Designing landscapes for bird conservation in the Southeastern United States

by

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Abstract

The Southeastern United States has high conservation importance because of the region's habitat and species diversity, ecological processes, and evolutionary potential; however, it also warrants strong concern because of historical habitat loss, future threats, and inadequate protection. Based on data from United States Geological Survey, we estimate that only 12% of Southern Coastal Plain ecoregion is under permanent protection. Conservation planning for this large and varied ecoregion is complicated by variable data availability across regions, habitats, and species. As part of a larger project to ensure adequate current and future habitat for bird populations, I defined a suite of focal species; developed a method to determine conservation priorities; and integrated future land cover conditions into conservation priorities.

For my first chapter, I elicited expert knowledge of specieshabitat associations in order to define a suite of focal species for specieshabitat modeling. I wanted to use multiple focal species to reduce the risk of missing endemic or range-restricted species, to include species with substantial public interest or conservation resources, and to represent all habitat types in the study region. Fifty-three experts attended elicitation meetings and were asked to identify and score the habitat characteristics required for each potential focal species. I used two selection methods to develop focal species lists based on expert knowledge. The Lambeck method systematically selected species based on their threat category and the structured decision making process based on species with non-overlapping habitat associations. I assessed the overall list composed of species on both lists using an online survey. From online responses, I added 11 species to the focal species list which we then used to model conservation priorities in the Southeastern US.

In order to prioritize large areas for conservation, I developed a process that integrates spatial reserve design principles including prioritizing vegetation patches that are large, round and close to other patches. I compare the results of this prioritization process using three different conservation proxies: vegetation types, focal species, and focal species values (*fsv*) derived from online expert elicitation. Three binary grids were used to develop priority surfaces based on vegetation type suitability, conservation lands, and urban. The other two prioritization methods used focal species to identify priority areas by using additional species-specific datasets potential habitat and putative source populations. We used the density of each binary grid, calculated by a two-dimensional kernel density estimator, to calculate conservation priority for each location in a regular 200m grid across the entire SAMBI area. Using only vegetation type density to create conservation priority maps resulted in more high conservation priority areas compared to focal species prioritization except for the most restricted vegetation types, such as those that were maritime-associated. Conservation priority surfaces created using focal species and *fsv* were very similar. Using vegetation type alone to create priority surfaces required fewer data and the data are more readily available (all sourced from publically available datasets), but it did not reflect species habitat use making it problematic for conservation efforts targeted at species.

Finally, in order to provide a tool to enable stakeholders to conserve species and habitats that are currently present and to integrate future habitat conditions to allow species to respond to climate change, I designed conservation priority areas for two habitats, open pine and maritime forest, that are expected to respond to different aspects of climate change, increased fragmentation and sea level rise, respectively. Land cover projections were developed for years 2000 to 2100 at 10-year time intervals for three global climate change models. We included five binary spatio-temporal grids to prepare habitat priority maps: (1) potential habitat and (2) putative source population distributions for each of the focal species; (3) suitability models for each habitat; (4) conservation lands; and (5) urban areas. Overall priority surfaces were created by combining priority surfaces from each time interval. For both habitats, differences between priority surfaces created with discounted or summed future conditions affected how valuable areas were to conservation but not where those areas were within the region, and surfaces did not differ significantly between climate scenarios. Similarities among alternatives of future conditions may be a result of scale because climate change may have a strong local, but weak regional effect. Having six similar alternatives suggests a set of consistent conservation priorities that can be relied upon to conserve bird populations in the study region. As additional information is gathered relating to climate-change-driven land cover changes, alternatives may diverge which makes repeating the modeling process very important.

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Chapter 1

Introduction

Conservation areas have been designed with a range of goals in mind including preserving biodiversity [114]; species abundance [116]; functional ecosystems [105] [121] or individual species [99] [107]. At a broad spatial scale, these conservation areas can work together to form a reserve system of complimentary sites that provides protection for a more varied set of organisms or ecosystems. The spatial arrangement of conservation areas within a reserve set has been the subject of much debate, although some basic principles have been agreed upon [133] [89]. Individual sites should be as large as possible to facilitate species persistence [22] and as round as possible to reduce the effect of edges and to maximize the amount of core habitat [89]. For a reserve system, several sites in close proximity or directly connected are of higher conservation value than a series of more distant sites because it facilitates dispersal among sites [37]. Finally, conservation areas should be systematically placed to protect vulnerable species, or ecosystems or biodiversity rather than being placed where economic or political forces permit protection [57].

