Final report to Atlantic Coast Joint Venture for: *Modelling the potential for alternative management strategies to improve the conservation status of saltmarsh sparrow and other tidal marsh specialist birds.*

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Scope of work and motivation

Information is urgently needed on the outcomes of potential management strategies to secure populations of saltmarsh sparrows (*Ammospiza caudacuta*) in the face of sea-level rise. The goals of this work were to develop demographic modeling to project the outcomes of the implementation of a variety of management scenarios and to create Geographic Information System (GIS) layers to guide the identification of areas for which these management actions are most likely to benefit saltmarsh sparrows. With input from key stakeholders and the Atlantic Coast Joint Venture, we developed a variety of management scenarios for three primary strategies: tide gate management to encourage saltmarsh sparrow reproduction, thin layer deposition, and encouraging marsh migration into coastal forest. We incorporated these scenarios into a demographic simulation of saltmarsh sparrow populations (based on Field et al. 2017) to develop global and statewide projections of the likely outcomes of management options. We also synthesized several datasets related to management, including the current distribution of saltmarsh sparrow populations (Wiest et al. 2018), the extent of tidal restriction (McGarigal et al. 2017), the extent of recent forest loss from sea-level rise (Hansen et al. 2018), and regional rates of sea-level rise (https://tidesandcurrents.noaa.gov). We used the resulting GIS layers to identify the areas of highest overlap between suitability for management and saltmarsh sparrow populations, which we also made available through an online decision support tool.

Methods

We used a combination of population projections and correlational spatial analyses to quantify the likely effectiveness of alternative management actions at both global and statewide scales. These complementary approaches addressed separate questions related to saltmarsh sparrow management that together provide guidance to managers about the likely effectiveness of alternative management strategies, including whether strategies at local scales are likely to be sufficient for meeting statewide population goals and potentially reversing global declines in saltmarsh sparrow populations. The primary questions related to saltmarsh sparrow management and how they are addressed by the analyses presented here are shown in Figure 1.

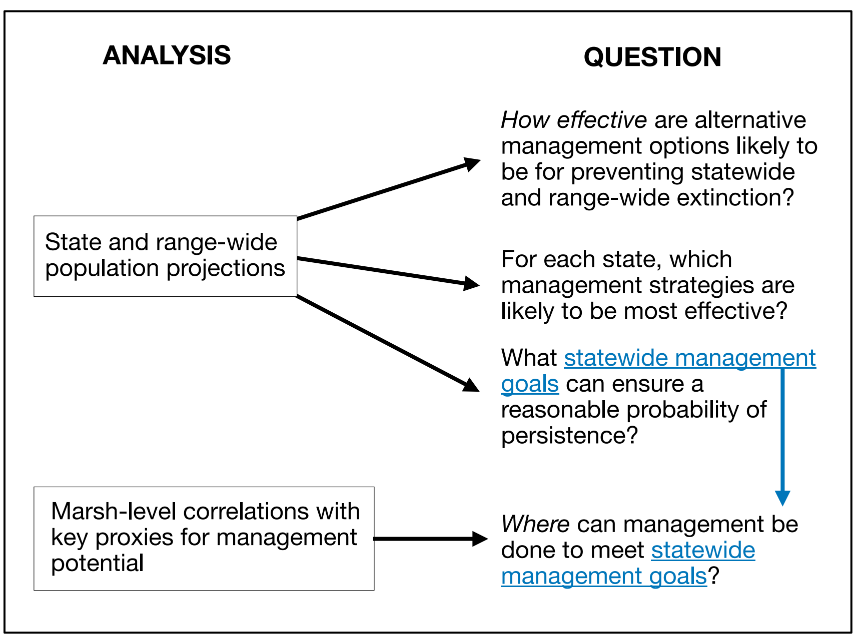

Figure 1. Conceptual diagram showing how the analyses presented here address key questions related to saltmarsh sparrow management. Spatial correlations provide information that can guide local management decisions, but do not, on their own, address questions related to whether such management is likely to be sufficient for achieving population goals. Spatial analyses should, therefore, be weighed in the context of the results of the population projections, and in particular the influence of alternative management strategies on statewide population trajectories and extinction risk.

Population projections

To project the influence of alternative management strategies on saltmarsh sparrow populations, we adapted the individual-based simulation model from Field et al. (2017). This modeling framework integrates data on saltmarsh sparrow vital rates with high-resolution tide projections – including components for sea-level rise, storm surge, and tide height – to model how reproduction is influenced by the balance between marsh elevation change and increased tidal flooding. Vital rate data are from the Saltmarsh Habitat and Avian Research Program (SHARP; Hodgman et al. 2015) and physical factors are integrated using data from tide gauges (https://tidesandcurrents.noaa.gov), statistical modeling of water levels, and astronomical tide projections. The output of the model is a set of saltmarsh sparrow population trajectories over the next century, at a global scale but using data primarily from the Long Island Sound region. The initial work using this modeling framework identified the potential for a reproductive threshold caused by increased tidal flooding beyond which reproduction is impossible and saltmarsh sparrows rapidly go extinct (Field et al. 2017). Because this framework explicitly models marsh elevation change and the influence of the height, timing, and frequency of tides, it was well suited to extensions that incorporate the potential influence of management efforts that target marsh elevation and high tides. One key assumption of this initial model, which we revisit here, is that projections are based on the assumption that there will be no additional habitat created by the widespread migration of marshes landward.

