Prepared in cooperation with the U.S. Fish and Wildlife Service

Optimization of Salt Marsh Management at the Long Island National Wildlife Refuge Complex, New York, Through Use of Structured Decision Making

Open-File Report 2021–1070
Version 1.1, August 2021

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

Cover. Photograph of salt marsh habitat at Wertheim National Wildlife Refuge, Brookhaven, New York; photograph by U.S. Fish and Wildlife Service.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

FWS	U.S. Fish and Wildlife Service
NWR	national wildlife refuge
NWRS	National Wildlife Refuge System
ppt	parts per thousand
USGS	U.S. Geological Survey

Optimization of Salt Marsh Management at the Long Island National Wildlife Refuge Complex, New York, Through Use of Structured Decision Making

By Hilary A. Neckles,[1] James E. Lyons,[1] Jessica L. Nagel,[1] Susan C. Adamowicz,[2] Toni Mikula,[2] and Monica R. Williams[2]

Abstract

Structured decision making is a systematic, transparent process for improving the quality of complex decisions by identifying measurable management objectives and feasible management actions; predicting the potential consequences of management actions relative to the stated objectives; and selecting a course of action that maximizes the total benefit achieved and balances tradeoffs among objectives. The U.S. Geological Survey, in cooperation with the U.S. Fish and Wildlife Service, applied an existing, regional framework for structured decision making to develop a prototype tool for optimizing tidal marsh management decisions at the Long Island National Wildlife Refuge Complex in New York. Refuge biologists, refuge managers, and research scientists identified multiple potential management actions to improve the ecological integrity of five marsh management units within the refuge complex and estimated the outcomes of each action in terms of performance metrics associated with each management objective. Value functions previously developed at the regional level were used to transform metric scores to a common utility scale, and utilities were summed to produce a single score representing the total management benefit that could be accrued from each potential management action. Constrained optimization was used to identify the set of management actions, one per marsh management unit, that could maximize total management benefits at different cost constraints at the refuge-complex scale. Results indicated that, for the objectives and actions considered here, total management benefits may increase consistently up to about $24,000, but that further expenditures may yield diminishing return on investment. Potential management actions in optimal portfolios at total costs less than $24,000 consistently included approaches for increasing drainage from the marsh surface within the marsh management units. The potential management benefits were derived from expected improvements in surface-water drainage and capacity for marsh elevation to keep pace with sea-level rise, and presumed increases in numbers of spiders (as an indicator of trophic health) and tidal marsh obligate birds. The prototype presented here does not resolve management decisions; rather, it provides a framework for decision making at the Long Island National Wildlife Refuge Complex that can be updated as new data and information become available. Insights from this process may also be useful to inform future habitat management planning at the refuges.

Introduction

The National Wildlife Refuge System (NWRS) protects extensive salt marsh acreage in the northeastern United States. Much of this habitat has been degraded by a succession of human activities since the time of European settlement (Gedan and others, 2009), and accelerated rates of sea-level rise exacerbate these effects (Gedan and others, 2011; Kirwan and Megonigal, 2013). Therefore, strategies to restore and enhance the ecological integrity of national wildlife refuge (NWR) salt marshes are regularly considered. Management may include such activities as reestablishing natural hydrology, augmenting or excavating sediments to restore marsh elevation, controlling invasive species, planting native vegetation, minimizing shoreline erosion, and remediating contaminant problems. Uncertainty stemming from incomplete knowledge of system status and imperfect understanding of ecosystem dynamics commonly hinders management predictions and consequent selection of the most effective management options. Consequently, tools for identifying appropriate assessment variables and evaluating tradeoffs among management objectives are valuable to inform marsh management decisions.

Structured decision making is a systematic approach to improving the quality of complex decisions that integrates assessment metrics into the decision process (Gregory and Keeney, 2002). This approach involves identifying measurable management objectives and potential management actions, predicting management outcomes, and evaluating tradeoffs to choose a preferred alternative. From 2008 to 2012, the

[1]U.S. Geological Survey.

[2]U.S. Fish and Wildlife Service.

U.S. Geological Survey (USGS) and U.S. Fish and Wildlife Service (FWS) used structured decision making to develop a framework for optimizing management decisions for NWR salt marshes in the FWS Northeast Region (that is, salt marshes in the coastal region from Maine through Virginia). The structured decision-making steps were applied through successive "rapid prototyping" workshops, an iterative process in which relatively short periods of time are invested to continually improve the decision structure (Blomquist and others, 2010; Garrard and others, 2017). The decision framework includes regional management objectives addressing critical components of salt marsh ecosystems, and associated performance metrics for determining whether objectives are achieved (Neckles and others, 2015). The regional objectives structure served as the foundation for a consistent protocol for monitoring salt marsh integrity at these northeastern coastal refuges, in which the monitoring variables are linked explicitly to management goals (Neckles and others, 2013). From 2012 to 2016, this protocol was used to conduct a baseline assessment of salt marsh integrity at all 17 refuges or refuge complexes in the FWS Northeast Region with salt marsh habitat (fig. 1).

The Long Island National Wildlife Refuge Complex consists of 10 parcels on Long Island, New York. Three of the parcels (Lido Beach Wildlife Management Area, Seatuck National Wildlife Refuge, and Wertheim National Wildlife Refuge) collectively protect about 193 hectares of salt marsh along the south shore of Long Island (fig. 2). These marsh areas provide critical nesting and wintering habitat for bird species of highest conservation priority, including

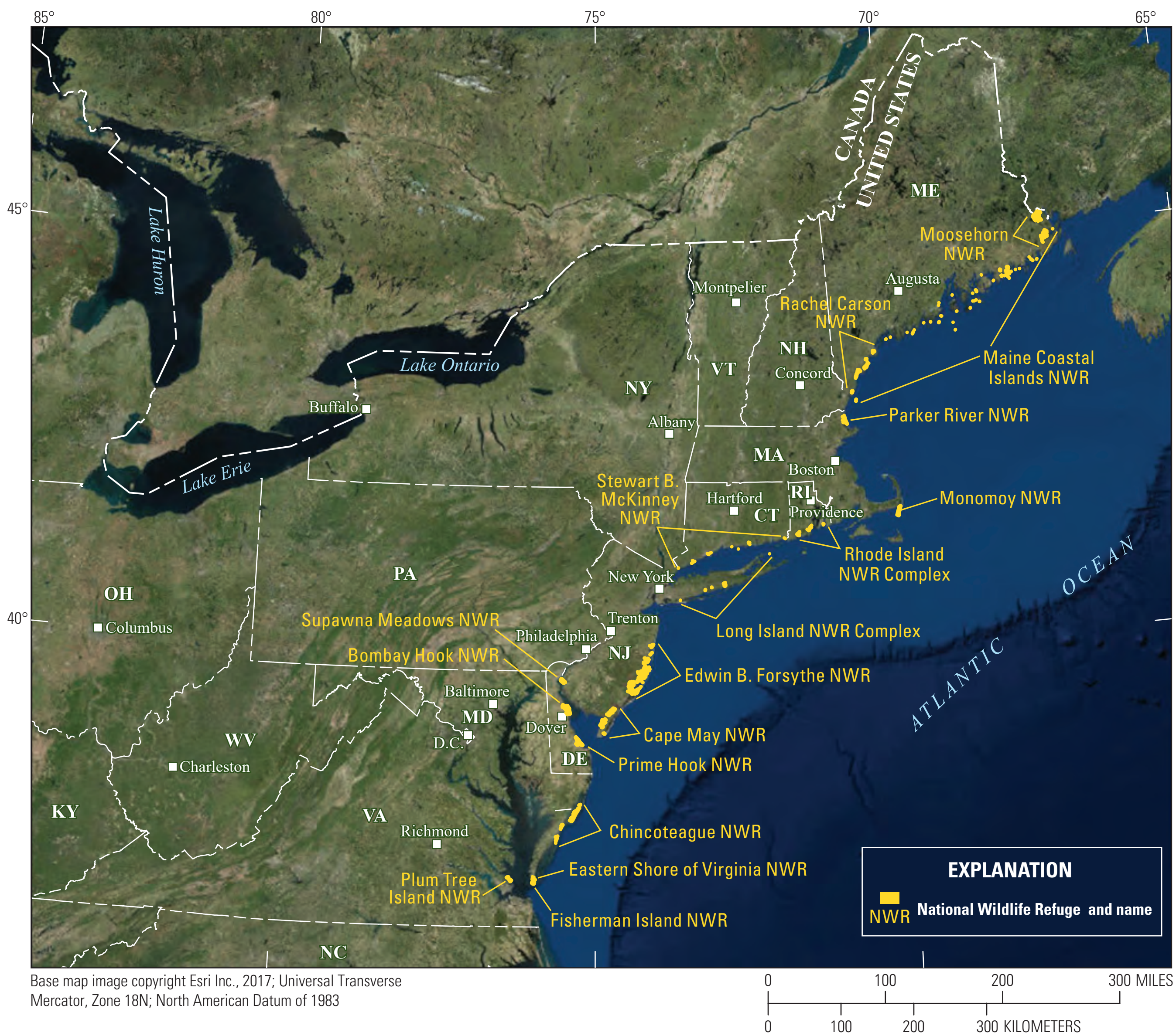

Figure 1. Map showing national wildlife refuges and national wildlife refuge complexes of the U.S. Fish and Wildlife Service where salt marsh integrity was assessed from 2012 to 2016 using the regional monitoring protocol.

Ammodramus caudacutus (saltmarsh sparrow), *Branta bernicla* (Atlantic brant), and *Anas rubripes* (American black duck), in the New England and mid-Atlantic coast bird conservation region of the U.S. North American Bird Conservation Initiative (FWS, 2006; Steinkamp, 2008; U.S. North American Bird Conservation Initiative, 2020). The salt marsh also provides important foraging habitat for wading bird species, such as *Ardea alba* (great egret), *Egretta thula* (snowy egret), *Ardea herodias* (great blue heron), and *Plegadis falcinellus* (glossy ibis), during breeding and migratory seasons (FWS, 2006; National Audubon Society, 2020). The primary concerns for salt-marsh integrity at this refuge complex are marsh degradation associated with historic hydrologic alterations, spread of the invasive reed *Phragmites australis* (hereafter referred to as *Phragmites*), and marsh submergence associated with rising sea level (FWS, 2006; Rochlin and others, 2012; New York State Energy Research and Development Authority, 2017). Salt-marsh management goals set by the FWS for the refuge complex focus on maintaining, restoring, and enhancing high quality habitat for breeding, migrating, and wintering birds. In this study, the regional structured decision-making framework was used to help prioritize management options within the three specified parcels at the refuge complex.

Purpose and Scope

This report describes the application of the regional structured decision-making framework (Neckles and others, 2015) to the Long Island National Wildlife Refuge Complex. The regional framework was parameterized to local conditions through rapid prototyping, producing a decision model for the refuge complex that can be updated as new information becomes available. Included are a suite of potential management actions to achieve objectives in five marsh management units at the refuge complex (fig. 2), approximate costs for implementing each potential action, predictions for the outcome of each management action relative to individual management objectives, and results of constrained optimization to maximize management benefits subject to cost constraints. This decision structure can be used to understand how specific actions may contribute to achieving management objectives and identify an optimum combination of actions, or “management portfolio,” to maximize management benefits at the refuge scale for a range of potential budgets. The prototype presented here provides a framework for continually improving the quality of complex management decisions at the Long Island National Wildlife Refuge Complex.

Description of Study Area

The Long Island National Wildlife Refuge Complex comprises 10 separate parcels across Long Island, New York. Three of the parcels, the Lido Beach Wildlife Management Area in Lido Beach, Seatuck National Wildlife Refuge in Islip, and Wertheim National Wildlife Refuge in Brookhaven, protect oases of salt marsh habitat along this highly developed shoreline. The salt marsh habitat within these three parcels is divided into one marsh management unit at the Lido Beach Wildlife Management Area (fig. 2*A*); one marsh management unit at the Seatuck National Wildlife Refuge (fig. 2*B*); and three marsh management units at the Wertheim National Wildlife Refuge (Western Unit, Eastern Unit, and Northern Unit; fig. 2*C*). Most of the land within 1 kilometer of the marsh management units at Lido Beach Wildlife Management Area and Seatuck National Wildlife Refuge consists of residential and commercial development, whereas most of the land within 1 kilometer of the units at Wertheim National Wildlife Refuge is categorized under natural land uses (land classified by the 2011 National Land Cover Database as categories other than agricultural or developed; Multi-Resolution Land Characteristics Consortium, 2020). All marsh management units contain extensive grid ditching from historic mosquito-control measures. Invasive plants occur in all marsh management units, and reducing the extent of *Phragmites* is a management goal for the complex (FWS, 2006). Average summer surface-water salinities in the marsh management units were about 28 parts per thousand (ppt) at the Lido Beach Wildlife Management Area (measured in 2014), 27 ppt at the Seatuck National Wildlife Refuge (measured in 2013), and 11–14 ppt at the Wertheim National Wildlife Refuge (FWS, 2016). Given these salinities, the surface water in the marsh management units is classified as mesohaline (5–18 ppt) at Wertheim National Wildlife Refuge and polyhaline (18–30 ppt) at Seatuck National Wildlife Refuge and Lido Beach Wildlife Management Area (as defined by Cowardin and others, 1979).

Figure 2. Map showing salt marsh management units within three parcels at the Long Island National Wildlife Complex in New York. *A*, Lido Beach Wildlife Management Area in Lido Beach, New York; *B*, Seatuck National Wildlife Refuge in Islip, New York; and *C*, Wertheim National Wildlife Refuge in Brookhaven, New York. U.S. Fish and Wildlife Service managed areas shown for reference.