The Southeastern United States has high conservation importance because of the region's habitat and species diversity, ecological processes, and evolutionary potential; however, it also warrants strong concern because of historical habitat loss, future threats, and inadequate protection [81]. Less than 12% of the land in the Southeast is under government protection or easement and resources are limited for management of these lands or for further land acquisitions. Conservation planning over this large and varied extent is further complicated by numerous stakeholders that have a vested interest in conservation efforts. State and federal governments, non-governmental organizations and private landowners are all involved with conservation of bird species throughout the Southeastern US and coordination amongst these groups is importance to ensure efforts are not unnecessarily duplicated. Therefore, it is important to develop tools that enable conservationists to prioritize regions for their conservation value.

I worked with the Atlantic Coast Joint Venture to develop a decision support tool to enable stakeholders to plan and coordinate conservation efforts for birds across the Coastal Plain of the Southeastern US. In order to provide the most useful decision support tool, I needed to address several significant sources of uncertainty. Each of my chapters addresses one or more of these sources of uncertainty. In addition, providing stakeholders with information about how uncertainty was addressed and how a decision tool was developed allows them to make more informed decisions [36].

To begin, I used two processes to create focal species lists based on expert derived data (Chapter 1). Conservation planning for this large region is complicated by inconsistent data availability across regions, habitats, and species. When empirical data about species and habitats are lacking, experts may be the best source of information [54]. Secondly, using the suite of focal species, I considered how using focal species to determine conservation priorities differed from using vegetation types (Chapter 2). Much discussion has taken place over how well focal species work to conserve biodiversity [104] [102], but working at a broad spatial extent, it is not possible to model every species. Finally, the very causes of concern to species persistence, climate change and urbanization, introduce further complexity to conservation planning because of their uncertainty. I developed a series of conservation priority surfaces under three different climate scenarios which gives stakeholders a sense of the possible variation in future conditions (Chapter 3).

Chapter 2

Incorporating expert knowledge in decision-support models for avian conservation

2.1 Introduction

Bird abundance in the United States has been declining for more than half a century, likely as a result of habitat changes [125] [78]. In the Southeastern United States, habitat and management changes including deforestation, reforestation, urban growth, and fire suppression have reduced the availability of high-quality habitats and have increased habitat fragmentation [130] [30] [126]. Short-term projections suggest that urbanization will continue to reduce forest areas and increase their fragmentation [129]. In the long term, climate change will alter precipitation and temperature patterns, and rising sea levels will reduce coastal habitat [43]. It is therefore important to conserve what is currently available (species, habitats, and ecosystems) and plan for future conservation. To effectively protect or increase bird populations in this context, conservation must maintain or increase habitat quality and quantity. However, given limited resources, it's important to focus efforts where they have the greatest benefit rather than where land is economically unimportant [95]. Furthermore, complex systems with multiple species and habitats may require trade-offs among conflicting conservation objectives.

The Southeastern United States has high conservation importance because of the region's habitat and species diversity, ecological processes, and evolutionary potential; however, it also warrants strong concern because of historical habitat loss, future threats, and inadequate protection [81]. Based on data from USGS [98], we estimate that only 12% of Southern Coastal Plain ecoregion is under permanent protection. Conservation planning for this large and varied ecoregion is complicated by variable data availability across regions, habitats, and species. Therefore, to support conservation planning, experts may be the best source of information [54].

In conservation planning, experts are often used to evaluate potential threats [18] [122], select high-priority areas [80] [15] [56], define initial values for Bayesian modeling [54] [49], and propose conservation targets [40] [23] [2]. Experts can provide critical insights when there are multiple conflicting objectives, when empirical data about species and habitats is lacking, threats are uncertain, and it's necessary to focus on a few key species. This is common when developing large-scale, long-term plans. However, when expert knowledge supports conservation decisions, little information may be provided or recorded about the experts or how their knowledge was collected and used [49].

To support avian conservation in the Southeastern United States by ensuring adequate current and future habitat, we elicited expert knowledge of specieshabitat associations, habitat management needs, and threats. This chapter highlights one aspect of our project: the use of expert knowledge to define a suite of focal species for specieshabitat modeling that would subsequently support the development of a decision-support tool. These species represent the present and future habitat needs of other species that cannot be modeled given time and resource constraints. The final tool will be a series of spatially explicit landscape models based on the habitat needs of focal species that indicate where to focus conservation efforts.