In addition to incorporating management strategies and scenarios into the Field et al. (2017) model, we have made several improvements to improve inference for areas outside of Long Island Sound and at the state scale (all code for this project is available on C. Field's GitHub repository: https://github.com/chrisf22/USFWSsals). First, we restructured the model to project both global and statewide populations, using the starting population sizes from Wiest et al. (2018). Next, to support these smaller scale projections, we 1) integrated regional sea level projections with uncertainty bounds, and 2) restructured the model to take advantage of the spatial variation in saltmarsh sparrow vital rates for areas outside of Long Island Sound. We made sea level projections using the methods from Kopp et al.

(2014) and incorporated spatial variation in vital rates from the data and analyses in Ruskin et al. (2016) and Field et al. (2018). Finally, we incorporated additional data on marsh elevation change to allow different estimates for the northern (New York to Maine) and southern (New Jersey*) parts of the saltmarsh sparrow range. (*SHARP demographic data on saltmarsh sparrow breeding do not extend south of New Jersey.)

Management scenarios

We incorporated into the projection model of Field et al. (2017) processes that simulate three primary management actions to quantify their influence on population trajectories. These actions were management of tide gates to hold back the tides most likely to cause reproductive failure, thin layer deposition of fill to allow marshes to keep pace with sea-level rise, and management of forested areas (e.g. tree cutting or girdling) adjacent to tidal marshes to encourage landward migration (see Figure 2 for specific scenarios for each strategy). We specified tide gate management as the number of high tides for which tide gates were closed during the saltmarsh sparrow breeding season (approximately late-May to late-August; see Ruskin et al. 2016). This management strategy is a potential option for marshes behind tidal restrictions that can be manipulated. In our simulations, closing tide gates resulted in 100% reproductive success during affected tidal peaks, which optimistically assumes that there will be no depredation during that time. Here we refer to the action of closing tide gates across the range to ensure reproductive success during one tidal peak as a “save”. We simulated a range of saves per season (see Figure 2), including a best-case, but unrealistic, scenario in which one third of the population was managed at the level of 100 saves each year in perpetuity. Our approach assumes that during periods between saves, marsh processes, including the balance between sea-level rise and marsh elevation change, continue unaffected by tide gate management. This assumption differs from an alternative specification that assumes that tidal range of areas behind tidal restrictions, including mean water level, can be managed precisely. Both our specification and this alternative specification, which is beyond the scope of this work, are optimistic in that they assume that tide gate management works perfectly and that it would be effective for all areas behind tidal restrictions, regardless of the current condition of restrictions.

We modeled thin layer deposition as a single event with a specified magnitude (Suzanne Paton pers. comm.), timing, and habitat recovery period (see Figure 2). With this specification, marsh elevation relative to sea level is altered directly by this event, but background rates of marsh elevation change and sea-level rise are unaffected by management. Given the large uncertainty around the effectiveness and time scales of coastal forest management aimed at encouraging marsh migration, we specified a best-case scenario for how such management could create new saltmarsh sparrow habitat. We specified that any areas subject to forest management would convert to tidal marsh over a short period of time (see Figure 2). The elevation relative to sea-level rise of converted habitat would revert to the beginning of the projections, essentially resetting those areas. After the point of conversion, marsh processes would continue as normal, according to the rates of marsh elevation change and sea-level rise specified in the model. In addition to these management scenarios, we modeled one alternative action, a reduction in global emissions, to provide a comparison to the more active approaches that are the primary focus of this work. We also used a best-case scenario for emissions, a return to 2016's level (Schaeffer et al. 2012), as previous work had shown that saltmarsh sparrow projections were not very sensitive to the range of realistic emissions scenarios (Field et al. 2017).

To integrate these management scenarios with the population model, we specified the spatial extent of management, which we varied by scenario, as a proportion of the saltmarsh sparrow population. To provide context for these population-based management targets, we estimated for each state the extent of marsh that would have to be managed to capture the given proportion of the population (Table 1). To relate population targets to marsh extent, we used the saltmarsh sparrow abundance estimates and marsh boundaries from Wiest et al. (2018), who used a 50-m buffering approach to group marshes into biologically-relevant units using the U.S. Fish and Wildlife Service's National Wetlands Inventory (https://www.fws.gov/wetlands/nwi/). For the final suite of scenarios, we used a combination of empirical data and population targets based on optimistic scenarios. For example, the extent for three of the scenarios for tide gate management were set according to proportion of saltmarsh sparrow populations currently behind tidal restrictions (Table

2), but we also considered a best-case scenario in which one third of the population was managed irrespective of whether that proportion currently occurs behind a restriction.