Figure 2.—Continued

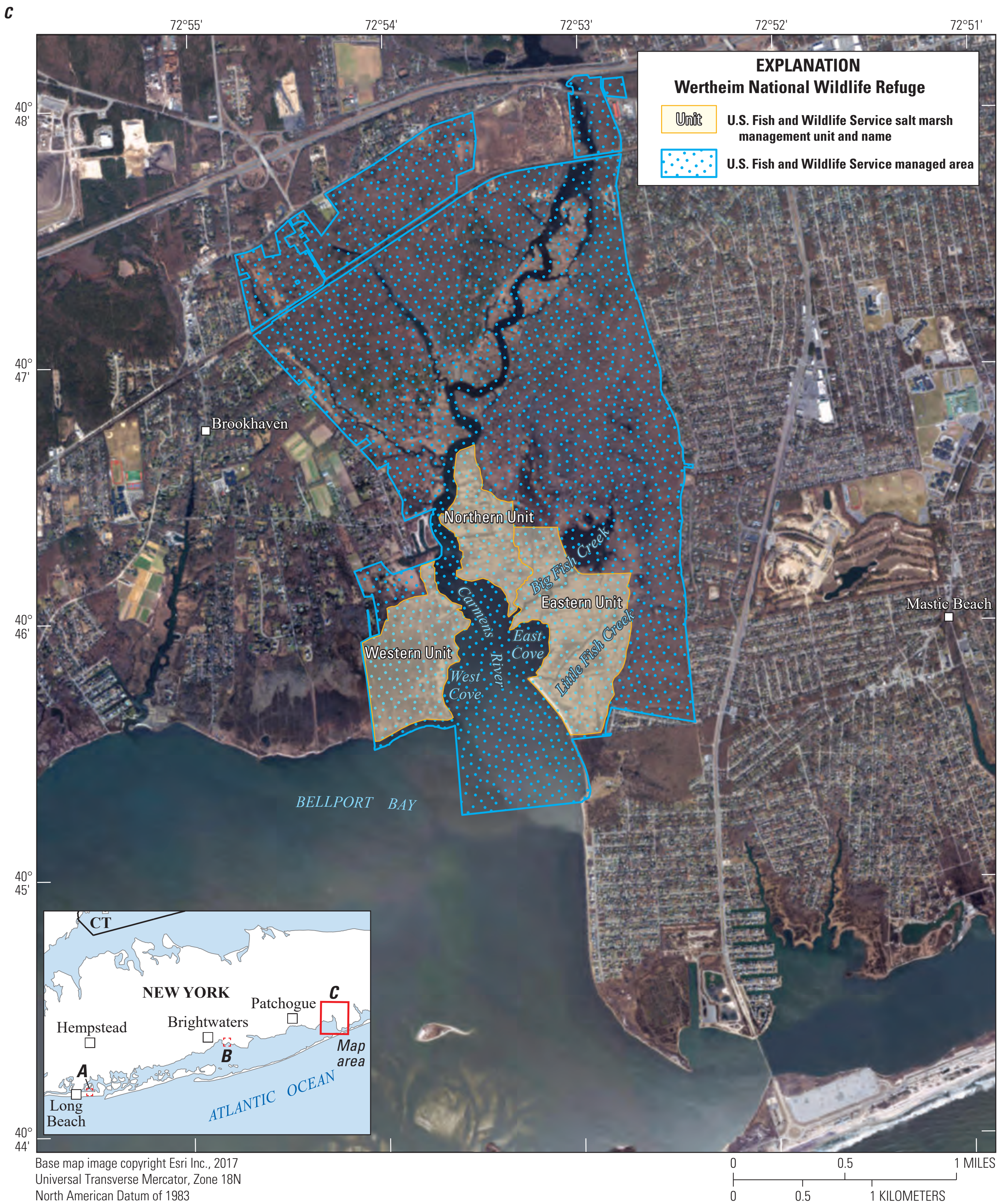

Figure 2.—Continued

Regional Structured Decision-Making Framework

A regional framework for assessing and managing salt marsh integrity at northeastern NWRs was developed through collaborative efforts of FWS regional and refuge managers and biologists, salt marsh research scientists, and structured decision-making experts. This process followed the discrete steps outlined by Hammond and others (1999) and Gregory and Keeney (2002):

- 1. Clarify the temporal and spatial scope of the management decision.
- 2. Define objectives and performance measures to evaluate whether objectives are achieved.
- 3. Develop alternative management actions for achieving objectives.
- 4. Estimate the consequences or likely outcomes of management actions in terms of the performance measures.
- 5. Evaluate the tradeoffs inherent in potential alternatives and select the optimum alternatives to maximize management benefits.

This sequence of steps was applied through successive workshops to refine the decision structure and incorporate newly available information. Initial development of the structured decision-making framework occurred during a weeklong workshop in 2008 to define the decision problem, specify management objectives, and explore potential strategies available to restore and enhance salt marsh integrity. During 2008 and 2009, workshop results were used to guide field tests of salt marsh monitoring variables (Neckles and others, 2013). Subsequently, in 2012, data and insights gained from these field tests were used in a two-part workshop to refine management objectives and develop the means for evaluating management outcomes (Neckles and others, 2015).

From the outset, FWS goals included development of an approach for consistent assessment of salt marsh integrity across all northeastern NWRs (fig. 1). Within this regional context, staff at a given refuge must periodically determine the best approaches for managing salt marshes to maximize habitat value while considering financial and other constraints. The salt marsh decision problem was thus defined as applying to individual NWRs over a 5-year planning horizon. The objectives for complex decisions can be organized into a hierarchy to help clarify what is most important to decision makers (Gregory and others, 2012). The hierarchy of objectives for salt marsh management decisions (table 1) was based explicitly on the conservation mission of the NWRS, which is upheld through FWS management to "ensure that the biological integrity, diversity, and environmental health of the System are maintained for the benefit of present and future generations of Americans," as mandated in the National Wildlife Refuge System Improvement Act of 1997 (16 U.S.C. §668dd note). Two fundamental objectives, or the overall goals for salt marsh management decisions, were drawn from this policy to maximize (1) biological integrity and diversity, and (2) environmental health, of salt marsh ecosystems. Participants in the prototyping workshops deconstructed these overall goals further into lower level objectives relating to salt marsh structure and function and identified performance metrics to evaluate whether objectives are achieved (table 1). In addition, performance metrics were weighted to reflect the relative importance of each objective (Neckles and others, 2015).

The hierarchy of objectives for salt marsh management (table 1) provides the foundation for identifying possible management actions at individual NWRs and predicting management outcomes. Workshop participants developed preliminary influence diagrams (app. 1), or conceptual models relating management actions to responses by each performance metric (Conroy and Peterson, 2013), to guide this process. To allow metric responses to be aggregated into a single, overall performance score, participants also defined value functions relating salt marsh integrity metric scores to perceived management benefit on a common, unitless "utility" scale (Keeney and Raiffa, 1993). Stakeholder elicitation was used to determine the form of each value function relating the original metric scale to the utility scale, ranging from 0, representing the lowest management benefit, to 1, representing the highest benefit (app. 2). Neckles and others (2015) provided details regarding development of the structured decision-making framework and a case-study application to Prime Hook National Wildlife Refuge in Delaware.

Table 1. Objectives hierarchy for salt marsh management decision problems.

[Two fundamental objectives (overall goals of the decision problem) draw directly from U.S. Fish and Wildlife Service (FWS) National Wildlife Refuge System policy to maintain, restore, and enhance biological integrity, diversity, and environmental health within the refuge complex. These are broken down into lower level objectives focused on specific aspects of marsh structure and function. Values in parentheses are weights assigned to objectives, reflecting their relative importance. Weights on any branch of the hierarchy (that is, objectives that are at the same level of the hierarchy under a fundamental objective) sum to one. The weight for each metric is the product of the weights from each level of the hierarchy leading to that metric. See also Neckles and others (2015). NA, not applicable]

FWS Objectives	Performance metrics	Unit of measurement
	Maximize biological integrity and diversity[1] (0.5)	
Maximize cover of native vegetation (0.24)	Cover of native vegetation	Percent
Maximize abundance and diversity of native nekton (0.18):	NA	NA
Maximize nekton abundance (0.50)	Native nekton density	Number per square meter
Maximize nekton diversity (0.50)	Native nekton species richness	Number of native species
Maintain sustainable populations of obligate salt marsh breeding birds (0.20)	Abundance of four species of tidal marsh obligate birds (clapper rail, willet, saltmarsh sparrow, seaside sparrow)	Number per marsh management unit from call-broadcast surveys, summed across all sampling points in unit
Maximize use by nonbreeding wetland birds (0.20)	Abundance of American black duck as indicator species	Relative abundance for refuge during wintering waterfowl season (low, medium, high)[2]
Maintain trophic structure (0.18)	Density of spiders as indicator taxon	Number per square meter
	Maximize environmental health[1] (0.5)	
Maintain natural hydrology (0.44):	NA	NA
Maintain natural flooding regime (0.50)	Percent of time marsh surface is flooded relative to ideal reference system	Absolute deviation from reference in percentage points
Maintain natural salinity (0.50)	Surface-water salinity relative to ideal reference system	Absolute deviation from reference in parts per thousand
Maintain the extent of the marsh platform (0.44)	Change in marsh surface elevation relative to sea-level rise	0=change in elevation is less than amount of sea-level rise; 1=change in elevation greater than or equal to amount of sea-level rise
Minimize use of herbicides (0.12)	Rate of application	Pints

[1]Fundamental objectives of salt marsh management decisions.

[2]Relative abundance based on local knowledge.

Application to the Long Island National Wildlife Refuge Complex

In February 2018, FWS regional biologists, biologists and managers from four northeastern NWR administrative units and USGS research scientists (table 2) participated in a 1.5-day rapid-prototyping workshop to apply the regional structured decision-making framework to the Eastern Shore of Virginia, Fisherman Island, and Plum Tree Island National Wildlife Refuges and the Long Island National Wildlife Refuge Complex. Participants worked within refuge-specific small groups to focus on management issues at individual refuges. Plenary discussions of common patterns of salt marsh degradation, potential management strategies, and mechanisms of ecosystem response offered additional insights to enhance refuge-specific discussions.

Participants identified a range of possible management actions for achieving objectives within each marsh management unit at the Long Island National Wildlife Refuge Complex and estimated the total cost of implementation over a 5-year period; the specific years of implementation were not identified in this prototype. Potential actions to enhance salt marsh integrity included restoring natural marsh hydrology, enhancing avian breeding success, controlling invasive plants, or altering marsh elevation (table 3, in back of report). Participants predicted the outcomes of each management action 5 years after initial implementation in terms of salt marsh integrity performance metrics. For most metrics, baseline conditions within each unit measured during the 2012–14 salt marsh integrity assessment (FWS, 2016) were used to predict the outcomes of a “no-action” alternative. Baseline conditions were estimated by using expert judgement for three metrics that lacked assessment data (abundance of American black ducks, density of spiders, and change in marsh surface elevation relative to sea-level rise). Regional influence diagrams relating management strategies to outcomes aided in predicting consequences of management actions (app. 1). Although the influence diagrams incorporated the potential effects of stochastic processes, including weather, sea-level rise, herbivory, contaminant inputs, and disease, on management outcomes, no attempt was made to quantify these sources of uncertainty during rapid prototyping. Management predictions also inherently included considerable uncertainty surrounding the complex interactions among controlling factors and salt marsh ecosystem components.

Following the workshop, the potential management benefit of each salt marsh integrity performance metric was calculated by converting salt marsh integrity metric scores (table 3, workshop output) to weighted utilities (table 4, in back of report) using regional value functions (app. 2). Weighted utilities were summed across all salt marsh integrity metrics for each action; this overall utility therefore represented the total management benefit, across all objectives, expected to accrue from a given management action (table 4). Constrained optimization (Conroy and Peterson, 2013) was used to find the management portfolio (the combination of actions, one action per marsh management unit) that maximizes the total management benefit across all units under varying cost scenarios for the entire refuge complex. Constrained optimization using integer linear programming was implemented in the Solver tool in Microsoft Excel (Kirkwood, 1997).

Budget constraints were increased in $2,500 increments up to $10,000; in $10,000 increments up to $100,000; in $50,000 increments up to $300,000; in $100,000 increments up to $1 million; and in $500,000 increments thereafter. The upper limit to potential costs was not determined in advance; rather, it reflected the total estimated costs of the proposed management actions. A cost-benefit plot of the portfolios identified through the optimization analysis was used to identify the efficient frontier for resource allocation (Keeney and Raiffa, 1993), which is the set of portfolios that are not dominated by other portfolios at similar costs (or the set of portfolios with maximum total benefit for a similar cost). The cost-benefit plot also revealed the cost above which further expenditures would yield diminishing returns on investment. To exemplify use of the decision-making framework to understand how a given portfolio could affect specific management objectives, the refuge-scale management benefits for individual performance metrics were compared between one optimal portfolio and those predicted with no management action taken.

Table 2. Participants in the workshop convened at the Eastern Shore of Virginia National Wildlife Refuge to apply a regional framework for optimizing salt marsh management decisions to three national wildlife refuge administrative units in February 2018.