2.2 Case study context

The elicitation exercises reported here formed the foundation for a much broader study that had three major objectives: to assess the current ability of habitats to sustain avian populations; to model future conditions based on projected urban growth, conservation programs, and climate change and predict the response of avian populations; and to enhance coordination among stakeholders during all planning stages. Stakeholders provide access to information that may be unavailable elsewhere, and help us to address the concerns of those who will enact conservation actions, thereby leading to better outcomes [97].

The project covered the South Atlantic Migratory Bird Initiative (SAMBI) area [128] (Fig 2.1). The area extends from the Atlantic Coast in the east to the boundary between the Coastal Plain and the western Piedmont. Historically, this area was dominated by fire-maintained longleaf pine (*Pinus palustris*) savanna [83], but only 2% of this habitat remains after conversion to agriculture, pine plantations, and urban areas [126]. Frequent fires created high biodiversity [126], including a high proportion (40%) of endemic plant species [127] and 30 threatened or endangered vertebrates [126]. Other important habitats include bottomland hardwood forest dominated by flood-tolerant species such as cypress (*Taxodium distichum*) and tupelo (*Nyssa aquatica*) [41]. Unique non-alluvial forested wetlands include rainfall-driven pocosins, Carolina bays, and pitcher plant (*Sarracenia* spp.) bogs [100]. SAMBI's coastal area has extensive barrier islands and highly productive estuarine wetlands [21].

2.3 Focal species approach

When ecosystem management targets focal species, the goal is to protect many other species [57]. In contrast to conservation based on ecosystems or ecosystem functions, focal species indicate the quantity and arrangement of conservation areas and allow planning at a finer scale [102]. Among focal species, sub-categories include indicator, keystone, flagship, umbrella, and landscape species [13]. Indicator species reflect ecosystem health or biodiversity [51]. We did not explicitly select biodiversity indicators because the low spatial resolution of remote-sensing data leads to the apparent co-occurrence of many species [26]. In comparison, keystone species are more influential than their abundance suggests [92]; in the SAMBI area, they include gopher tortoises (*Gopherus polyphemus*), which excavate burrows used by many other species [31]. Flagship species are species that attract public support and may promote conservation of associated species, even though this may not be an explicit conservation goal in flagship species management [111]. Umbrella species require large habitat patches, so their conservation explicitly protects many other species in those large areas [79]. Landscape species resemble umbrella species in requiring large areas, but also require a specific habitat composition [106]. Because the SAMBI area has so many different conservation goals (e.g., restoring rare species, increasing populations of hunted species, preserving common species), we did not want to restrict experts to any one type of focal species. Using multiple focal species reduces the risk of missing endemic or range-restricted species when planning reserves [50] [40] and explicitly includes species with substantial public interest or conservation resources.

Using focal species to guide conservation efforts has been criticized. Andelman and Fagan [3] showed that selecting focal species using a range of criteria did not improve protection of the greatest number of species at a minimum number of sites than randomly chosen species. The effectiveness of focal species also varies with the taxa that are selected [102]. For instance, basing conservation areas on birds did not protect butterflies [28], nor did protecting large mammals protect smaller mammals [12] However, focal species can be effective in more limited situations; for example, protecting focal butterflies protected other butterflies and protecting focal birds protected other birds [28]. Since our objective was to use avian focal species to represent other birds, rather than overall biodiversity, the focal species approach was appropriate for our purposes.

Although focal species are commonly used for conservation planning, selecting them based on expert knowledge is less common. In the Bolivian Andes and the Republic of the Congo, Coppolillo et al. [18] selected landscape species for conservation planning. They selected four to six large vertebrate species at each site to represent the habitat requirements, threat sensitivity, and ecological function of other species, and their importance to humans. At both locations, experts identified potential focal species, scored each species using the above mentioned criteria, and selected the final suite of focal species. These experts were field biologists, managers, and people who knew the species or area; they scored species using (in order) published and unpublished literature and their own knowledge. Although

Coppolillo et al. used experts to select these species, they reported insufficient detail to guide other researchers interested in using experts to support conservation efforts. For example, they didn't discuss the extent to which the experts resorted to non-literature information sources nor did they detail how they elicited information from the experts.

