficient contribution toward waterbird populations. As such, land managers independently maximize decision-making related to habitat manipulations and timing, and independently monitor their effectiveness at providing sufficient quantity and quality of habitats for waterbirds.

3. Flyway scale: Similar to alternatives at the regional scale, alternatives include all possible ways that available resources could be distributed among management sites in the flyway.

Objectives

Our fundamental objective is to achieve viable, self-sustaining waterbird populations in the Atlantic and Mississippi Flyways. If our management actions achieve the set target value for a given species, we would then select actions that benefit those species that are below the target value. Also, some species may be perceived as more desirable or carry more importance for various reasons, so we would like to weight those actions that benefit more desirable species over less desirable species. Thus, we seek to maximize:

$\sum_{s=1}^{S} u(N_{s,t})$, subject to some budgetary constraint,

where $u(N_{s,t})$ represents the utility of species *s* as a function of its population size *N* at a given time *t*. Thus, we seek to maximize the change in total utility over time. For a first prototype, we suggest the following utility function: such that the utility for a species *s* at time *t*,

$$u(N_{s,t}) = \begin{cases} w_s & , N_s > T_s \\ w_s \dfrac{N_s}{T_s} & , \text{otherwise} \end{cases}$$

where T_s is the target population size of species *s* and w_s is the weighted value for species *s*.

Our means objectives associated with this fundamental objective include efficient and effective cross-scale management decision-making for waterbird habitat quantity and quality during migration and winter.

At the local scale, managers must estimate the current state of habitat quality relative to potential habitat quality, identify efficient and effective management treatments that maximize habitat quality, prioritize management units for treatments, evaluate the performance of management treatments, and consider the acquisition and management of additional habitat. Local scale decisions should target wetland units with the greatest potential contributions toward waterbirds objectives and strive to optimize management among the wetland units available at the local site. Basic conventional management treatments to achieve habitat quality are generally known or the information is available. However, what often is unknown are site-specific responses to management actions as influenced by managed wetland infrastructure, soil characteristics, seed banks, invasive species, hydrology, weather, evapotranspiration rates, or amount and juxtaposition of surrounding habitats (Fig. 1). Thus, monitoring information at the local scale contributes toward increased understanding of site capabilities and is also critical to integration at the regional or flyway scale.

At the regional scale, the primary decision is one of prioritizing management needs of competing species and management units, and then allocating resources to those management sites where the greatest waterbird return on investment will be realized (Fig. 2). *The objective is to maximize total bird-days for all management sites subject to regional budget constraints.* To make informed and transparent decisions for allocating funds, regional managers need to know the potential increase in waterbird habitat quality across all sites and the associated cost of treatments to maintain or achieve that habitat quality. We acknowledge that management sites differ in regard to relative contribution toward waterbird populations and habitat (quantity and quality), annual costs to maintain that contribution, and potential to efficiently improve contributions.

The information required to optimize distribution of funds (i.e. management resources) is the actual or potential increase in waterbird use given a certain amount of funds for improvement of habitat quality or habitat creation and restoration (Fig. 2). At each management site information will be needed on the cost of management, quality of habitats, and response of target species to management. This information will be used to calculate the slope of bird use to dollars expended at each management site, i.e. “management potential” (Fig. 2). Here, bird-days are used to evaluate performance of management alternatives, i.e, different allocation strategies.

At flyway scales, managers determine if there is a sufficient quantity of quality waterbird habitat at the appropriate locations and times to support the population objectives set by the respective bird initiatives (i.e., North American Waterfowl Management Plan, Waterbird Conservation for the Americas, and the United States Shorebird Conservation Plan). The only difference from the regional scale is that flyway decision makers consider any suitable habitat, not just those already owned by a partner. Once the full suite of potential habitat has been identified, a process similar to that at the regional scale (Fig. 2) can be used to allocate partner resources (existing and new) across the landscape. The outcome should optimize waterbird habitat conservation at the flyway scale. The location, quantity, and quality of habitat patches (stop-over or wintering sites) along the flyway are critical to the energetic demands of waterbirds and therefore critical information for decision-making at the regional scale. Habitat gaps or deficiencies identified at the flyway scale will influence the spatial allocation of management resources, by providing greater “weight” to allocation of resources at those locations. This interdependency will influence the regional, and thus local, allocation decisions when critical habitat is required at management sites that might not be as cost-efficient to manage or not owned by a partner.