[FWS, U.S. Fish and Wildlife Service; NWR, National Wildlife Refuge; USGS, U.S. Geological Survey]

Affiliation	Participant
FWS NWR specialists	
Eastern Shore of Virginia and Fisherman Island NWRs	Pam Denmon
Eastern Shore of Virginia and Fisherman Island NWRs	Robert Leffel
Long Island NWR Complex	Monica Williams
Plum Tree Island NWR	William Crouch
Plum Tree Island NWR	Lauren Cruz
FWS regional expert	
Rachel Carson NWR	Susan Adamowicz
Research scientists	
USGS Eastern Ecological Science Center	James Lyons
USGS Eastern Ecological Science Center	Hilary Neckles

Results of Constrained Optimization

Potential management actions identified to improve marsh integrity at the Long Island National Wildlife Refuge Complex included adding sediment to the marsh surface to increase elevation; enhancing marsh drainage through creating runnels or removing ditch plugs; restoring marsh morphology through filling ditches; and controlling invasive plants or predators (table 3). For costs ranging from $0 to $625,000, the estimated management benefits for individual actions across all metrics, measured as weighted utilities, ranged from 0.493 (for implementing invasive plant control in the Wertheim–Northern Unit) to 0.973 (for removing ditch plugs and cleaning ditches in the Wertheim–Western Unit), out of a maximum possible total management benefit of 1.0 (table 3, table 4). In all but one marsh management unit (Lido Beach Wildlife Management Area), the alternative with both the lowest management benefit and lowest cost was applying herbicide to control invasive plants.

Constrained optimization was applied to identify the optimal management portfolios over 5 years for a range of total costs to the refuge complex. As total cost increased from $0 (no action in any unit) to about $302,000, the total management benefit at the refuge scale increased from 2.735 to 4.609 (a 67-percent increase; table 5) out of a possible maximum of 5.0 (the maximum possible management benefit of 1.0 for any management action, summed across the five marsh management units). Graphical analysis showed a fairly consistent increase in management benefit as costs increased to $23,900 (fig. 3, portfolio 6). Portfolio 6 represented the turning point in the cost-benefit analysis; as expenditures increased beyond the cost of portfolio 6, total management benefit continued to increase but at a lower rate, yielding diminishing returns on investment. There was very little gain in management benefit for expenditures greater than about $49,000 (fig. 3, portfolio 8).

Several patterns emerged relative to the potential management actions selected by constrained optimization within the set of portfolios that yielded the greatest total management benefit per unit cost (table 5, portfolios 2 through 6). These portfolios consistently included actions that could improve drainage from the marsh surface. Portfolios up to a total cost of about $10,000 included excavating runnels at the Lido Beach Wildlife Management Area and removing ditch plugs at one or more of the Wertheim National Wildlife Refuge units. As costs increased from $10,000 to $23,900, portfolios included multiple actions within some of the marsh management units, such as removing ditch plugs and cleaning ditches at Wertheim Northern Unit (portfolio 5) or digging runnels and grading the marsh platform at Seatuck National Wildlife Refuge (portfolio 6). In contrast, some management actions were not included in any portfolio. For example, trapping mesopredators or creating nest mounds were identified to increase sparrow populations at all the marsh management units, but these actions were never selected. Similarly, the management portfolios never included actions that incorporated sediment deposition or invasive plant control.

Examination of the refuge-scale metric responses to actions included in portfolio 6, which is the turning point in the cost-benefit plot (fig. 3), revealed how implementation could affect specific management objectives. The actions included were predicted to achieve large gains in the overall management benefits derived from increased numbers of tidal marsh obligate birds, increased density of spiders (as an indicator of trophic health), reduced duration of flooding, and the capacity of marsh elevation to keep pace with sea-level rise, and modest gains in the benefits derived from changes in density and species richness of nekton (fig. 4). Ecologically, the combination of actions in portfolio 6 may result in an average 203-percent increase in tidal marsh obligate bird counts (averaged across all marsh management units), 20-percent increase in nekton density, 14-percent increase in nekton species richness, 63-percent decrease in the deviation of surface flooding from the ideal reference condition, and 80-percent increase in spider density (derived as the average difference between the predicted metric scores for the actions implemented in portfolio 6 and the "no-action" alternative; table 3). Implementation of actions in this portfolio was also predicted to improve the capacity for marsh elevation to keep pace with sea-level rise in four of the five marsh management units. The management benefits predicted for portfolios 2 through 5, at total costs up to $19,300, were derived primarily from expected improvements in surface-water drainage and capacity for marsh elevation to keep pace with sea-level rise, and presumed increases in densities of spiders and numbers of tidal marsh obligate birds (table 3, table 4).

Table 5. Actions included in various management portfolios to maximize the total management benefits subject to increasing cost constraints at the Long Island National Wildlife Refuge Complex, New York.

[Letter designations for actions refer to specific actions and are listed in table 3 and table 4. Portfolios represent the combination of potential actions, one per marsh management unit, that maximized the total management benefit across all units, subject to a refuge-wide cost constraint. The management actions constituting individual portfolios were selected using constrained optimization. The total cost represents the sum of costs estimated for each action included in the portfolio. The maximum possible total management benefit for the refuge complex is 5.0, derived as the maximum possible total management benefit of 1.0 for any management action within one management unit, summed across five units. NWR, National Wildlife Refuge; WMA, Wildlife Management Area]

Portfolio	Marsh management unit					Total cost (dollars)	Total management benefit
	Seatuck NWR	Lido Beach WMA	Wertheim Western Unit	Wertheim Eastern Unit	Wertheim Northern Unit		
1	A	A	A	A	A	0	2.753
2	A	B	A	A	D	2,375	3.294
3	A	B	A	C	D	4,875	3.603
4	A	B	D	C	D	9,875	4.005
5	H	B	D	C	M	19,300	4.129
6	E	B	D	C	D	23,900	4.263
7	H	F	D	C	D	36,800	4.308
8	E	F	D	C	D	48,900	4.474
9	E	F	D	C	M	56,400	4.506
10	E	F	I	C	M	63,150	4.509
11	E	F	O	C	M	131,400	4.534
12	F	F	I	C	M	158,725	4.563
13	F	F	O	C	M	226,975	4.588
14	F	F	O	K	M	301,975	4.609

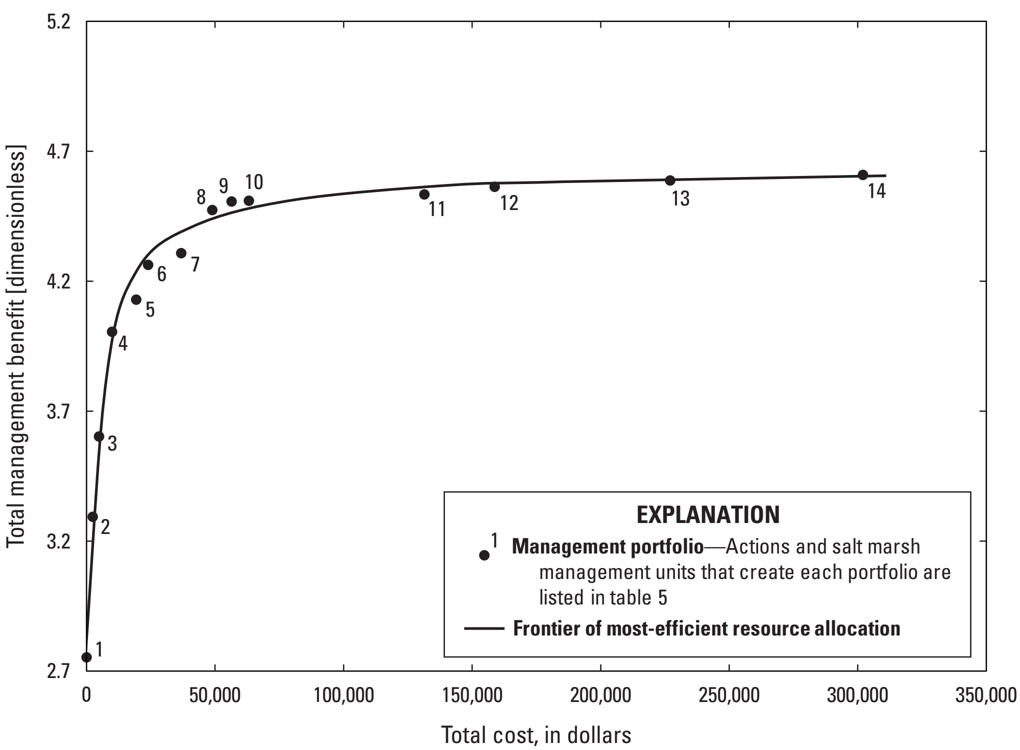

Figure 3. Graph showing predicted total management benefit of various portfolios, expressed as weighted utilities, relative to total cost at the Long Island National Wildlife Refuge Complex in New York. Each portfolio (dot with number) represents a combination of five management actions, one per marsh management unit, as identified in table 5. The line represents the efficient frontier for resource allocation.

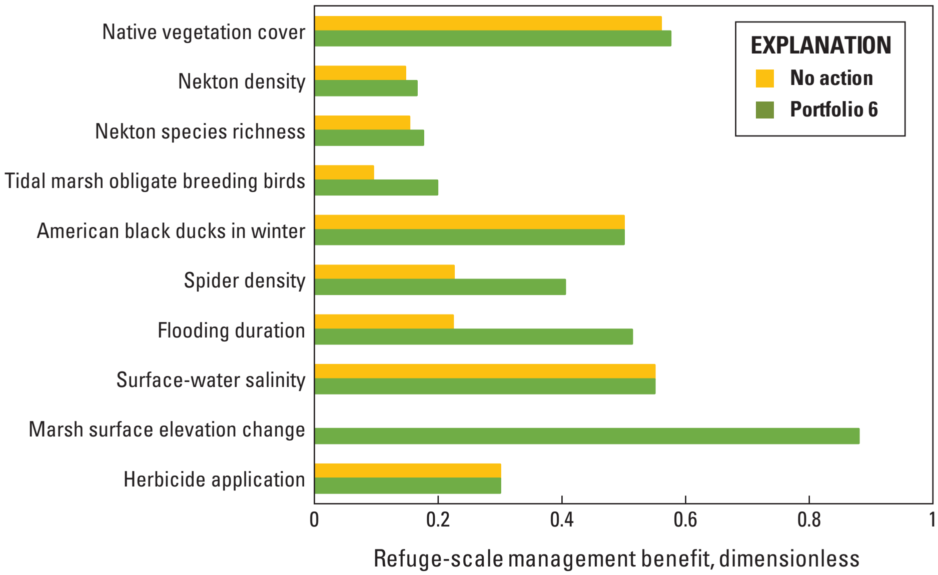

Figure 4. Predicted management benefit at the refuge scale for individual performance metrics, expressed as weighted utilities, resulting from implementation of the management actions included in portfolio 6, in comparison to the management benefit from the baseline "no-action" portfolio, at the Long Island National Wildlife Refuge Complex in New York. Baseline ("no action") predicted management benefit for marsh surface elevation change is 0. The actions included in each portfolio are listed in table 5.

Considerations for Optimizing Salt Marsh Management

A regional structured decision-making framework for salt marshes in NWRs in the northeastern United States was applied by the USGS, in cooperation with the FWS, to develop a tool for optimizing management decisions at the Long Island National Wildlife Refuge Complex. Use of the existing regional framework and a rapid-prototyping approach permitted NWR biologists and managers, FWS regional authorities, and research scientists to construct a decision model for the refuge complex within the confines of a 1.5-day workshop. This preliminary prototype provides a local framework for decision making while revealing information needs for future iterations. Insights from this process may also be useful to inform future habitat management planning at the refuge complex.

The suite of potential management actions and predicted outcomes included in this prototype (table 3) were based on current understanding of the Long Island National Wildlife Refuge Complex salt marshes and hypothesized process-response pathways (app. 1). Tidal flooding is the predominant physical control on the structure and function of salt marsh ecosystems (Pennings and Bertness, 2001), and there is widespread scientific effort to elucidate how salt marshes may respond to accelerating rates of sea-level rise and management strategies to enhance their sustainability (Kirwan and Megonigal, 2013; Roman, 2017). Management actions to improve drainage or raise the elevation of the marsh surface are increasingly proposed to reduce vulnerability of northeastern salt marshes threatened with submergence (Wigand and others, 2017). At the Long Island National Wildlife Refuge Complex, various actions were identified to remedy alterations to salt marsh hydrology associated with mosquito control. In particular, ditch plugs were installed in many northeastern marshes to increase surface water habitat for larvivorous fish (Meredith and others, 1985), but this hydrologic manipulation may promote marsh subsidence (Vincent and others, 2013). In this prototype, removing ditch plugs was expected to alleviate the extended water-logging of the marsh substrate that can lead to vegetation loss and subsidence, thereby enhancing marsh capacity to maintain elevation. The predicted high management benefit yielded by ditch plug removal led to its frequent selection within optimal management portfolios. Multiple interacting factors influence the long-term success of restoration actions in prolonging marsh integrity and improving marsh resilience (Roman, 2017). Future iterations of this decision model can incorporate improved understanding of both implementation costs and marsh responses to management actions. In addition, during construction of the regional decision model, a lack of widely available data on rates of vertical marsh growth led to the adoption of a very coarse scale of measurement for change in marsh surface elevation relative to sea-level rise (table 1). From 2008 to 2014, three surface elevation tables (Lynch and others, 2015) were installed in each marsh management unit to obtain high-resolution measurements of change in marsh surface elevation. Incorporating this information into subsequent iterations of this structured decision-making framework would likely improve predictions related to the potential for marsh surface elevation to keep pace with sea-level rise.