2.4 Elicitation of focal species

For our purposes, we wanted a species suite that would represent all habitat types defined by the SAMBI Plan [128], including species with large area requirements and species requiring management. Our initial list of potential focal species comprised 65 key species identified in the SAMBI Plan. We subsequently used the two processes described in Section 4.1 to develop lists based on expert knowledge using two selection methods. Finally, we validated the two subsets of the overall list against the original list of 65 species.

2.4.1 Two approaches

To select focal species, we used Lambeck's selection process [50] and a method rooted in structured decision-making (SDM). The former method has been used to select focal species (e.g., [102]); the latter was a modification of Gregory and Keeny's [29] decision-making process. We designed our elicitation process to work with the SDM method, but added the Lambeck method because it refines the species selection by focusing on landscape design and management rather than expert elicitation.

Lambeck modified the umbrella species concept by systematically selecting species based on their threat category [50], with an emphasis on protecting the most sensitive species [102]. For example, connectivity should support species with restricted dispersal ability, and patch size should sustain species with large area requirements. This method used empirical data from published literature and field research rather than expert opinion. Rather than eliciting quantitative data from experts during the Lambeck analysis, we modified the method to accept qualitative expert data. We believed this would help experts reach a consensus more quickly and maximize participation by experts who lacked confidence in their ability to provide precise data.

Gregory and Keeney [29] have broad experience in decision analysis and have used their SDM methods to define and solve resource management issues. SDM, unlike the Lambeck method, helps stakeholders to make decisions, and we modified the process to use expert opinion. SDM comprises a five-step procedure for solving problems: state the problem, establish objectives that can be evaluated, design alternative solutions, evaluate each alternative's consequences, and assess tradeoffs before reaching a decision. Although SDM can help individuals to reach a decision, it is especially useful for groups.

In our modified SDM process, we used habitat characteristics as objectives and potential focal species as alternatives based on their association with each habitat characteristic. Experts prepared an alternatives table that rated each species according to the strength of its linkage with each characteristic. As experts characterized habitat needs, similarities emerged among species. High similarity between the habitat requirements of two species justified removal of the species of lower conservation or management concern from the species list. The species list was reduced using criteria that will be used to manage the conservation system [132]; in the SAMBI project, this will be through habitat acquisition (coarse-scale) and enhancement (medium-scale), so we emphasized similarities among coarse- and medium-scale habitat characteristics. The level of spatial detail is an important aspect of the present exercise, since habitat planning and management will be based on remote-sensing data (satellite photos used to provide land-use and vegetation type data) stored in the geographical information system software that will be used in a subsequent stage of this project to develop landscape models.

2.4.2 Expert selection

The Atlantic Coast Joint Venture, a partnership of governmental and non-governmental organizations that strives to provide healthy ecosystems to support healthy avian populations across jurisdictions, organized the SAMBI project. Working through the Joint Venture gave us access to many experts. We limited participation to experts associated with SAMBI but did not limit their number. We wanted the largest group possible because no individual understands all potential focal species [122] and broad participation reduces the bias caused by extreme views [54]. We invited all SAMBI members, including biologists and managers, from the Joint Venture team. Of 278 invitees, 53 attended elicitation meetings. During follow-up surveys, we again invited all SAMBI members; of those who attended the elicitation meetings, 16 participated in a conference call and 15 completed at least part of the surveys.

Experts included representatives from state and federal government agencies in Virginia, North Carolina, South Carolina, Georgia, and Florida; non-governmental organizations included The Nature Conservancy, Ducks Unlimited, Audubon Society state chapters, the Tall Timbers Research Station, the North Carolina Museum of Natural Sciences, the University of Florida, and the University of Georgia.

Our initial list included 65 potential focal species identified in the SAMBI Conservation Plan [128]. We wanted experts to consider the species associated with particular habitat characteristics (Table 2.1). Large scale specieshabitat associations were found in the literature [34], but medium-scale details of habitat preferences were difficult to determine. We felt that experts who study or work with a species would know this information, even if they did not publish it. Our preliminary work with the experts suggested that certain habitat characteristics extended across habitats and could be considered apart from the larger habitat types. For instance, bare ground is found in both grasslands and wetlands, and closed canopies are found in both deciduous and mixed forests. We presented the species list alphabetically to avoid biasing expert responses.