Predictive models:

For local scale management, we developed a graphical model of managed wetland systems (Fig. 1). We described major factors influencing habitat quality and quantity in terms of management actions and additional driving factors. In future prototypes, it will be necessary to develop quantitative predictive models that represent the relationships between management actions and outcomes related to waterbirds. It may be helpful to develop competing models of how the managed wetlands respond to various management actions and of the waterbird response to changes in habitat.

For the regional scale decision about allocation of resources, we developed a predictive model for bird-days at a given site as a function of available habitat, management potential, and available funds (Fig. 2). We developed a prototype spreadsheet model for 20 hypothetical sites and used linear programming to find the optimal allocation of resources (Table 1).

Information Needs:

Monitoring information is required to inform management decisions across spatial scales. Figure 3 depicts a structured decision making framework for waterbird management and the role of monitoring to inform management decisions at the various spatial scales.

Monitoring information is required for determining:

1. Quantity and quality of available habitat at local management sites, monitoring data that can be aggregated to determine habitat availability and quality at larger scales. This information will be used to identify habitat deficits relative to flyway population goals and the location of those deficits.
2. Waterbird abundance (or other appropriate monitoring metric) and species composition of waterbirds during migration and winter periods. Achieving sustainable waterbird populations is our fundamental management objective. This information will be used to evaluate if our objectives are met and to evaluate the effectiveness and efficiency of different management treatments. Information on abundance of birds will also assist to identify unique and specific waterbird contributions of each management site; enhance public understanding of a waterbird management network; and determine the relevance of waterbird management practices at each spatial scale.
3. Spatial distribution of habitat patches within each flyway.
4. Habitat quality as a function of management treatments at the local scale. This information will inform local decisions when prioritizing locations, timing, and treatments to achieve desired quantities and quality of habitats.
5. Management treatments and cost of treatments. This information will be combined with quantity and quality of actual and potential habitat at each managed site to allow regional managers to optimize allocation of funds to achieve desired flyway population objectives.

Decision Analysis

Although our prototype of integrated wetland management and monitoring includes three geographic scales, much of our effort during the workshop focused on the regional scale decision about allocation of resources among existing sites. It was not possible to fully develop all aspects of the integrated wetland management program in the time available during the workshop. Flyway scale decisions and local management decisions will be developed in future versions of the prototype.

To date, regional decisions have not been explicitly linked to actual or potential contribution toward waterbird objectives. Rather, other criteria along with perceptions of waterbird contribution at individual management sites have been used to allocate annual budgets.

We developed a linear model that describes changes in bird-days at each site as a function of available habitat, management potential, and available funds (Fig. 2). A critical parameter of this model is management potential, which is represented by the slope of the lines in Figure 2. Management potential is the rate of increase in bird-days for a given investment of resources. We used linear programming (Solver in Microsoft Excel) to find the optimal allocation of funds among 20 hypothetical sites. The optimal allocation resulted in 30,000 more bird-days than equal allocation among all sites, a 23% increase in bird days (Table 1). The consequences of not allocating resources as a function of a site's actual and potential waterbird contribution are thus a reduction in bird-days by reducing regional management to an opportunistic process.

This model represents a first prototype; many refinements are possible and sensitivity analyses will be necessary before the prototype will be ready to inform allocation decisions. For example, it will be necessary to collect data on management expenditures and changes in bird use to parameterize this model. We anticipate that the final model might not be linear and may end up using a different technique. Finally, we note that a similar process could be used to identify optimal combinations of management actions for a wetland complex at the local scale.

Uncertainty

Natural resources management is often complicated by at least four sources of uncertainty (Williams 1997). We briefly review the ways that uncertainty may impact aspects of integrated wetland management and monitoring. The implications of each type of uncertainty, and more explicit descriptions of important sources of uncertainty, will be explored during model refinement and development of specific monitoring protocols.