Results of constrained optimizations (table 5) based on the objectives, management actions, and predicted outcomes included in this prototype identified four areas in which to improve the utility of the prototype for refuge decision making. First, although reducing the extent of *Phragmites* is a management concern at the Long Island National Wildlife Refuge Complex, application of herbicides as a control measure was not selected for any optimal portfolio. The transparency of the structured decision-making framework reveals the tradeoffs associated with applying herbicide to reduce the spread of invasive plants. In most instances, controlling invasive plants was predicted to increase the percent cover of native vegetation and the abundance of tidal marsh obligate birds (table 3), and increase the management benefits associated with achieving these specific objectives (table 4). However, spraying all but small quantities of herbicides, which are a potential environmental contaminant, also had direct negative consequences on the objective to minimize herbicide use (table 4); whereas applying 35 pints of herbicide per year at the Lido Beach Wildlife Management Area was predicted to increase the total management benefit, applying the quantities of herbicide necessary to control widespread, multiple stands of invasive plants in the other marsh management units was predicted to decrease the total management benefit (table 4). Thus, the benefits associated with use of herbicide to reduce invasive plants may not offset the negative value of environmental contaminants. These results emphasize the importance that refuge managers have placed on controlling spread of *Phragmites* through various methods, including increasing porewater salinity through tidal restoration (FWS, 2006). This prototype could be adapted to allow managers to evaluate the relative expected benefits and detriments of chemical and other control methods.

Second, controlling predators (Roberts and others, 2017, 2019) and constructing islands as nesting habitat (Benvenuti, 2016) have been proposed for increasing reproductive success of saltmarsh sparrows, but the efficacy of these management actions is unknown. The lack of information to predict management benefits may have contributed to the exclusion of these management actions from optimal portfolios, suggesting that these and other methods to improve nest success might warrant investigation. Future iterations of the decision model might consider additional actions targeting saltmarsh sparrows. For example, recent studies identified acquisition of adjacent parcels for inland marsh-migration (Wiest and others, 2014) and removal of trees or other tall structures near marsh edges to enhance openness (Marshall and others, 2020) as potential approaches for limiting declines of saltmarsh sparrow populations.

Third, partially filling mosquito ditches with plant fiber has shown short-term promise in promoting ditch “self healing” through natural sedimentation and revegetation, but the long-term success of this technique for restoring marsh elevations requires further investigation (Burdick and others, 2020). Although such ditch remediation was identified as a possible mechanism to achieve salt marsh management goals at Wertheim National Wildlife Refuge (table 3), this action was never included in an optimal portfolio. Long-term monitoring of marsh recovery trajectories following experimental ditch remediation will allow refinement of the decision model for Long Island National Wildlife Refuge Complex.

Finally, the constrained optimizations analyzed in this report were based on approximations of management costs. A detailed list of actual expenses can be compiled as salt marsh management is undertaken around the region, including staff time for project planning, as well as materials, equipment, contracts, and staff time for implementation. This will allow future iterations of the decision model to include more accurate cost estimates.

The prototype model for the Long Island National Wildlife Refuge Complex provides a useful tool for decision making that can be updated in the future with new data and information. The spatial and temporal variability inherent in parameter estimates were not quantified during rapid prototyping. Previously, preliminary sensitivity analysis revealed little effect of incorporating ecological variation in abundance of marsh-obligate breeding birds on the optimal solutions for Prime Hook National Wildlife Refuge (Neckles and others, 2015). This lends confidence to use of this framework for decision making; however, including probability distributions for each performance metric in the decision model could be a high priority for future prototypes. Future monitoring of salt marsh integrity performance metrics will be useful to refine baseline parameter estimates and to determine the background rate of change in the absence of management actions; feedback from measured responses to management actions around the region will help reduce uncertainties surrounding management predictions. The structured decision-making framework applied here to the Long Island National Wildlife Refuge Complex is based on a hierarchy of regional objectives and regional value functions relating performance metrics to perceived management benefits. It will be important to ensure that subsequent iterations reflect evolving management objectives and desired outcomes. Elements of the decision model could be further adapted, for example through differential weighting of objectives or altered value functions, to reflect specific, local management goals and mandates. Future optimization analyses that use this framework could also incorporate additional constraints on action selection, such as ensuring that particular actions within individual marsh management units are included in optimal management portfolios, to further tailor the model to refuge-specific needs.

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Table 3. Possible management actions for achieving objectives within marsh management units at the Long Island National Wildlife Refuge Complex, New York, estimated costs over 5 years, and predicted outcomes expressed relative to performance metrics.

[Potential management actions, costs, and predicted outcomes developed by workshop participants using expert judgement. Predicted consequences of management actions were aided by influence diagrams (app. 1). %, percent; ppt, parts per thousand]

Management action	Estimated cost over 5 years (dollars)	Performance metrics									
		Native vegetation (% cover)	Nekton: Density (number of animals per square meter)	Nekton: Species richness (number)	Tidal marsh obligate birds (summed number per point)	American black ducks use[1]	Spider density (number per square meter)	Hydrology: Duration of surface flooding[2] (%)	Hydrology: Surface-water salinity[2] (ppt)	Marsh surface elevation change relative to sea-level rise[3]	Herbicide application (pints per year)
Seatuck National Wildlife Refuge											
A. No action	0	70	55	6	0.12	High	15	18	0	0	0
B. Place dredged sediments	104,000	77	55	6	0.3	High	1	5	0	1	0
C. Grade marsh platform to facilitate ebb tide drainage	32,000	77	55	6	0.4	High	1	10	1	1	0
D. Dig runnels by hand	675	77	55	6	0.4	High	15	5	1	0	0
E. Grade partial marsh platform and dig runnels	14,025	77	55	6	0.4	High	15	8	1	1	0
F. Place dredged sediments and plant area	109,600	77	55	6	1	High	30	5	2	1	0
G. Remove ditch plugs with low ground pressure equipment	2,500	77	55	6	0.4	High	30	8	1	0	0
H. Remove some ditch plugs and dig runnels	1,925	77	65	7	0.4	High	30	6	1	0	0
I. Remove dredge spoil material, plant historic disposal area	25,000	85	55	6	0.12	High	15	18	1	0	0
J. Control invasive plants	30,000	95	55	6	0.12	High	15	18	1	0	220
K. Remove dredge spoil, plant area and control invasive plants	40,000	95	55	6	0.12	High	15	18	1	0	220
L. Trap mesopredators to increase sparrow population	450	77	60	6	1.5	High	15	18	0	0	0
Lido Beach Wildlife Management Area											
A. No action	0	95	13	7	1.5	High	15	30	0	0	0
B. Dig runnels by hand	1,125	97	15	9	3	High	30	10	0	0	0
C. Create living shoreline: hybrid with low profile breakwaters	140,625	98	15	7	3.5	High	15	25	0	0	0
D. Create living shoreline: high energy with offshore breakwaters	42,900	97	13	7	3.5	High	15	30	0	0	0
E. Create sparrow nest mounds from dredged material	50,000	97	13	7	3	High	30	30	0	1	0

Table 3. Possible management actions for achieving objectives within marsh management units at the Long Island National Wildlife Refuge Complex, New York, estimated costs over 5 years, and predicted outcomes expressed relative to performance metrics.—Continued

[Potential management actions, costs, and predicted outcomes developed by workshop participants using expert judgement. Predicted consequences of management actions were aided by influence diagrams (app. 1). %, percent; ppt, parts per thousand]

Management action	Estimated cost over 5 years (dollars)	Performance metrics									
		Native vegetation (% cover)	Nekton		Tidal marsh obligate birds (summed number per point)	American black ducks use[1]	Spider density (number per square meter)	Hydrology		Marsh surface elevation change relative to sea-level rise[3]	Herbicide application (pints per year)
			Density (number of animals per square meter)	Species richness (number)				Duration of surface flooding[2] (%)	Surface-water salinity[2] (ppt)		
Lido Beach Wildlife Management Area—Continued											
F. Dig runnels and create some sparrow nest mounds	26,125	97	15	7	3	High	30	10	0	1	0
G. Create living shoreline: combination of low profile and high energy offshore breakwaters	183,525	98	15	7	3.5	High	15	30	0	0	0
H. Control invasive plants	45,000	99	13	7	3	High	15	30	0	0	35
I. Trap mesopredators to increase sparrow population	300	97	15	7	5	High	15	30	0	0	0
J. Create sparrow nest mounds and trap mesopredators	50,300	97	15	7	6	High	30	30	0	1	0
K. Create deeper depression within marsh pools for nekton	400	97	20	9	3	High	15	30	0	0	0
L. Remove annual debris by hand	400	97	13	7	3.5	High	15	25	0	0	0
Wertheim—Western Unit											
A. No action	0	95	33	7	3.5	High	15	60	8	0	0
B. Remediate ditches using coir logs	10,000	99	33	7	6	High	15	60	8	0	0
C. Dig runnels by hand	6,750	99	35	7	6	High	30	45	6	0	0
D. Remove ditch plugs with low ground pressure equipment	5,000	99	35	7	6.5	High	30	15	4	1	0
E. Fill ditch	150,000	99	33	7	5.5	High	15	60	8	0	0
F. Clean ditches with low ground pressure equipment	75,000	99	35	7	6	High	30	15	4	1	0
G. Deposit sediment in spot locations	6,250	99	33	7	5.5	High	15	55	8	0	0
H. B+C	16,750	99	35	7	6	High	30	45	6	0	0
I. C+D	11,750	99	40	7	6.5	High	30	15	4	1	0
J. C+F	81,750	99	40	7	6	High	30	10	4	1	0

Table 3. Possible management actions for achieving objectives within marsh management units at the Long Island National Wildlife Refuge Complex, New York, estimated costs over 5 years, and predicted outcomes expressed relative to performance metrics.—Continued

[Potential management actions, costs, and predicted outcomes developed by workshop participants using expert judgement. Predicted consequences of management actions were aided by influence diagrams (app. 1). %, percent; ppt, parts per thousand]

Management action	Estimated cost over 5 years (dollars)	Performance metrics									
		Native vegetation (% cover)	Nekton		Tidal marsh obligate birds (summed number per point)	American black ducks use[1]	Spider density (number per square meter)	Hydrology		Marsh surface elevation change relative to sea-level rise[3]	Herbicide application (pints per year)
			Density (number of animals per square meter)	Species richness (number)				Duration of surface flooding[2] (%)	Surface-water salinity[2] (ppt)		
Wertheim—Western Unit—Continued											
K. Control invasive plants	150,000	99	33	7	6	High	15	60	8	0	300
L. Create sparrow nest mounds from dredged material	250,000	99	33	7	6.5	High	30	60	8	0	0
M. Trap mesopredators to increase sparrow population	3,750	99	35	7	6.5	High	15	60	8	0	0
N. Create sparrow nest mounds and trap mesopredators	257,500	99	35	7	7	High	30	60	8	0	0
O. D+F	80,000	100	35	9	6.5	High	30	5	2	1	0
Wertheim—Eastern Unit											
A. No action	0	70	35	7	1	High	15	11	10	0	0
B. Remediate ditches using coir logs	5,000	77	46	9	1.5	High	15	11	10	0	0
C. Remove ditch plugs with low ground pressure equipment	2,500	80	55	9	2	High	30	5	6	1	0
D. Fill ditch with sediment	150,000	77	46	9	1.5	High	15	10	10	0	0
E. Clean ditches with low ground pressure equipment	75,000	80	55	9	1.75	High	30	5	6	1	0
F. Deposit sediment in spot locations	625,000	77	46	9	1.75	High	15	11	10	0	0
G. Control invasive plants	300,000	90	50	9	2	High	15	11	10	0	300
H. Create sparrow nest mounds from dredged material	500,000	77	46	9	2.5	High	30	11	10	0	0
I. Trap mesopredators to increase sparrow population	3,000	77	48	9	2.5	High	15	11	10	0	0
J. Create sparrow nest mounds and trap mesopredators	503,000	77	48	9	3	High	30	11	10	0	0
K. C+E	77,500	80	60	10	3	High	30	0	4	1	0

Table 3. Possible management actions for achieving objectives within marsh management units at the Long Island National Wildlife Refuge Complex, New York, estimated costs over 5 years, and predicted outcomes expressed relative to performance metrics.—Continued

[Potential management actions, costs, and predicted outcomes developed by workshop participants using expert judgement. Predicted consequences of management actions were aided by influence diagrams (app. 1). %, percent; ppt, parts per thousand]

Management action	Estimated cost over 5 years (dollars)	Performance metrics									
		Native vegetation (% cover)	Nekton		Tidal marsh obligate birds (summed number per point)	American black ducks use[1]	Spider density (number per square meter)	Hydrology		Marsh surface elevation change relative to sea-level rise[3]	Herbicide application (pints per year)
			Density (number of animals per square meter)	Species richness (number)				Duration of surface flooding[2] (%)	Surface-water salinity[2] (ppt)		
Wertheim—Northern Unit											
A. No action	0	88	41	7	0.5	High	15	41	9	0	0
B. Dig runnels by hand	1,125	91	45	8	1.5	High	30	35	7	0	0
C. Clean ditches with low ground pressure equipment	75,000	91	45	8	1.5	High	30	10	4	1	0
D. Remove ditch plugs with low ground pressure equipment	1,250	93	50	8	2	High	30	15	4	1	0
E. Remediate ditches using straw wattle for erosion control	1,500	91	45	8	1.5	High	15	41	9	0	0
F. Fill ditch with sediment	150,000	91	41	8	1	High	15	41	9	0	0
G. Remediate ditches using coir blanket for trapping sediment	43,560	91	45	8	1.5	High	15	41	9	0	0
H. Assess and clean ditches	7,500	93	50	8	1.5	High	30	10	4	1	0
I. Control invasive plants	120,000	95	45	8	2	High	15	41	9	0	200
J. Create sparrow nest mounds from dredged material	200,000	91	41	8	2.5	High	30	41	9	0	0
K. Trap mesopredators to increase sparrow population	900	91	45	8	2.5	High	15	41	9	0	0
L. Create sparrow nest mounds and trap mesopredators	150,900	91	45	8	3	High	30	41	9	0	0
M. D+H	8,750	93	55	9	2.5	High	30	5	2	1	0

[1]Relative abundance for refuge during wintering waterfowl season.