2.4.3 Focal species identification meetings

From August to November 2008 we held 2-day meetings in each state. The first day introduced the SDM process and summarized the project; during the afternoon, we began species selection. During the selection process, we divided experts into four groups based on their stated area of knowledge or comfort: waterfowl (e.g., ducks, geese, and swans), land birds, waterbirds (e.g., herons, rails, gulls, and terns), and shorebirds (e.g., sandpipers and plovers). We generally had more waterfowl experts than other types, but we also had several land bird experts. We usually combined shorebird and waterbird experts because so few were present. At the Georgia meeting, only one individual had shorebird and waterbird expertise, but North Carolina and Florida had numerous experts in this category.

On the second day, we reviewed the previous day's work and discussed landscape design issues. To encourage discussion, we started with simple examples. For example, we picked a bird with well-known, well-defined habitat preferences and asked experts to review that example. We knew some experts personally and could direct questions to an appropriate expert. Facilitators answered questions and clarified characteristics during meetings to reduce bias due to imprecise language [49]. To elicit information, we asked experts to identify important habitat characteristics for the SAMBI priority species [128]. At the first meeting, we did not initially present the specieshabitat association tables because creating an alternatives table without preconceptions is a key step in the SDM process [29]. However, this made the process unworkably slow because experts wanted to assign the species to habitats rather than to habitat characteristics, so we subsequently presented our prepared tables, and were much more successful at focusing experts on the process. For subsequent meetings, we started with matrices of potential focal species and habitat characteristics. We asked each expert to identify and score the habitat characteristics required for each potential focal species in their group (Table 2.2). Their scoring choices ranged from 1 (beneficial or preferred) to 5 (detrimental or avoided). Experts could also report insufficient information or that the relationship was neutral by not scoring the species. We also let experts answer in more detail, for example, to describe a relationship where the species preferred a moderate level of a habitat characteristic but avoided either extreme. For each species, we also asked the experts to note whether the species were umbrella, flagship, biodiversity indicator, keystone, and habitat or dietary specialist or generalist. We did not provide access to published data (e.g., field guides, species accounts, Internet searches), so they answered based on their own knowledge or experience.

Experts were comfortable with the scoring system except when we did not clarify the direction of the scoring. For example, the "depth of water" characteristic was confusing because we did not specify whether this meant shallow or deep water. When opinions differed about species preferences for deep versus shallow water, the results were ambiguous. When experts revealed this problem, we asked them to add a brief description after their score to indicate how they interpreted the scale so we understood their intent when we compiled our data. Subsequently, we provided definitions so that all experts used the same scoring criteria.

During our elicitation meetings, experts were given equal weight and group members worked to achieve consensus. Because we held meetings in each state, experts tended to know each other. This made it possible that professional relationships influenced their answers [29], such as when someone deferred to a superior in their organization, so the answers may have been biased towards the opinions of the most senior experts. We did not address this source of bias because we assumed that the most senior experts had the most experience and knowledge and that this therefore provided an acceptable, if unmeasured, weighting.

After experts completed the exercise, we compiled their answers and presented them to the whole group the next day. We did not prevent them from commenting on the results from other groups. During this stage of the process, we did not need a high level of individual participation because the smaller groups had already reached a consensus before sharing their results with the full group. A few experts sometimes monopolized the discussion, which may have introduced bias [49]. When this happened, we asked the original group to confirm whether their results should be modified. When group members had different opinions, we recorded all answers rather than forcing an artificial consensus. On the second day, we also asked experts to define key characteristics that ensured the functionality of each habitat, such as fire in an open pine ecosystem. The habitat characteristics were similar to those used for focal species, and we framed our problem by asking whether each habitat characteristic was important to the habitat's functioning. Experts then scored the characteristics as limiting (i.e., restricted the habitat's value) or compensatory (i.e., important, but allowed tradeoffs among characteristics). This was done as a group, and experts discussed each habitat until they reached a consensus.

The initial set of meetings provided a framework for selecting potential focal species and modeling the habitat conuration. For both selection methods (Lambeck and SDM), we used the same data tables, but we used different processes to create the focal species lists (Fig 2.2). For each species and each corresponding habitat characteristic, we created an overall score by combining the scores from all states. We used the majority score unless there was a disagreement (a characteristic was said to be both avoided and preferred by a species), in which case we kept the range of scores.