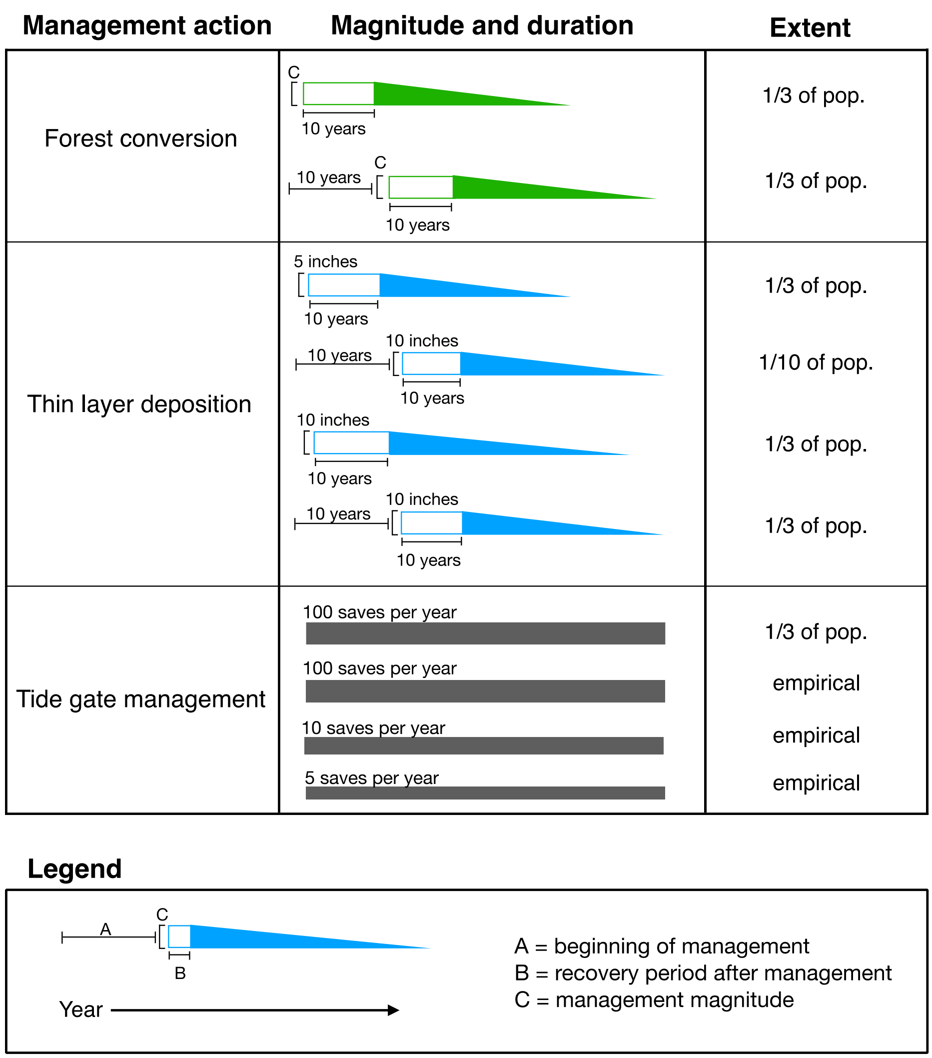

Figure 2. Conceptual diagram for how we specified alternative management strategies and scenarios. Each scenario varies by 1) three primary parameters (the timing of the beginning of management, the recovery period after management, and the magnitude of the management) and 2) the extent of the population that experiences management (specified as a proportion of the population). The values used for these parameters for each scenario are shown in Figure 3. Tide gate management is shown as a solid gray bar that

does not taper over time because that action (specified by the number of "saves" per year) continues in perpetuity.

Table 1. The minimum area of marsh in each state required to comprise 33% and 10% of the statewide saltmarsh sparrow population. Area is shown as both the number of marshes and hectares. Estimates based on Wiest et al. (2018).

	Number of marshes (33% of pop.)	Number of marshes (10% of pop.)	Ha of marsh (33% of pop.)	Ha of marsh (10% of pop.)
VA	2	1	13106	7689
MD	1	1	27779	27779
DE	1	1	16937	16937
NJ	2	1	7982	5807
NY	12	2	1429	612
CT	3	1	874	376
RI	6	1	301	75
MA	3	1	3271	416
NH	1	1	2269	2269
ME	1	1	888	888

Table 2. The proportion of the saltmarsh sparrow population, in each state, that is in restricted marshes, using data from Wiest et al. (2018) and McGarigal et al. (2017).