[2]Measures absolute deviation from reference point representing ideal condition.

[3]Measures change relative to sea-level rise: 0, lower than sea-level rise; 1, above sea-level rise.

Table 4. Normalized predicted outcomes and estimated total management benefits of possible management actions within 5 marsh management units at the Long Island National Wildlife Refuge Complex, New York.

[Numeric table entries are weighted utilities, which were calculated as raw utilities multiplied by objective weights. Unitless raw utilities were derived from metric scores (**table 3**) using existing regional value functions (app. 2). Objective weights for individual metrics were calculated as the product of the weights on the branch of the objective's hierarchy leading to each metric (table 1). The total management benefit for each action is the sum of weighted utilities across all performance metrics.]

Management action	Performance metrics										Management benefit
	Native vegetation	Nekton		Tidal marsh obligate birds	American black ducks	Spider density	Hydrology		Marsh surface elevation change	Herbicide application	
		Density	Species richness				Duration of surface flooding	Surface-water salinity			
Seatuck National Wildlife Refuge											
A. No action	0.105	0.041	0.027	0.002	0.1	0.045	0.081	0.11	0	0.06	0.570
B. Place dredged sediments	0.109	0.041	0.027	0.004	0.1	0	0.110	0.11	0.22	0.06	0.781
C. Grade marsh platform to facilitate ebb tide drainage	0.109	0.041	0.027	0.006	0.1	0	0.110	0.11	0.22	0.06	0.783
D. Dig runnels by hand	0.109	0.041	0.027	0.006	0.1	0.045	0.110	0.11	0	0.06	0.608
E. Grade partial marsh platform and dig runnels	0.109	0.041	0.027	0.006	0.1	0.045	0.110	0.11	0.22	0.06	0.828
F. Place dredged sediments and plant area	0.109	0.041	0.027	0.014	0.1	0.09	0.110	0.11	0.22	0.06	0.881
G. Remove ditch plugs with low ground pressure equipment	0.109	0.041	0.027	0.006	0.1	0.09	0.110	0.11	0	0.06	0.653
H. Remove some ditch plugs and dig runnels	0.109	0.045	0.0315	0.006	0.1	0.09	0.110	0.11	0	0.06	0.661
I. Remove dredge spoil material, plant historic disposal area	0.113	0.041	0.027	0.002	0.1	0.045	0.081	0.11	0	0.06	0.579
J. Control invasive plants	0.118	0.041	0.027	0.002	0.1	0.045	0.081	0.11	0	0.016	0.539
K. Remove dredge spoil, plant area and control invasive plants	0.118	0.041	0.027	0.002	0.1	0.045	0.081	0.11	0	0.016	0.539
L. Trap mesopredators to increase sparrow population	0.109	0.043	0.027	0.021	0.1	0.045	0.081	0.11	0	0.06	0.596
Lido Beach Wildlife Management Area											
A. No action	0.118	0.013	0.0315	0.021	0.1	0.045	0.037	0.11	0	0.06	0.536
B. Dig runnels by hand	0.119	0.015	0.0405	0.043	0.1	0.09	0.110	0.11	0	0.06	0.687
C. Create living shoreline: hybrid with low profile breakwaters	0.119	0.015	0.0315	0.050	0.1	0.045	0.055	0.11	0	0.06	0.586
D. Create living shoreline: high energy with offshore breakwaters	0.119	0.013	0.0315	0.050	0.1	0.045	0.037	0.11	0	0.06	0.565

Table 4. Normalized predicted outcomes and estimated total management benefits of possible management actions within 5 marsh management units at the Long Island National Wildlife Refuge Complex, New York.—Continued

[Numeric table entries are weighted utilities, which were calculated as raw utilities multiplied by objective weights. Unitless raw utilities were derived from metric scores (**table 3**) using existing regional value functions (app. 2). Objective weights for individual metrics were calculated as the product of the weights on the branch of the objective's hierarchy leading to each metric (table 1). The total management benefit for each action is the sum of weighted utilities across all performance metrics.]

Management action	Performance metrics										Management benefit
	Native vegetation	Nekton		Tidal marsh obligate birds	American black ducks	Spider density	Hydrology		Marsh surface elevation change	Herbicide application	
		Density	Species richness				Duration of surface flooding	Surface-water salinity			
Lido Beach Wildlife Management Area—Continued											
E. Create sparrow nest mounds from dredged material	0.119	0.013	0.0315	0.043	0.1	0.09	0.037	0.11	0.22	0.06	0.823
F. Dig runnels and create some sparrow nest mounds	0.119	0.015	0.0315	0.043	0.1	0.09	0.110	0.11	0.22	0.06	0.898
G. Create living shoreline: combination of low profile and high energy offshore breakwaters	0.119	0.015	0.0315	0.050	0.1	0.045	0.037	0.11	0	0.06	0.567
H. Control invasive plants	0.120	0.013	0.0315	0.043	0.1	0.045	0.037	0.11	0	0.053	0.552
I. Trap mesopredators to increase sparrow population	0.119	0.015	0.0315	0.071	0.1	0.045	0.037	0.11	0	0.06	0.588
J. Create sparrow nest mounds and trap mesopredators	0.119	0.015	0.0315	0.086	0.1	0.09	0.037	0.11	0.22	0.06	0.868
K. Create deeper depression within marsh pools for nekton	0.119	0.019	0.0405	0.043	0.1	0.045	0.037	0.11	0	0.06	0.573
L. Remove annual debris by hand	0.119	0.013	0.0315	0.050	0.1	0.045	0.055	0.11	0	0.06	0.584
Wertheim—Western Unit											
A. No action	0.118	0.029	0.0315	0.050	0.1	0.045	0.000	0.11	0	0.06	0.543
B. Remediate ditches using coir logs	0.120	0.029	0.0315	0.086	0.1	0.045	0.000	0.11	0	0.06	0.581
C. Dig runnels by hand	0.120	0.030	0.0315	0.086	0.1	0.09	0.000	0.11	0	0.06	0.627
D. Remove ditch plugs with low ground pressure equipment	0.120	0.030	0.0315	0.093	0.1	0.09	0.092	0.11	0.22	0.06	0.946
E. Fill ditch	0.120	0.029	0.0315	0.079	0.1	0.045	0.000	0.11	0	0.06	0.573
F. Clean ditches with low ground pressure equipment	0.120	0.030	0.0315	0.086	0.1	0.09	0.092	0.11	0.22	0.06	0.939
G. Deposit sediment in spot locations	0.120	0.029	0.0315	0.079	0.1	0.045	0.000	0.11	0	0.06	0.573
H. B+C	0.120	0.030	0.0315	0.086	0.1	0.09	0.000	0.11	0	0.06	0.627
I. C+D	0.120	0.033	0.0315	0.093	0.1	0.09	0.092	0.11	0.22	0.06	0.949

Table 4. Normalized predicted outcomes and estimated total management benefits of possible management actions within 5 marsh management units at the Long Island National Wildlife Refuge Complex, New York.—Continued

[Numeric table entries are weighted utilities, which were calculated as raw utilities multiplied by objective weights. Unitless raw utilities were derived from metric scores (**table 3**) using existing regional value functions (app. 2). Objective weights for individual metrics were calculated as the product of the weights on the branch of the objective's hierarchy leading to each metric (table 1). The total management benefit for each action is the sum of weighted utilities across all performance metrics.]

Management action	Performance metrics										Management benefit
	Native vegetation	Nekton		Tidal marsh obligate birds	American black ducks	Spider density	Hydrology		Marsh surface elevation change	Herbicide application	
		Density	Species richness				Duration of surface flooding	Surface-water salinity			
Wertheim—Western Unit—Continued											
J. C+F	0.120	0.033	0.0315	0.086	0.1	0.09	0.110	0.11	0.22	0.06	0.960
K. Control invasive plants	0.120	0.029	0.0315	0.086	0.1	0.045	0.000	0.11	0	0	0.521
L. Create sparrow nest mounds from dredged material	0.120	0.029	0.0315	0.093	0.1	0.09	0.000	0.11	0	0.06	0.633
M. Trap mesopredators to increase sparrow population	0.120	0.030	0.0315	0.093	0.1	0.045	0.000	0.11	0	0.06	0.589
N. Create sparrow nest mounds and trap mesopredators	0.120	0.030	0.0315	0.100	0.1	0.09	0.000	0.11	0	0.06	0.641
O. D+F	0.120	0.030	0.0405	0.093	0.1	0.09	0.110	0.11	0.22	0.06	0.973
Wertheim—Eastern Unit											
A. No action	0.105	0.030	0.0315	0.014	0.1	0.045	0.106	0.11	0	0.06	0.602
B. Remediate ditches using coir logs	0.109	0.036	0.0405	0.021	0.1	0.045	0.106	0.11	0	0.06	0.629
C. Remove ditch plugs with low ground pressure equipment	0.111	0.041	0.0405	0.029	0.1	0.09	0.110	0.11	0.22	0.06	0.911
D. Fill ditch with sediment	0.109	0.036	0.0405	0.021	0.1	0.045	0.110	0.11	0	0.06	0.632
E. Clean ditches with low ground pressure equipment	0.111	0.041	0.0405	0.025	0.1	0.09	0.110	0.11	0.22	0.06	0.907
F. Deposit sediment in spot locations	0.109	0.036	0.0405	0.025	0.1	0.045	0.106	0.11	0	0.06	0.632
G. Control invasive plants	0.116	0.038	0.0405	0.029	0.1	0.045	0.106	0.11	0	0	0.585
H. Create sparrow nest mounds from dredged material	0.109	0.036	0.0405	0.036	0.1	0.09	0.106	0.11	0	0.06	0.688
I. Trap mesopredators to increase sparrow population	0.109	0.037	0.0405	0.036	0.1	0.045	0.106	0.11	0	0.06	0.644
J. Create sparrow nest mounds and trap mesopredators	0.109	0.037	0.0405	0.043	0.1	0.09	0.106	0.11	0	0.06	0.696
K. C+E	0.111	0.043	0.045	0.043	0.1	0.09	0.110	0.11	0.22	0.06	0.932

Table 4. Normalized predicted outcomes and estimated total management benefits of possible management actions within 5 marsh management units at the Long Island National Wildlife Refuge Complex, New York.—Continued

[Numeric table entries are weighted utilities, which were calculated as raw utilities multiplied by objective weights. Unitless raw utilities were derived from metric scores (**table 3**) using existing regional value functions (app. 2). Objective weights for individual metrics were calculated as the product of the weights on the branch of the objective's hierarchy leading to each metric (table 1). The total management benefit for each action is the sum of weighted utilities across all performance metrics.]

Management action	Performance metrics										Management benefit
	Native vegetation	Nekton		Tidal marsh obligate birds	American black ducks	Spider density	Hydrology		Marsh surface elevation change	Herbicide application	
		Density	Species richness				Duration of surface flooding	Surface-water salinity			
Wertheim—Northern Unit											
A. No action	0.115	0.034	0.0315	0.007	0.1	0.045	0.000	0.11	0	0.06	0.502
B. Dig runnels by hand	0.116	0.036	0.036	0.021	0.1	0.09	0.018	0.11	0	0.06	0.588
C. Clean ditches with low ground pressure equipment	0.116	0.036	0.036	0.021	0.1	0.09	0.110	0.11	0.22	0.06	0.900
D. Remove ditch plugs with low ground pressure equipment	0.117	0.038	0.036	0.029	0.1	0.09	0.092	0.11	0.22	0.06	0.892
E. Remediate ditches using straw wattle for erosion control	0.116	0.036	0.036	0.021	0.1	0.045	0.000	0.11	0	0.06	0.525
F. Fill ditch with sediment	0.116	0.034	0.036	0.014	0.1	0.045	0.000	0.11	0	0.06	0.515
G. Remediate ditches using coir blanket for trapping sediment	0.116	0.036	0.036	0.021	0.1	0.045	0.000	0.11	0	0.06	0.525
H. Assess and clean ditches	0.117	0.038	0.036	0.021	0.1	0.09	0.110	0.11	0.22	0.06	0.903
I. Control invasive plants	0.118	0.036	0.036	0.029	0.1	0.045	0.000	0.11	0	0.02	0.493
J. Create sparrow nest mounds from dredged material	0.116	0.034	0.036	0.036	0.1	0.09	0.000	0.11	0	0.06	0.582
K. Trap mesopredators to increase sparrow population	0.116	0.036	0.036	0.036	0.1	0.045	0.000	0.11	0	0.06	0.539
L. Create sparrow nest mounds and trap mesopredators	0.116	0.036	0.036	0.043	0.1	0.09	0.000	0.11	0	0.06	0.591
M. D+H	0.117	0.041	0.0405	0.036	0.1	0.09	0.110	0.11	0.22	0.06	0.924

Appendix 1. Regional Influence Diagrams

The influence diagrams (following the style of prototype diagrams in Neckles and others, 2015) in this appendix (figs. 1.1–1.8) relate possible management strategies to performance metrics. Shapes represent elements of decisions, as follows: rectangles for actions, rectangles with rounded corners for deterministic factors, ovals for stochastic events, and hexagons for consequences expressed as a performance metric.