Biological Uncertainty:

Biological uncertainty refers to unknown relationships among biological variables or other components of system models. The largest source of biological uncertainty in our prototype is the response of waterbirds to a given level of funding for management actions. This relationship, or "management potential" for a particular site, has not been measured as far as we are aware. It will require data on funding, management actions, and waterbird response to estimate model parameters empirically. In addition, in our graphical model of managed wetlands (Fig. 1), there is uncertainty about the impact of surrounding landscape on waterbird abundance at a management site. Additional biological uncertainties may be identified within the definition of waterbird habitat and habitat quality.

Partial Management Control:

This uncertainty revolves around the situation where we believe a management action can be conducted yet circumstances beyond our control result in the inability to perform a specified action as planned. Clearly it is not always possible to execute management actions exactly as prescribed for a variety of reasons beyond the control of managers. Wetland managers, for example, may not be able to execute a prescribed drawdown if water control structures fail. Regional managers experience partial management control if funds are not used by local managers in a way that produces maximum benefits for waterbirds.

Partial Observability:

This uncertainty arises because the system being managed is viewed or measured indirectly. At the regional and flyway scale, errors in estimating the distribution, availability, quantity, and quality of habitats will occur. Especially since all sites used by migrating and wintering waterbirds will not be monitored. If we choose to define our sampling frame as all available sites, then our monitoring program represents a sampling scheme, i.e., an indirect measurement of the system. Imperfect detection of waterbirds is another form of partial observability.

Environmental Stochasticity:

Unforeseen environmental variation will impact both habitat manipulations at the local scale, as well as population distribution at larger landscape scales. Planned management treatments will be impacted by unpredicted weather effects (i.e., floods, droughts and abnormal temperature regimes) at the local scale. Major weather events during a season may re-distribute waterbirds across the larger landscape, thereby confounding predicted results of management actions. Another level of uncertainty will be the influence of global climate change on the re-distribution of waterbirds during migration and winter.

Discussion

Value of decision structuring:

The team felt that the Structured Decision Making (SDM) process was an excellent method to deconstruct the problem to its basic elements and critically discuss each item (Hammond et al. 1999). The team's initial problem was to develop a defensible waterbird monitoring program at the three spatial scales of local management site, regional and flyway. However, after initial discussions about the objective it became clear that the problem entailed a need to develop sound management of waterbird populations and habitats in a framework of cross-scale integration and to ensure clear links between management and the monitoring program. By having these discussions, the team was able to focus on the fundamental objective of viable, self-sustaining waterbird populations and identify the various factors that impact achievement of the objective. Through discussion of these factors, we were able to identify key monitoring needs required to inform management decision-making. Thus, we were able to explicitly link monitoring to management objectives and actions (Nichols and Williams 2006, Lyons et al. 2008).

The team felt that the discussions and product developed during the week allowed us to view waterbird monitoring from a holistic perspective versus the current paradigm of focusing on each site independently. The workshop format and diverse participants allowed us to develop a transparent decision structure for waterbird management. This process will hopefully foster "buy-in" by other partner agencies, and encourage criticism and suggested improvements to create a network of partners working together to improve our waterbird management.

The team felt that selection of participants to address the case study was critical. Our team was comprised of individuals from non-governmental organizations working toward continental scale conservation and from several administrative levels of the USFWS, from biologists working at the local level to regional managers making broad budgetary decisions. The varied responsibilities and backgrounds of our team were extremely valuable to facilitating a holistic discussion about waterbird management.