State	Saltmarsh sparrow abundance	Saltmarsh sparrow abundance in restricted marshes	Proportion of the saltmarsh sparrow population in restricted marshes	Area of restricted tidal marsh (ha)
VA	4430	119	0.03	1002
MD	15025	1884	0.13	7985
DE	4191	378	0.09	3299
NJ	20715	1633	0.08	7055
NY	5773	421	0.07	1108
CT	1594	38	0.02	175
RI	900	62	0.07	92
MA	6512	193	0.03	936
NH	1085	122	0.11	353
ME	1622	43	0.03	287

Correlational spatial analyses

The goal of the spatial analyses was to identify marsh complexes across the saltmarsh sparrow range where population size overlaps with three indicators of management suitability. “Tidal restriction” is the proportion of a marsh complex behind a tidal restriction, which indicates the potential to use tidal gate management (see Table 2). “Sea-level rise” is the rate of sea level rise. Marsh complexes with lower rates of sea-level rise would require less deposition for the same benefit, which would likely reduce costs, negative impacts to the habitat, and the recovery period. “Forest loss” is the extent of recent forest loss (between 2000-2018). Marsh complexes with greater loss at the upland edge likely have characteristics, such as slope and ecological factors, that are more likely to be conducive to marsh migration. We identified marsh complexes that are within the top 20% for both saltmarsh sparrow abundance and each of these indicators of management suitability. For “Sea-level rise”, we used the bottom 20%, as opposed the top 20%, as a threshold, consistent with the possibility that marshes with lower rates would require less intensive thin layer management. The data sources used for these indicators are described in more detail below:

<u>Saltmarsh sparrow abundance</u>: Estimates of marsh-level density from a Bayesian network analysis that generated estimates for every marsh complex in the tidal marsh patch layer described above and available at www.tidalmarshbirds.org (Wiest et al. 2018).

<u>Tidal restriction</u>**:** Area of marsh (ha) that is behind a tidal restriction, from the tidal restriction layer developed by University of Massachusetts Landscape Ecology Lab’s Designing Sustainable Landscapes (McGarigal et al. 2017): http://jamba.provost.ads.umass.edu/web/lcc/dsl/metrics/DSL_documentation_tidal_restrictions.pdf

<u>Forest loss</u>: The area within a 100 m buffer of tidal marsh that experienced loss between 2000-2018 (as a proportion of total buffer area). Forest loss data are from Hansen et al. (2018) and were extracted using Google Earth Engine.

Sea-level rise: The rate of sea-level rise at the tide gauge closest to the marsh complex (https://tidesandcurrents.noaa.gov).

Visualizations of the spatial correlations between these indicators and saltmarsh sparrow populations are available via two online tools, which have associated documentation (see **Attachments**). These tools allow the user to filter data by state and use thresholds to identify particular marsh complexes with high management suitability, according to the indicators. The spatial correlations and tools described above are appropriate for high-level filtering, which includes ruling out areas with low regional or statewide importance to saltmarsh sparrows and identifying sites that meet minimum criteria for management. Because site-level comparisons across the entire saltmarsh sparrow range must necessarily rely on data layers that have coverage over large scales, care must be taken to account for that fact that making many such comparisons increases the probability of encountering sites that are affected by the error rate of the underlying datasets. We recommend, therefore, that these tools be used in conjunction with ground truthing, which could take the form of rapid assessments, to ultimately decide whether a site is suitable for management. For example, the data layer of tidal restrictions can only identify their locations and the extent of their impact, but more information on the type of restriction, its condition, and whether or not it can be manipulated would be necessary to ultimately determine its suitability for management. The saltmarsh sparrow abundance estimates also have wide uncertainty bounds that cannot be easily visualized in this type of spatial analysis. While we show the best estimate (the mean) in our tools, local surveys would be critical for validating these estimates, which must necessarily rely on projections to un-surveyed areas in order to obtain complete coverage (SHARP is testing "rapid demo" assessment methods that would aid such decision making). The sources of the datasets used in these tools (see above) should be consulted when determining what level of confidence is warranted for decision-making at the level of individual marshes. For example, Wiest et al. (2018) has a more in-depth discussion of the strengths and weakness of the saltmarsh sparrow abundance estimates and the Designing Sustainable Landscapes project has metadata that address the accuracy of the tidal restriction layer.

Results

The influence of management on global and statewide population trajectories

Our projections suggest that intensive management of saltmarsh sparrows is unlikely to be sufficient for reversing population declines or preventing extinction. The influence on saltmarsh sparrow populations of a range of potential management scenarios, including a best-case scenario for each management strategy, is shown in Figures 3 and 4. Statewide projections from these modeled scenarios are shown in Figure 5. None of the modeled scenarios delayed extinction for more than a mean of 12 years. This scenario was also a best-case scenario that would not likely be possible to implement in practice (10 inches of thin layer deposition across one third of the marsh currently occupied by the saltmarsh sparrow population, with actions taking place as soon as possible; Figure 3). For tide gate management, only the best-case scenario resulted in a meaningful delay in extinction (100 saves per year across one third of the population in perpetuity; Figure 4). Our projections suggest that a delay of approximately 10 years would be possible by encouraging marsh migration across one third of the population, if management takes place around 2030, which would allow new habitat to be created as the window for reproduction is closing in current habitat (Figure 3). In general, the management options we considered here were more effective than the best-case scenario for emissions reduction, which we specified as a return to 2016's level of emissions (Figure 3). Our projections suggest that there is not likely to be large differences between states in terms of extinction date or the effectiveness of management, especially in light of the uncertainty in the projections, which is a result of uncertainty in parameter values and demographic stochasticity (see below for discussion of assumptions and uncertainty).