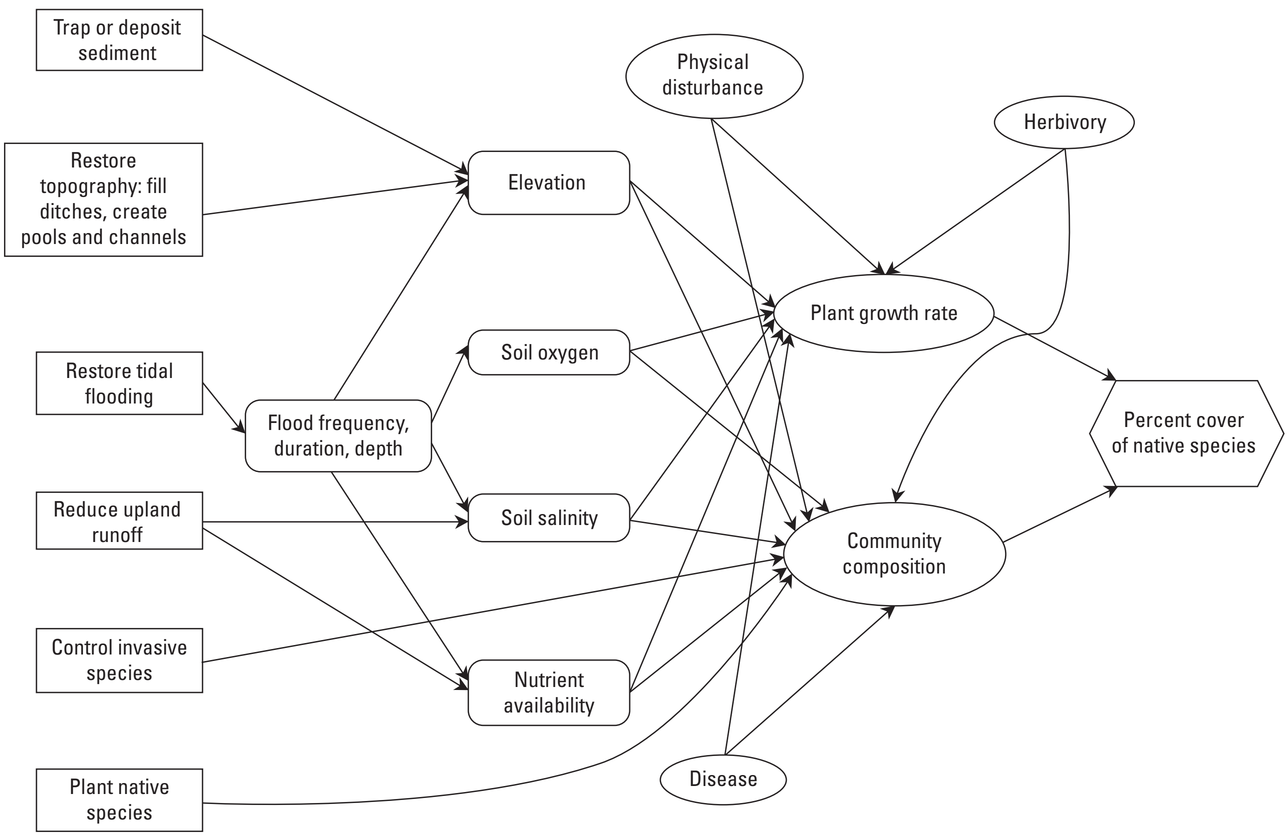


Figure 1.1. Influence diagram used to estimate percent cover of native vegetation in response to implementing certain management actions.

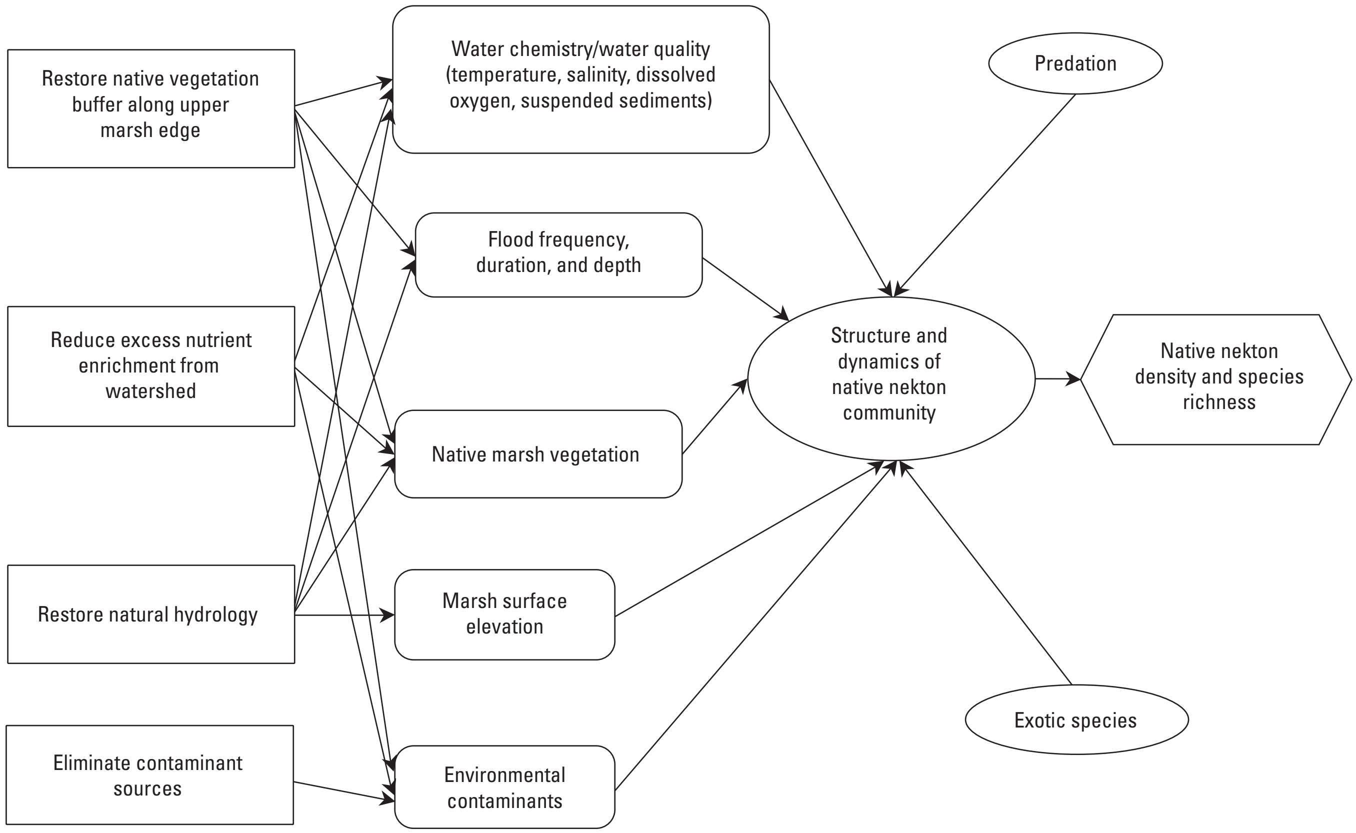


Figure 1.2. Influence diagram used to estimate nekton density and species richness in response to implementing certain management actions.

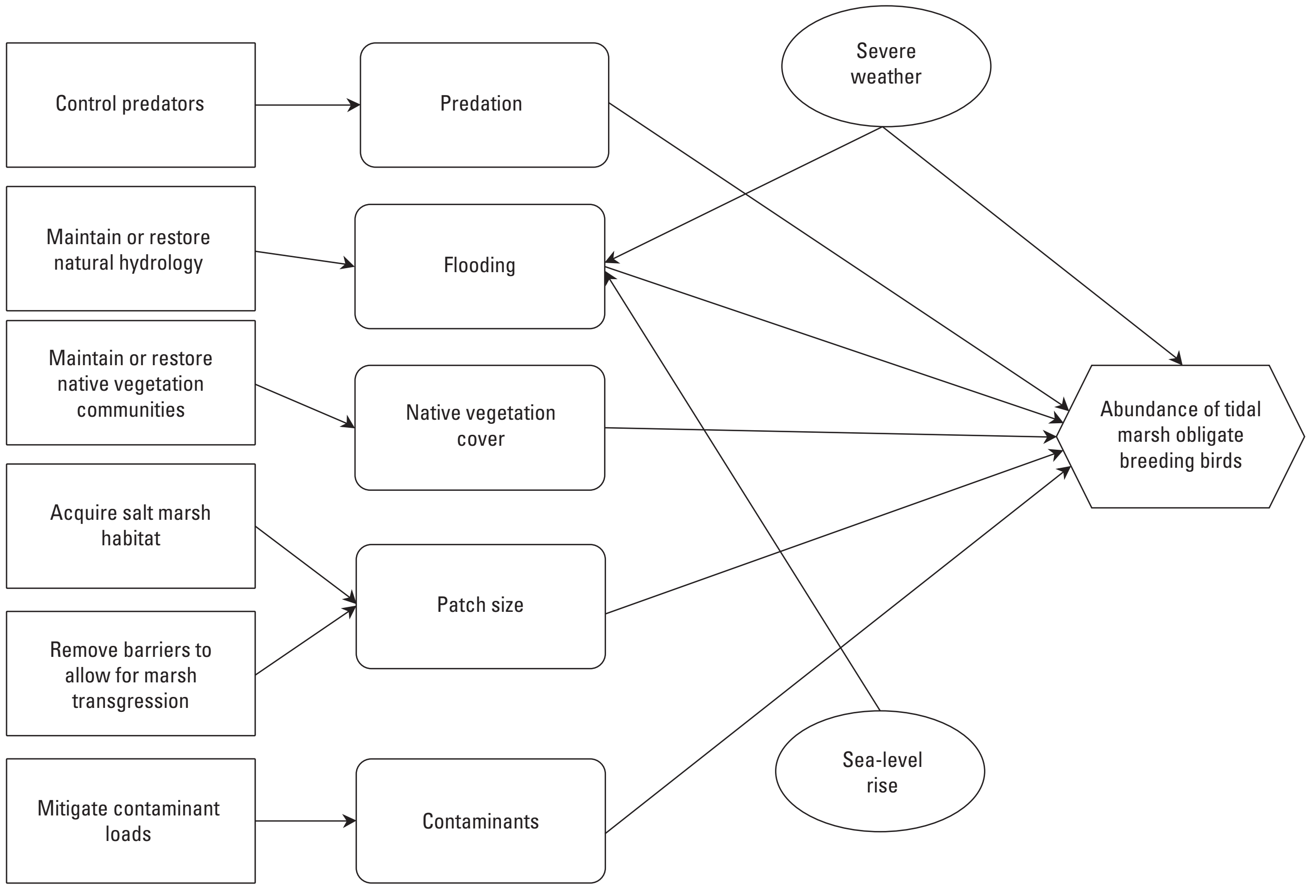


Figure 1.3. Influence diagram used to estimate abundance of tidal marsh obligate breeding birds in response to implementing certain management actions.

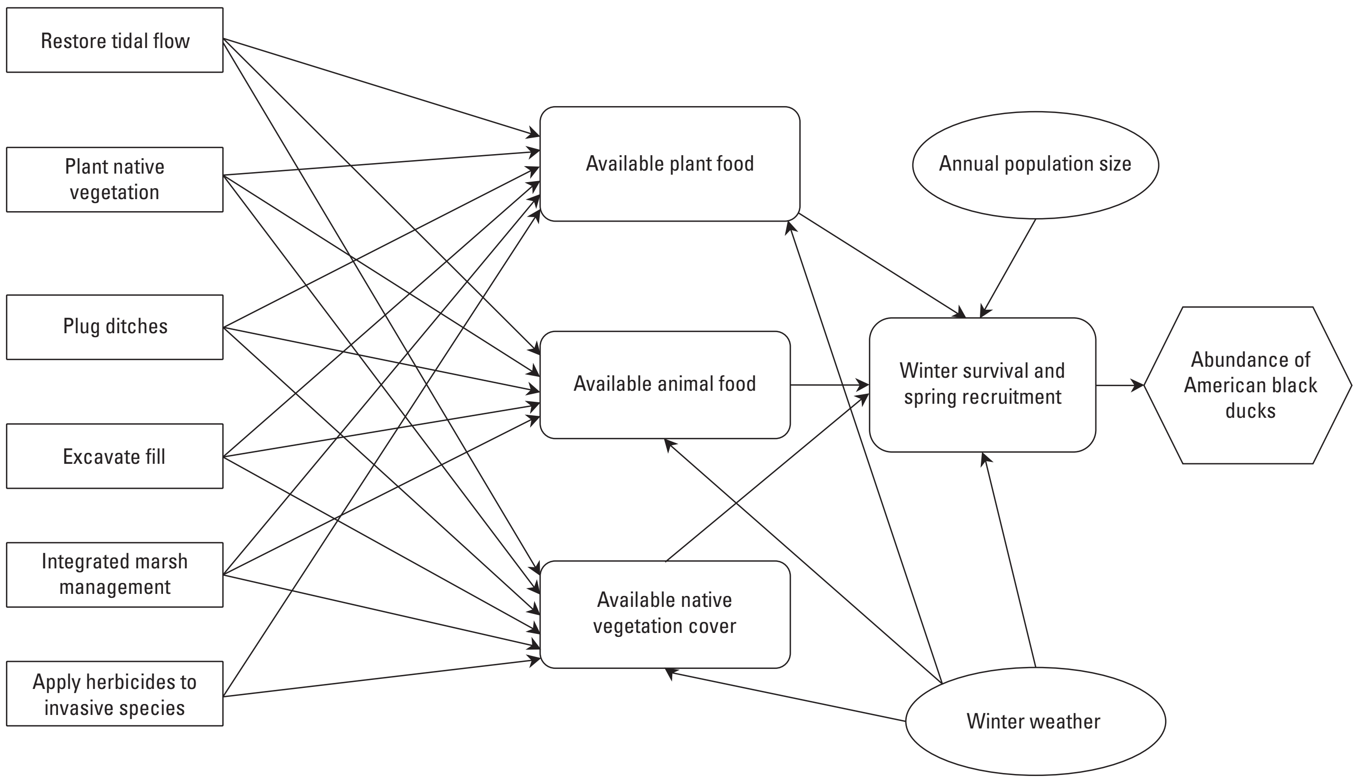


Figure 1.4. Influence diagram used to estimate abundance of American black ducks in winter, as indicator species for nonbreeding wetland birds, in response to implementing certain management actions.