Further development required

Our team recognized that the product from this SDM workshop was only a small initial step toward the development of a much larger waterbird management and monitoring program that will be comprised of a large number of partners. To this end, extensive input and communication with the numerous partners and stakeholders must be initiated. Following are necessary additional actions to further develop this program:

1. The prototype management model and identified monitoring needs must be critically reviewed by others. Ideally, additional meetings within each of the flyways with multiple stakeholders representing multiple-scale decision-makers must be conducted. The prototype should be critically discussed and refined at these meetings to incorporate the knowledge and perspectives of additional land managers.
2. Create a coordination team assigned the responsibility for continued development of this proposed waterbird management program.
3. Given refinements of the prototype resulting from the above mentioned meetings (1), we envision the creation of additional expert teams to address protocols to measure the following:
    a. Waterbird abundance within a variety of habitat types that will allow comparison of waterbird numbers from one site to another and aggregation to larger scales.
    b. Waterbird energetics and distribution of habitat along a flyway during migration and winter periods. A product is required to identify the appropriate amounts and distribution of habitats in each flyway, to assist in prioritizing expenditure of funds at critical locations to meet waterbird migration and wintering needs.
    c. Quantity and quality of waterbird habitats. A quick and reliable process to measure habitats and response to management treatments is necessary. This effort should also include models to predict increases in habitat quantity and quality given proposed management treatments.
    d. Timing of waterbird management treatments and cost of treatments. Recording timing, type, and cost of treatments is critical to identify waterbird response to management and to optimize allocation of funds to management sites.
4. As each of the above monitoring products is developed, additional meetings will be required with numerous stakeholders and partners to obtain input into the protocols, and ensure that appropriate management information needs are met at each spatial scale.
5. Development of a centralized, web-based data management system to efficiently store and facilitate analysis and sharing of data to support cross-scale management decisions.
6. Assign responsibilities for analysis and reporting of information at the regional and flyway-wide scale. Presently, individuals at local management sites are responsible for using local information for management decisions. At larger spatial scales, the joint ventures assume this responsibility. These individuals must work with larger landscape

decision-makers to identify the format and due dates of annual reports to annually inform the waterbird decision process.

7. To adequately prioritize allocation of funding resources to local management, it will be necessary to assign priorities (i.e., weights) to individual waterbird species or guilds of species. Thus, we recommend that ecoregional (e.g. Bird Conservation Region plans) and flyway-wide strategic resource plans be used to determine weighted ranks for waterbird species. Ranks must be developed within and across traditional groups of waterbird species (waterfowl, shorebirds, and wading birds).
8. Higher level managers must secure implementation funds to both complete the development of this waterbird management and monitoring process and operationally implement the process once it is complete.

Prototyping process

The team felt that the prototyping process was an excellent means to discuss, analyze, and make progress on our task. The sequence of steps within the SDM process led to more focused discussions as subsequent steps logically followed previously made decisions. At several times during the workshop the team became ‘bogged-down’ in discussions that were more detailed than necessary for our task. During these occasions team members or coaches recognized this and re-focused discussions to the appropriate level of detail.

The team felt that the development of influence diagrams was very helpful for us to focus on important issues and identify the various steps within the process. Additionally, given the varying spatial scales of waterbird management we are attempting to address, we found it very useful to break into smaller sub-groups to address different information needs at the different spatial scales.

Selection of team participants is critical to workshop success. Our team consisted of local site managers and higher level decision makers. This brought varied perspectives into our discussions which were extremely valuable to our process. The team felt that having higher level decision makers on the team greatly enhanced the probability of successfully implementing results of the SDM process.

The SDM process was fairly new to members of the team, with our background mostly comprised of pre-workshop readings. We felt that these readings were valuable to prepare us for the workshop (Starfield 1997, Hammond et. al. 1999, Nicolson et al. 2002). Moreover, we felt that the coaches, consultants, and observers who assisted the team were invaluable to the process. Special thanks to B. Wintle for assistance with the formulation and optimization of the allocation model. Without these individuals assisting us through the process, we would have experienced greater difficulty identifying and focusing on the factors that influence this complex, multi-scale problem.

Recommendations

(See *Further development required* for recommendations specific to our team’s task.)

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Tables

Table 1. Optimal allocation of resources among sites to maximize bird-days. In this example, optimal allocation is based on management potential and two constraints specifying that each site receive between 1 and 20% of the budget. The hypothetical budget is set at $50,000.00. The funding is distributed to maximize bird-days. The optimal allocation of funds achieves 30,000 more bird days than the equal allocation of resources among all sites. The constraints included here are for demonstration purposes only and are not necessary to determine optimal allocation.