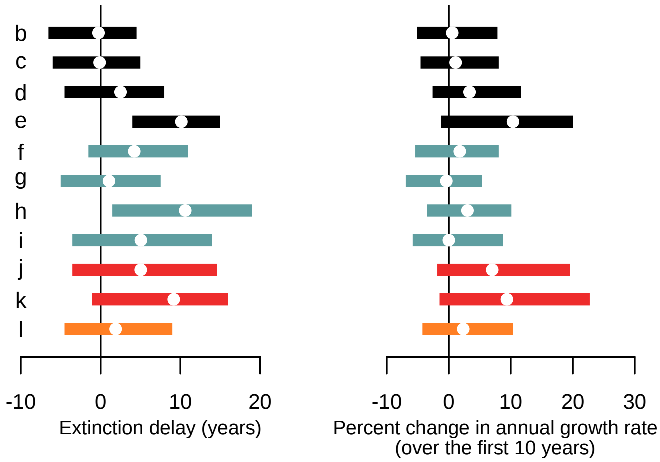

Figure 3. The influence of three primary management strategies on saltmarsh sparrow extinction date (left) and the change in the population growth rate for the first 10 years of the projections (right). White dots show the means among simulated population trajectories and the bars show the 95% confidence intervals. Each color shows a management strategy, with bars of that color representing different scenarios that vary by timing and effort (tide gate management is black, thin layer deposition is blue, encouraging migration is red, and emissions reduction is orange). The management scenarios, which are labeled with letters in the figure, are shown below:

a) No management.

<u>*In situ* management</u>

b) Realistic area/low intensity tide gate management: Proportion of nests determined by area of tidal restriction; saves for ***5 high tides per season***.

c) Realistic area/medium intensity tide gate management: Proportion of nests determined by area of tidal restriction; saves for ***10 high tides per season***.

d) Realistic area/high intensity tide gate management: Proportion of nests determined by area of tidal restriction; saves for ***100 high tides per season***.

e) Optimistic area/high intensity tide gate management: Proportion of nests determined by area of tidal restriction; saves for ***100 high tides per season***.

f) Optimistic area/low intensity thin layer deposition: Area of management determined by the area required to manage ***33%*** of the nests in each state; ***5 inches*** of fill; management happens in ***year 0*** and takes ***10 years*** before habitat is suitable again

g) Realistic area/high intensity thin layer deposition: Area of management determined by the area required to manage ***10%*** of the nests in each state; ***10 inches*** of fill; management happens in ***year 10*** and takes ***10 years*** before habitat is suitable again

h) Optimistic area/high intensity thin layer deposition: Area of management determined by the area required to manage ***30%*** of the nests in each state; ***10 inches*** of fill; management happens in ***year 0*** and takes ***10 years*** before habitat is suitable again

i) Optimistic area/high intensity thin layer deposition: Area of management determined by the area required to manage ***30%*** of the nests in each state; ***10 inches*** of fill; management happens in ***year 10*** and takes ***10 years*** before habitat is suitable again

Assisted ecosystem migration

j) Optimistic area/optimistic forest dieback: Area of management determined by the area required to ensure that 33% of the nests in each state are in corridors of forest dieback and marsh migration; upland converts to high marsh (high marsh reverts to elevation from the start of the population projection); management happens in ***year 0*** and takes **10** ***years*** to convert to high marsh.

k) Optimistic area/optimistic forest dieback: Area of management determined by the area required to ensure that 33% of the nests are in corridors of forest dieback and marsh migration; upland converts to high marsh (high marsh reverts to elevation from the start of the population projection); management happens in ***year 10*** and takes ***10 years*** to convert to high marsh.

Global collective action

l) Global emissions reduction: Zero emissions by 2016

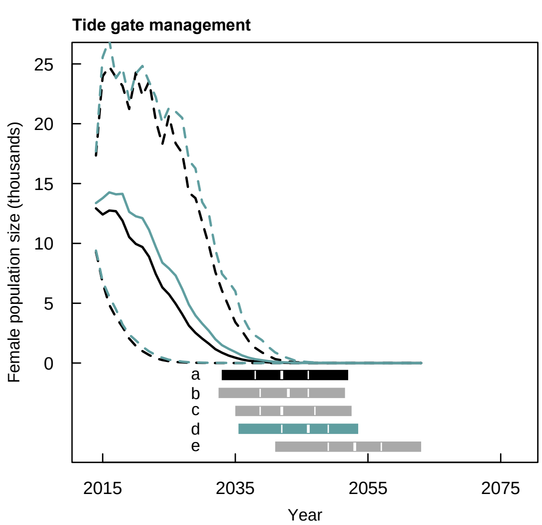

Figure 4. Saltmarsh sparrow population trajectories with and without tide gate management. Solid lines show the mean of the projected population trajectories; dotted lines shown the 95% confidence intervals (trajectory with management is shown in blue; trajectory without management is shown in black). Each bar shows the 95% confidence interval of extinction date for a management scenario. The black bar shows no management, while the other bars show different management scenarios. The blue bar denotes for which scenario

the full population trajectory is shown. The median and quartiles are shown as white tick marks. Letters correspond to the management scenarios outlined in Figure 1.