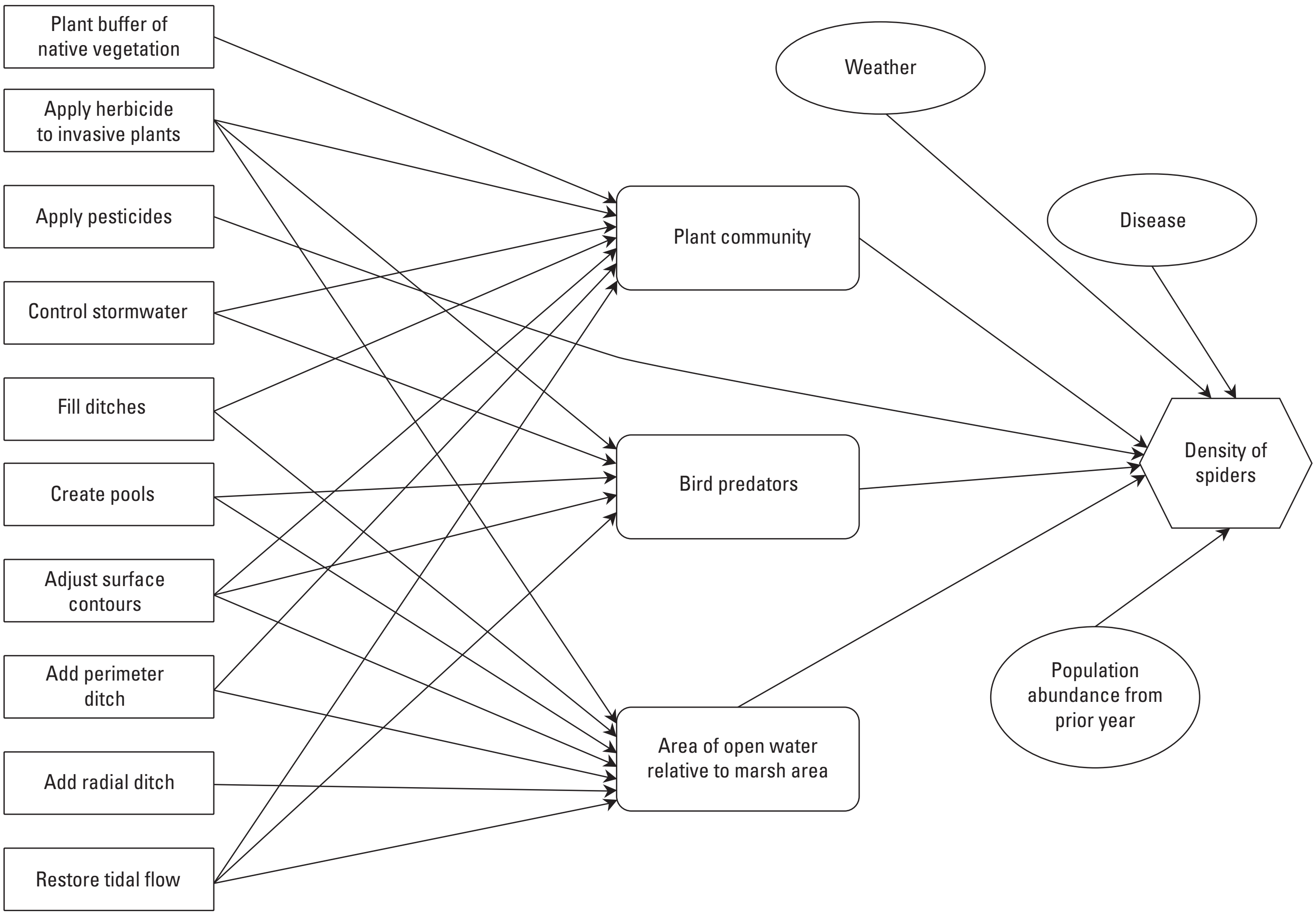


Figure 1.5. Influence diagram used to estimate density of spiders, as indicator of trophic health, in response to implementing certain management actions.

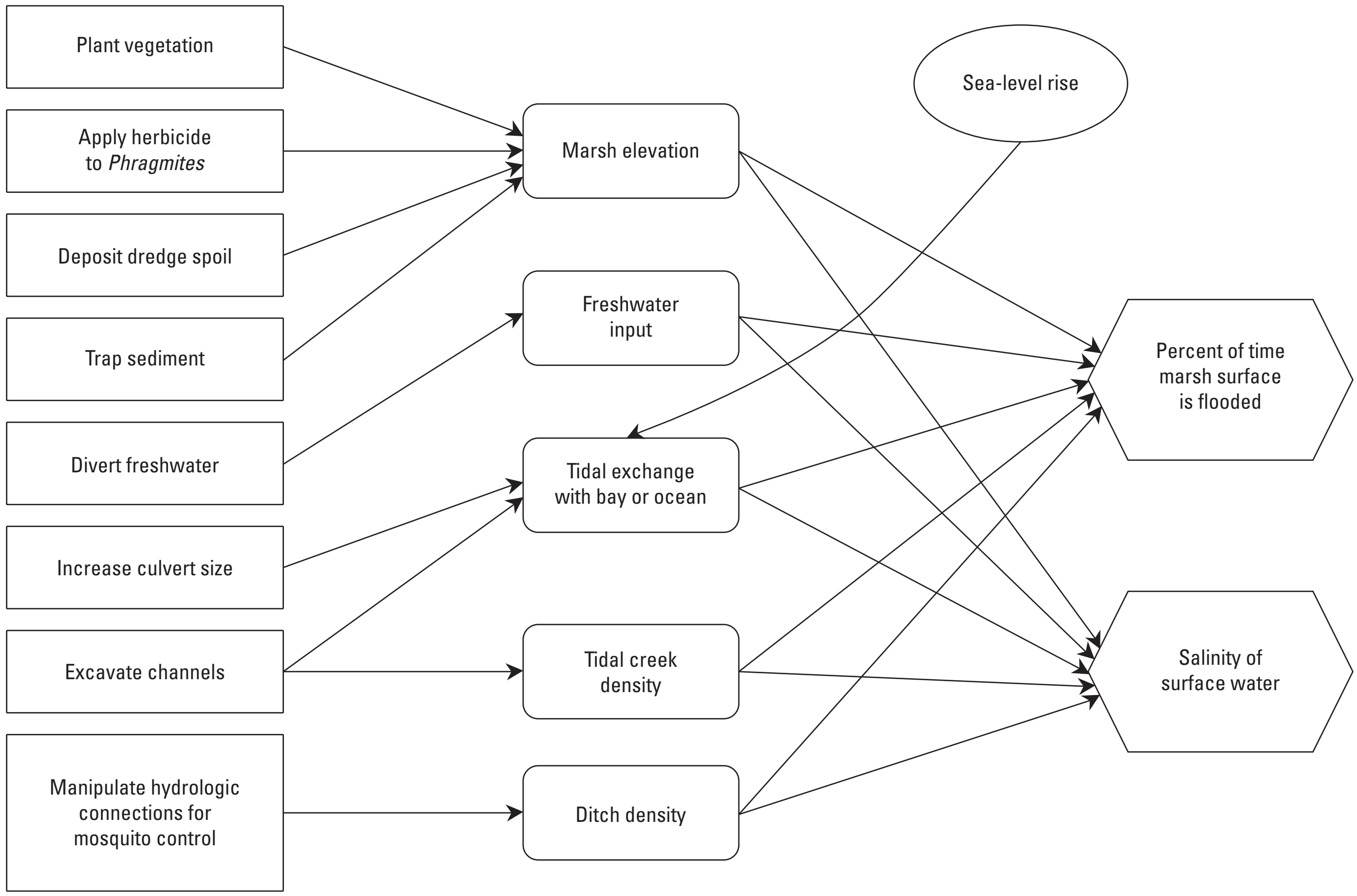


Figure 1.6. Influence diagram used to estimate percent of time marsh surface is flooded and salinity of marsh surface water in response to implementing certain management actions.

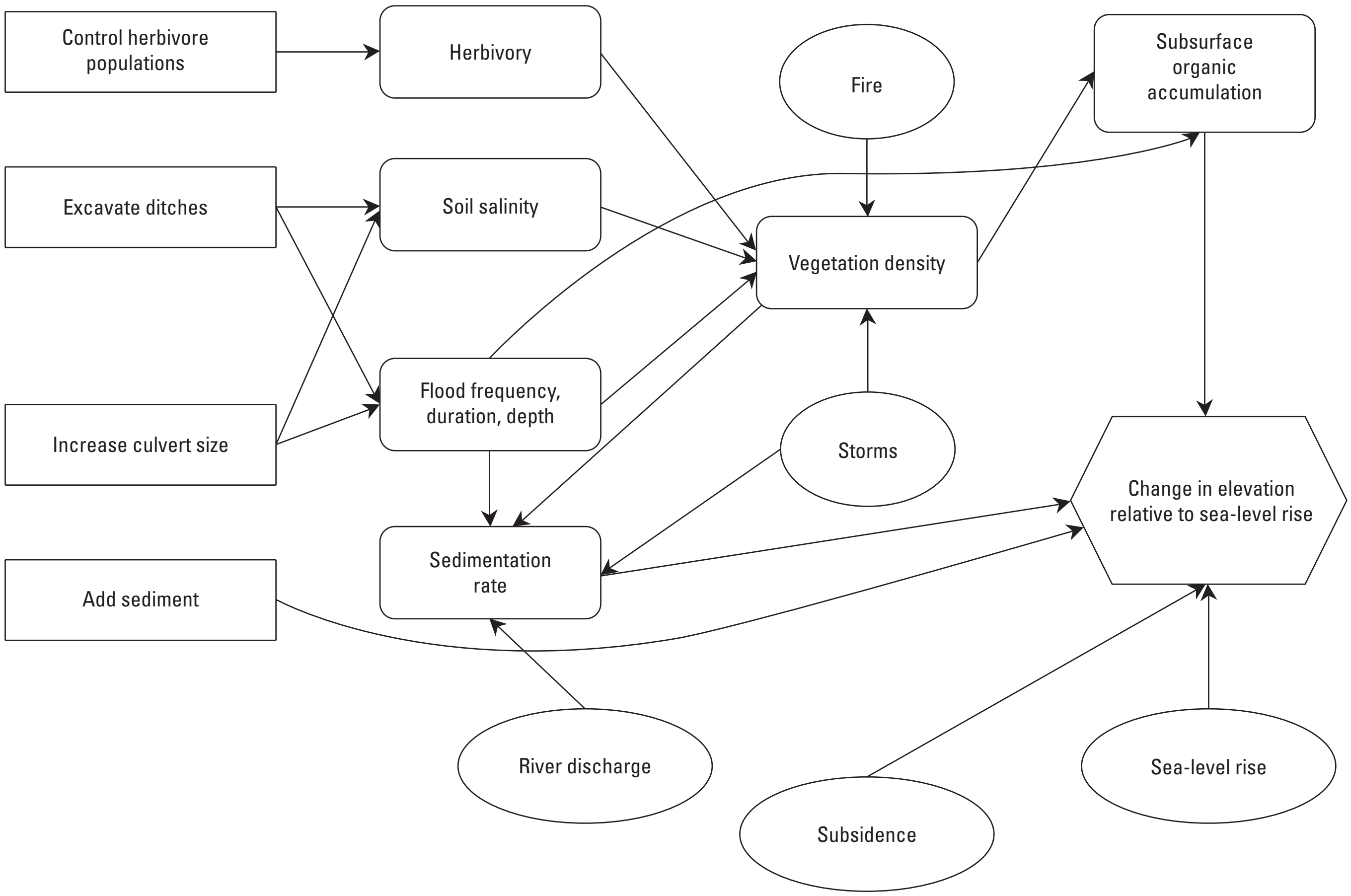


Figure 1.7. Influence diagram used to estimate change in elevation of the marsh surface relative to sea-level rise in response to implementing certain management actions.

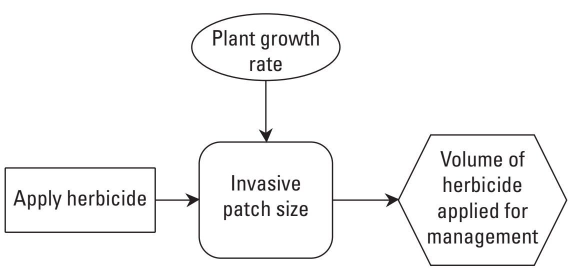


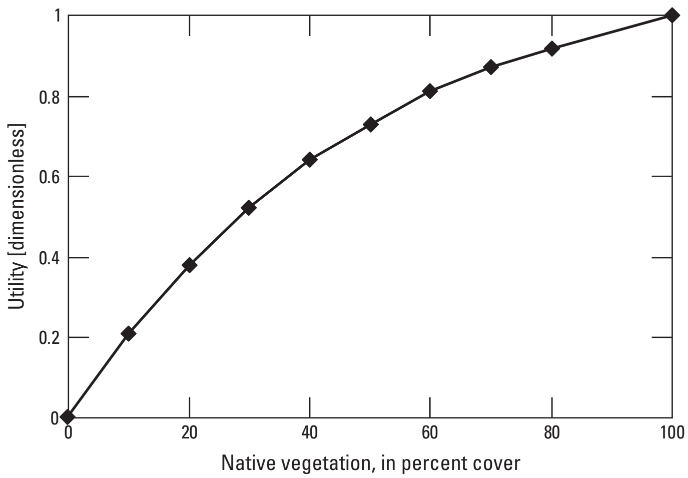
Figure 1.8. Influence diagram used to estimate volume of herbicide that could be applied if a decision was made to use chemical control for removing unwanted vegetation.