Sites	Bird-days	alpha	Available Habitat	Management Potential (Δ)	Dollars
1	23945	5	289	3	$7,500
2	1045	5	9	2	$500
3	22920	5	84	3	$7,500
4	19042	5	149	3	$6,099
5	2135	5	227	2	$500
6	11368	5	225	3	$3,414
7	1305	5	161	1	$500
8	11558	5	263	3	$3,414
9	830	5	66	1	$500
10	1325	5	165	1	$500
11	1940	5	188	2	$500
12	11383	5	228	3	$3,414
13	10418	5	35	3	$3,414
14	11428	5	237	3	$3,414
15	2340	5	268	2	$500
16	1155	5	31	2	$500
17	1350	5	170	1	$500
18	11363	5	224	3	$3,414
19	10598	5	71	3	$3,414
20	705	5	41	1	$500
Optimal allocation	**158155**				**$50,000**
Equal allocation	**128155**				

Figures

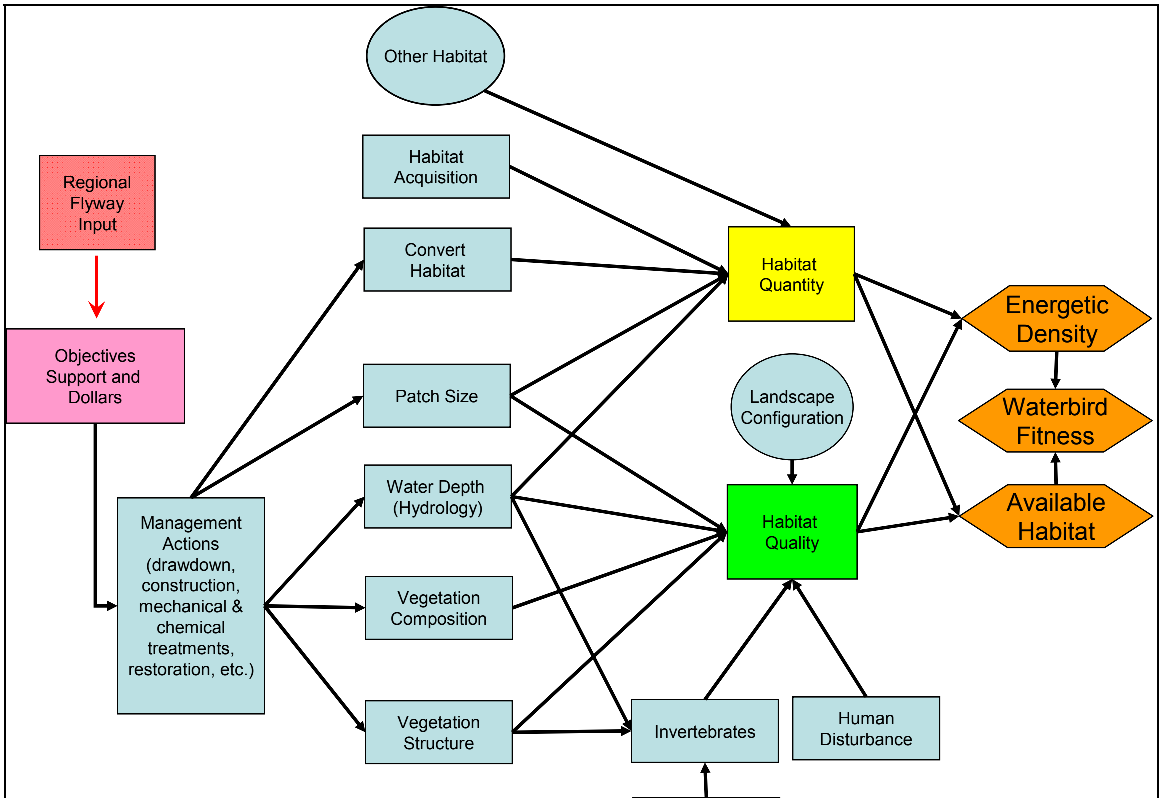

Figure 1. Influence Diagram for Local Scale Management Actions

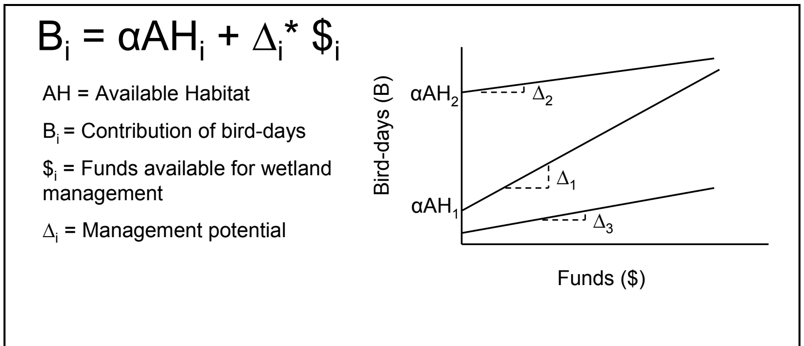

Figure 2. Potential Contribution to Population Sustainability at Each Management Site

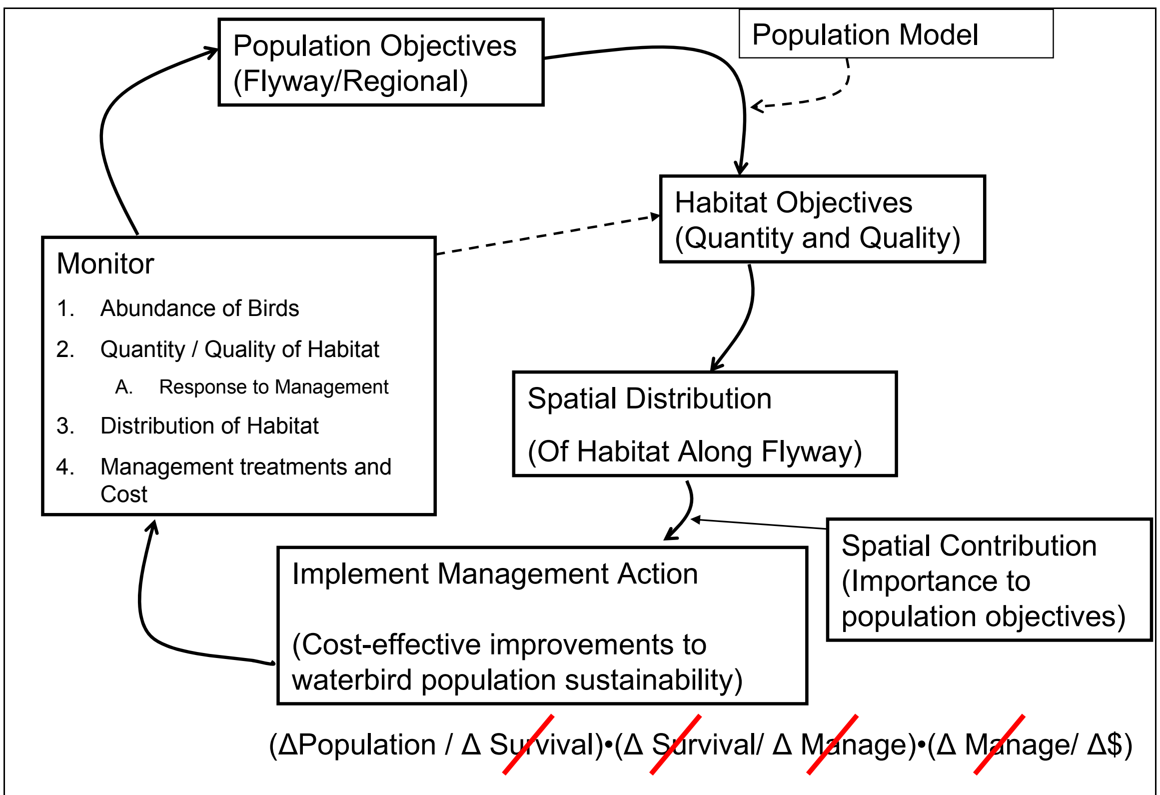

Figure 3. Structured Decision Making Framework for Management of Wetland Birds