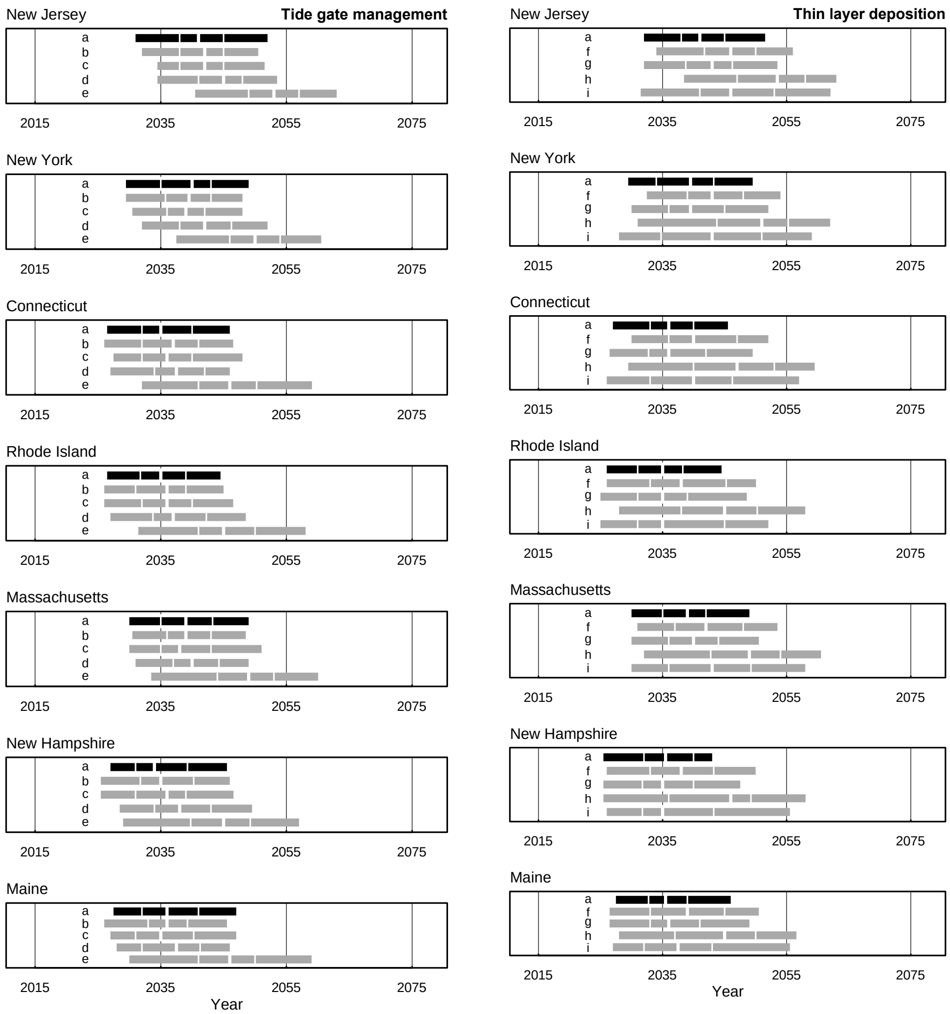

Figure 5. The influence of tide gate management (left) and thin layer deposition (right) on the statewide extinction dates for saltmarsh sparrows. Each bar shows the 95% confidence interval of extinction date for a management scenario (black bars are no management). The median and quartiles are shown as white tick marks. Letters correspond to the management scenarios outlined in Figure 1.

Correlational spatial analyses

An example of the GIS layer showing overlap between management suitability and saltmarsh sparrow populations is shown in Figure 6. The results from this GIS layer, which are provided as a .shp file (see **Deliverables**) are also summarized in Figure 7, Table 2, and as an online decision support tool (https://biologicalrisk.shinyapps.io/usfwssals/). Additional visualizations of the overlap between saltmarsh sparrow populations and potential for management to encourage marsh migration are provided as an .html file (see **Deliverables**). It is important to note that while these tools can guide local decision making about which marshes would be suitable for management, the population projections suggest that unless management is widespread, perhaps at a scale without modern precedent or beyond realistic logistical limits, management is unlikely to have significant population-level impacts. Taken together, the population projections and spatial analyses suggest that there are limited remaining options for maintaining saltmarsh sparrow populations at their current sizes through active management. Our analyses were primarily focused on guiding management at local scales that could scale up to impacts at the population level, so caution should be exercised when using the projections to make inferences about the effects of management at very small population sizes. Future modeling efforts that are more narrowly focused on small population sizes might be worthwhile, and the modeling framework used here, which is open source, could be adapted for those efforts. There are currently several impediments to carrying out these analyses, however, such as uncertainty about vital rates at small populations sizes, including density dependence, as well as gaps in data for population processes that might become more important, such as immigration, emigration, and gene flow. Despite the limitations of the analyses here for making inferences about very small populations, our projections are robust at the population sizes that are required for ensuring that populations are viable in the long term (e.g. greater than approximately 5000 individuals).