2.4.4 Analysis of the elicited data using the Lambeck method

We used Lambeck's process [50] to create a list of the potential focal species (Fig 2.2). To begin the Lambeck process, we reduced the length of the expert-elicited list by excluding species that had secure populations, abundant game species, and species identified as being of moderate concern (thus, low priority) in the SAMBI Plan. If there was any uncertainty, we retained a species. In the next step, we subdivided the remaining species based on differences in pattern and process; that is, we distinguished species that required habitat reconstruction from those that could live in existing habitat with appropriate management. Reconstruction-limited species required changes to the landscape pattern, such as creating additional habitat patches, improving connectivity between patches, or creating larger habitat patches[50]. Management-limited species are sensitive to the rate or intensity of landscape processes, such as fire frequency or grazing intensity [50]. We did not make these categories mutually exclusive because some species may currently lack adequate habitat and their habitat may require management once it has been established.

Among the reconstruction-limited species, we defined three subcategories based on the expert scores: Area-limited species required a large patch size, and resource-limited species had preferred or required habitat characteristics that could not be detected by remote sensing. For example, several duck species rely on submerged aquatic vegetation and other species require dead standing trees for nesting, but currently these habitat characteristic cannot be mapped using remote sensing. The third subdivision was dispersal-limited species. However, experts concurred that this was not a limiting factor for the priority species in the SAMBI area.

We defined management-limited species as any species that scored "beneficial" or "preferred" for any of the disturbance categories, as well as any species that required human-based management, including several duck species that relied on managed wetlands for their winter habitat.

In the final step, Lambeck suggests that for each habitat, one should select the most limited species for each pattern and process, and design the landscape based on the needs of those species. For example, the species with the largest area requirement would define the minimum patch size, the species with the shortest dispersal distance would define the maximum distance between patches, and the species most sensitive to disturbance would define the management protocol. We chose not to take this step because we wanted to retain the largest possible list for the experts to evaluate.

2.4.5 Analysis of the elicited data using the SDM method

To select the focal species using SDM, we used five habitat characteristics scored by the experts that could be estimated from landscape-level data: proximity to coast, water type, water depth, forest type, and canopy (Table 2.2; Fig 2.3). For example, some species prefer coastal areas, some avoid coastal areas, and some have no preference. Among those that preferred coastal areas, we further subdivided species according to their preferred habitat types such as intertidal beach, coastal marshes, and shallow areas. We subdivided birds that avoided coastal areas, but which still required open water or wetland habitats, into birds that preferred shallow water and those that had no preference regarding water depth. Birds exhibiting no preference in their use of coastal and non-coastal areas were subdivided into those that used riparian areas, avoided riparian areas, used emergent marshes, or preferred shallow water. Forest-associated species were divided by the type of forest they preferred and then into those that preferred closed and open canopy. Finally, some birds preferred open habitats.

After grouping birds based on these associations, we selected one species as the representative focal species. We generally picked species with the most complete habitat associations. For example, we selected the American Oystercatcher as a focal species associated with shallow water along beaches. Species with similar requirements included the Piping Plover, the Red Knot, the Whimbrel, the Least Tern, and the Black Skimmer.

2.4.6 Results: a list of focal species to support conservation planning in the SAMBI region

The focal species selected using the SDM and Lambeck methods included 35 of the initial 65 species, with 11 species common to both lists (Fig. 2.2). The SDM method selected 10 species that were not chosen using the Lambeck method, and the Lambeck method selected 14 species that were not chosen using SDM. The column labeled "Online survey" represents information that we used to validate our results.

To create a list of species that would be validated and used to develop the decision-support tool, we used species common to both lists, all selected land birds that appeared in both lists, and waterbirds, waterfowl, and shorebirds that appeared in the SDM list. We excluded the Lambeck list from the latter group because the experts agreed that waterfowl, waterbird, and shorebird habitat tended to overlap at the level of the data we used, and the

SDM method let us assess where habitat overlaps were likely to occur; it was therefore a better list for our purposes. We retained all land birds because we had no reason to prefer either selection method.

2.4.7 Validation through online surveys

To validate the list of focal species, we created a follow-up survey using the online survey software SurveyMonkey [118]. The online survey included supporting documentation and was introduced to respondents during a conference call. We asked the experts to review and rank the selected focal species and to add or remove species as necessary. We provided criteria for evaluating whether a species was a suitable focal species. The focal species could meet more than one of the following criteria: representative of other species, well-known biology, easily sampled or observed, sensitive to disturbance, umbrella species, flagship species, habitat specialist, dietary specialist, or keystone species [13] Our questionnaire listed species associated with each habitat type in the SAMBI Plan [128], with focal species highlighted, although we did not state the selection method used to select them. The participants scored the suitability of each species as a focal species using ranks ranging from 1 (very poorly) to 5 (very well); they could also respond that they had insufficient personal knowledge to rank the species.