Reference Cited

Neckles, H.A., Lyons, J.E., Guntenspergen, G.R., Shriver, W.G., and Adamowicz, S.C., 2015, Use of structured decision making to identify monitoring variables and management priorities for salt marsh ecosystems: Estuaries and Coasts, v. 38, no. 4, p. 1215–1232. [Also available at https://doi.org/10.1007/s12237-014-9822-5.].

Appendix 2. Utility Functions for the Long Island National Wildlife Refuge Complex

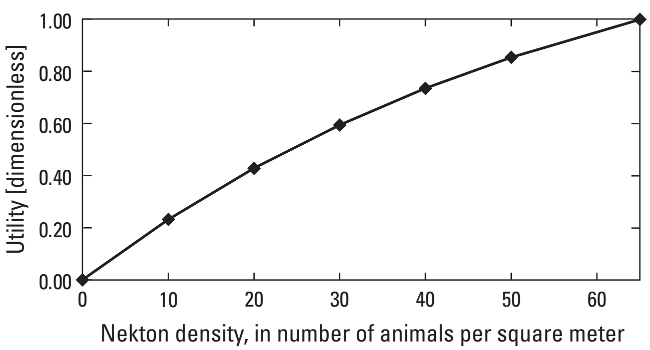
Utilities [$u(x)$] are derived as monotonically increasing, monotonically decreasing, or step functions over the range of performance metric x. In the functions in figures 2.1–2.10, x, *Low*, *High*, and ρ are expressed in performance metric units; *Low* and *High* represent the endpoints of the given metric range for the Long Island National Wildlife Refuge Complex; and ρ represents a shape parameter derived by stakeholder elicitation (Neckles and others, 2015). Break points in step functions were also derived by stakeholder elicitation.



$$u(x) = \frac{1 - e^{\frac{-(x - Low)}{\rho}}}{1 - e^{\frac{-(High - Low)}{\rho}}}$$

where
Low = 0
High = 100
ρ = 50

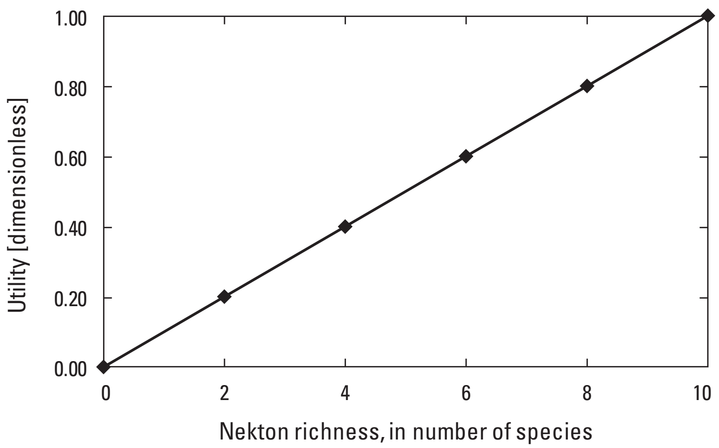
Figure 2.1. Native vegetation at the Long Island National Wildlife Refuge Complex, New York.



$$u(x) = \frac{1 - e^{\frac{-(x - Low)}{\rho}}}{1 - e^{\frac{-(High - Low)}{\rho}}}$$

where
Low = 0
High = 65
ρ = 60

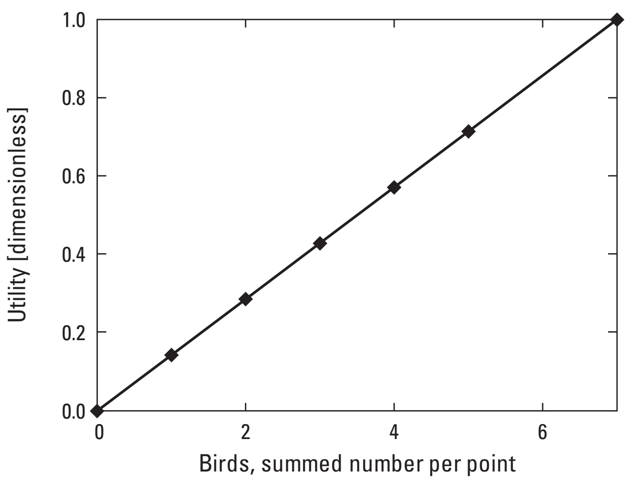
Figure 2.2. Native nekton density at the Long Island National Wildlife Refuge Complex, New York.



$$u(x) = \frac{x - Low}{High - Low}$$

where
Low = 0
High = 10

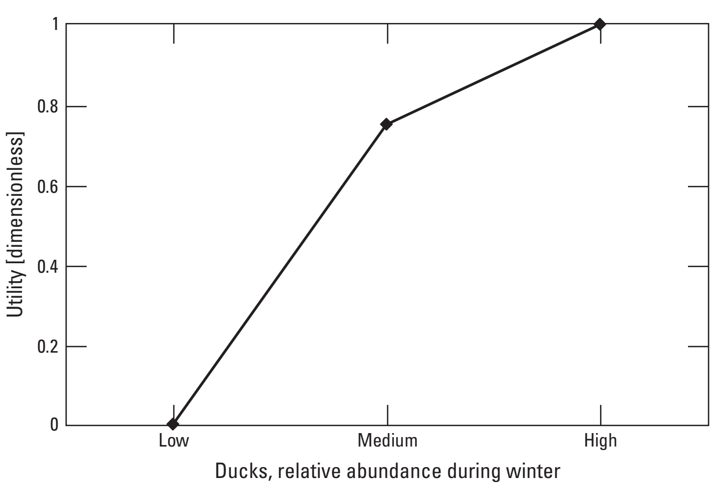
Figure 2.3. Native nekton species richness at the Long Island National Wildlife Refuge Complex, New York.



$$u(x) = \frac{x - Low}{High - Low}$$

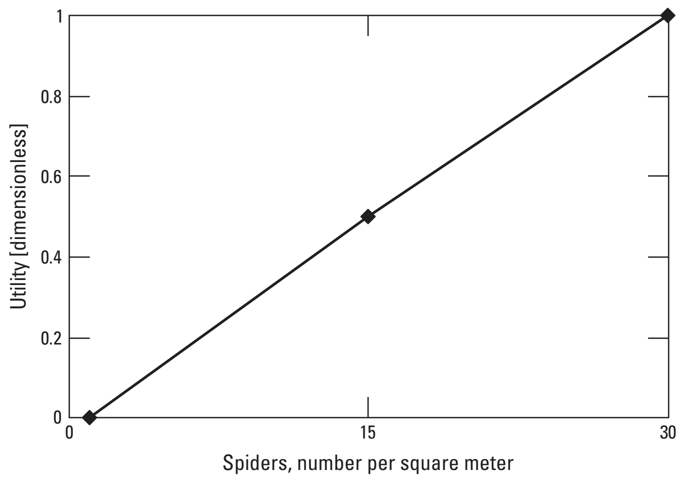
where
Low = 0
High = 7

Figure 2.4. Tidal marsh obligate birds at the Long Island National Wildlife Refuge Complex, New York.



If $x = Low$, then $u(x) = 0$
If $x = Medium$, then $u(x) = 0.75$
If $x = High$, then $u(x) = 1$

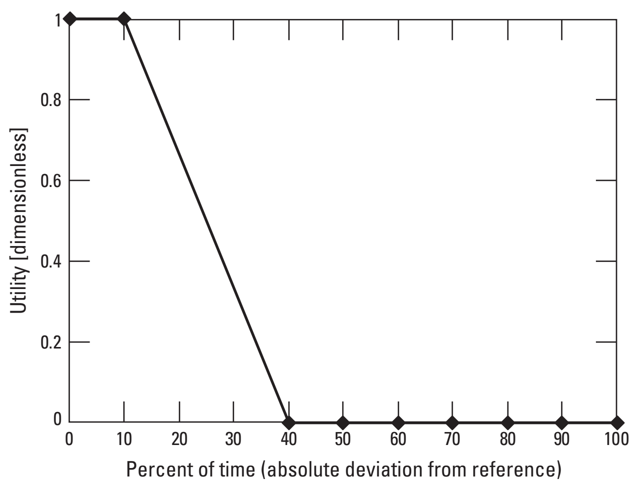
Figure 2.5. American black ducks at the Long Island National Wildlife Refuge Complex, New York.



If $x \leq 15$, then $u(x) = 0.5 \times \frac{x-1}{14}$

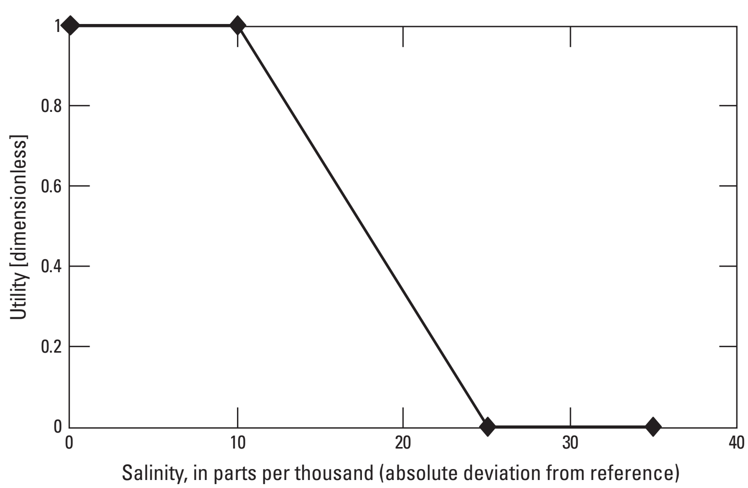
If $x > 15$, then $u(x) = 0.5 + (0.5 \times \frac{x-15}{15})$

Figure 2.6. Marsh spiders at the Long Island National Wildlife Refuge Complex, New York.



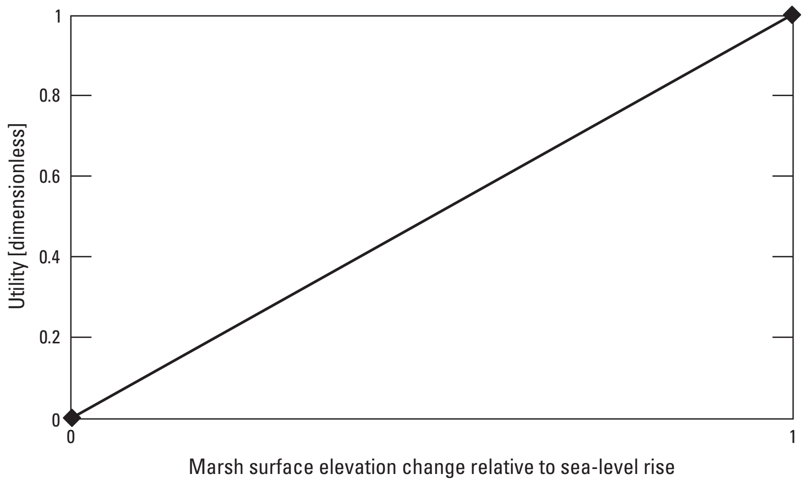
If $x \leq 10$, then $u(x) = 1$
If $x \geq 40$, then $u(x) = 0$
If $10 < x < 40$, then $u(x) = 1 - \frac{x-10}{30}$

Figure 2.7. Duration of surface flooding at the Long Island National Wildlife Refuge Complex, New York.



If $x \leq 10$, then $u(x) = 1$
If $x \geq 25$, then $u(x) = 0$
If $10 < x < 25$, then $u(x) = 1 - \frac{x-10}{15}$

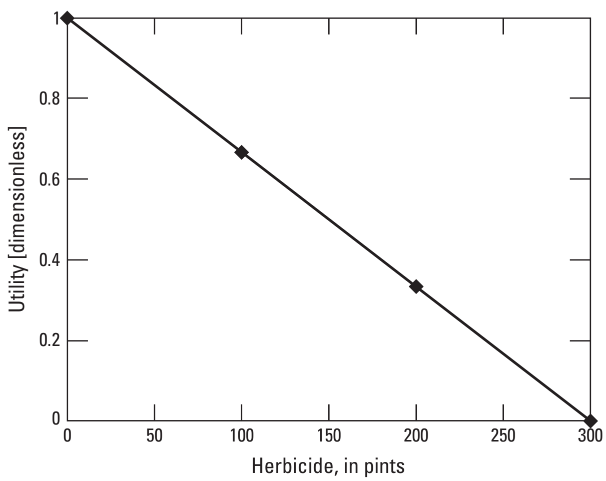
Figure 2.8. Salinity of surface water at the Long Island National Wildlife Refuge Complex, New York.



$$u(x) = \frac{x - Low}{High - Low}$$

where
Low = 0, lower than sea-level rise
High = 1, above sea-level rise

Figure 2.9. Change in marsh surface elevation relative to sea-level rise at the Long Island National Wildlife Refuge Complex, New York.



$$u(x) = \frac{High - x}{High - Low}$$

where
Low = 0
High = 300

Figure 2.10. Application of herbicides at the Long Island National Wildlife Refuge Complex, New York.

Reference Cited

Neckles, H.A., Lyons, J.E., Guntenspergen, G.R., Shriver, W.G., and Adamowicz, S.C., 2015, Use of structured decision making to identify monitoring variables and management priorities for salt marsh ecosystems: Estuaries and Coasts, v. 38, no. 4, p. 1215–1232. [Also available at https://doi.org/10.1007/s12237-014-9822-5.]

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