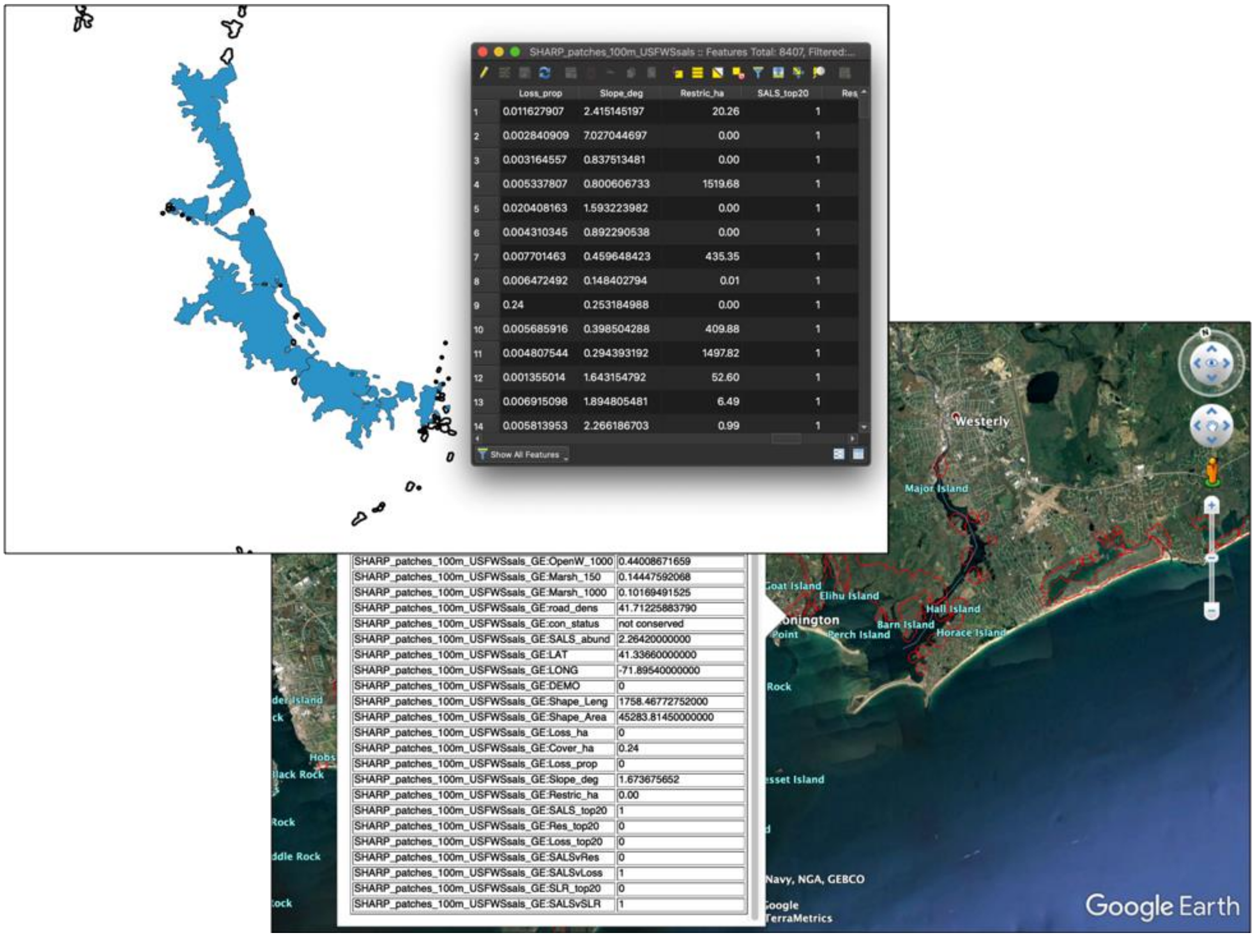

Figure 6. GIS layers showing overlap between indicators of management suitability and saltmarsh sparrow populations are provided as .shp and .kml files (see **Deliverables**).

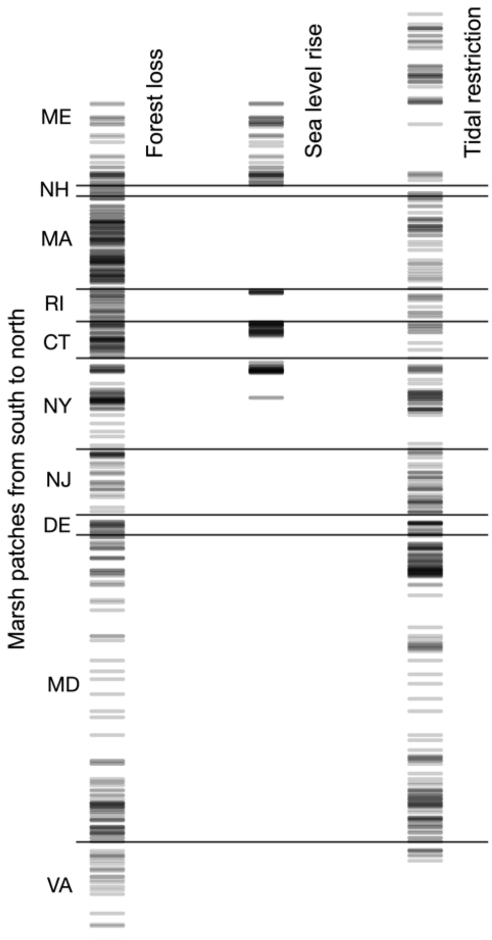

Figure 7. A summary of the GIS layer that shows overlap between areas of high saltmarsh sparrow abundance and values for three variables that might indicate that a marsh complex is appropriate for management. These management actions are attenuating high tides using tide gates (the proportion of a marsh patch that is behind a tidal restriction; "Tidal restriction"), thin layer deposition to allow marshes to keep pace with sea-level rise (the rate of sea-level rise; "Sea-level rise"), and encouraging marsh migration (the extent of forest loss between 2000-2018; "Forest loss"). Each marsh patch that is within the top 20% for both saltmarsh sparrow abundance and the variable related to management is shown as a semi-transparent tick mark. Darker areas show areas that have more marsh complexes that meet this 20% threshold for both variables. For rates of sea-level rise, the threshold used is the bottom 20%, as opposed the top 20%, since it is possible that marshes with lower rates would require less intensive thin layer management.

Important model and scenario assumptions

All population projections rely on a set of assumptions; however, our approach aims for realism and therefore has fewer assumptions than simpler models. An outline of model assumptions and a global sensitivity analysis of the model's parameters are available in Field et al. (2017). One important assumption is that saltmarsh sparrow habitat does not change over time. Our projections model the tidal frame relative to the marsh surface, and its effects on reproduction, but do not model the effect of increased tidal inundation on plant communities. This assumption has the effect of making the projections more optimistic, as increasing evidence suggests the extent of saltmarsh sparrow habitat, primarily high elevation marsh, is decreasing (e.g. Donnelly and Bertness 2001, Field et al. 2016). An additional assumption is that saltmarsh sparrow nesting behavior, and its effects of vital rates, is not changed by natural selection. As discussed above, these assumptions are likely reasonable, or tend in the direction of optimism, for all but very small population sizes.

In addition to the assumptions of the underlying population projections, our analyses rely on simplifying assumptions for specifying management actions and scenarios. In all cases, however, we erred on the side of optimism in the sense that we assumed that all management actions had the intended effects 100% of the time, and that management could be employed across large areas of the saltmarsh sparrow range. We think this optimistic bias is warranted, however, since even these best-case scenarios were not sufficient for preventing saltmarsh sparrow extinction, suggesting that there is little value in modeling scenarios that would be less effective. For simplicity, we modeled management scenarios as taking place in the absence of complementary approaches to management or land protection. While in many cases multiple management actions will happen at the same marsh complexes, we do not have reason to believe that there are synergistic effects that would increase effectiveness beyond the additive contributions of individual management actions that we have modeled here.

Deliverables

1 and *3*: A GIS data layer is attached that identifies locations across the species range where there is potential to use existing tidal restrictions to modify tidal flow in ways that might benefit saltmarsh sparrows, and where there is potential to use tree removal to facilitate marsh migration at the upland edge of current coastal marshes. This layer is provided as .shp and .kml files, including a metadata file ('SHARP_patches_100m_USFWSsals_metadata.pdf'). This layer is also summarized in two provided decision support tools (https://biologicalrisk.shinyapps.io/usfwssals/ and 'SALS_forest_stats_plots.html') and associated documentation ('Shiny_metadata.pdf').

2, *4*, and *5*: Model results are provided in the above figures that quantify the potential effects of modifying tidal restrictions on saltmarsh sparrow populations at the state and regional level, and the potential effects of tree removal on saltmarsh sparrow populations at the state and regional level. Information is also provided that summarizes model results as the total area of marsh that would be required to be managed (e.g., via thin-layer deposition) to achieve a stable saltmarsh sparrow population. All code for these model results are provided as annotated scripts via an open source GitHub repository: https://github.com/chrisf22/USFWSsals

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