The scoring process let us create a "focal species value" and a measure of uncertainty that we used to assign species weights in the landscape model (Table 2.3). The mean score provided a measure of the relative value of each focal species and the variation in scores provided us with a measure of uncertainty. For example, if all participants assigned a score of 4 to a species, we were confident that the species was a good focal species. In contrast, we had less confidence if participants assigned an equal number of 3s, 4s, and 5s. For example, experts differed in their opinions of the Black-Throated Green Warbler as a focal species for alluvial forested wetlands: 4 of 12 experts thought it was a good or very good focal species. In contrast, 12 of 13 experts scored the Prothonotary Warbler, which was not included in our focal species list, as a good or very good focal species; the other expert declared insufficient personal knowledge. We did not remove any species from the focal species list based on the online validation, but we did add 11 species (Table 2.2) to our landscape model based on the expert scores.

2.5 Discussion

Neither selection method produced a list that we considered entirely suitable for conservation planning. Each method selected at least one species per habitat included in the SAMBI Plan, but the online validation survey included several species that were not included by either method and several that were not suitable focal species. For example, experts gave Bachman's Sparrow, the Cerulean Warbler, the Redhead, the Canvasback, and the Sandhill Crane an average focal species value less than 2 ("poor"). However, the Redhead and the Canvasback were added to the initial focal species list because they were resource-limited species according to Lambeck's definition [50]. When re-evaluating the species, experts may have reduced the value of these species because we did not indicate that resource limitation was a criterion. Species values may also have decreased if they were uncommon in the study region, such as the Cerulean Warbler [35] and the Sandhill Crane [120], or if they only overwintered in the region, such as the Redhead [135] and the Canvasback [74]. Bachman's Sparrow had a low value in only one habitat (early successional and shrub-scrub) of the three in which it occurs; it had a high value in the other two habitats (longleaf pine - slash pine (*Pinus elliotti*) flatwoods and mature open pine). We began our online surveys by informing the experts that our list required revision, and engaging the experts in this way let them criticize more freely.

In our list of potential focal species, we only used species in the SAMBI plan [128] that were associated with particular habitats, although experts could add species during the meetings. This gave us 65 species, out of a total of 172 species rated as being of highest, high, and moderate concern (see Table 1 in Watson and Malloy [128]). It was important that the habitats of our focal species represent the full suite of habitats used by all species identified in the SAMBI Plan, and we believe we accomplished this because the focal species we chose cover all habitats in the SAMBI Plan.

There may be concerns about the repeatability of our selection process because we asked experts to score birdhabitat associations without referring to published materials. We made this choice rather than using references to complete the tables ourselves because elicitation of knowledge not found in the published literature was a key goal of the process [86] [97]. A different set of experts may provide different knowledge, thereby limiting the repeatability of the results. However, using a large group of experts and limiting answers to a discrete qualitative scale improved the reliability of the process. Using a simple scoring process likely also improved the ability to reach consensus. For example, asking experts to quantify canopy heterogeneity would produce a wide array of values, but similar focal species would be selected as long as there was general agreement on the direction and strength of the relationship between habitat quality and factors such as canopy heterogeneity. Insisting on consensus can eliminate potentially important differences of opinion among experts, but it was appropriate for our project. Grouping the experts (e.g., land vs. water birds) probably increased the repeatability of our results by eliminating outlier answers that would arise when experts speculated about specieshabitat combinations they were not truly familiar with.

Although neither the Lambeck method nor the SDM method was ideal for selecting a suite of focal species, combining expert opinion with these processes had benefits for selecting focal species. Both methods provided an initial list of species we could subsequently ask the experts to validate. Many expert knowledge studies have not included detailed information about their process (e.g., [18]). We hope that our experience will help others who are considering a focal species approach based on expert elicitation. To improve such a process, we suggest the following:

2.5.1 Quantitative vs. qualitative data

Qualitative data is easier to explain to experts and does not require extensive analytical knowledge [54]. Requesting qualitative rather than quantitative data probably increased our response rate because more experts would have felt sufficiently confident to participate, and this also decreased the time it took us to collect and review the data. Eliciting quantitative data would have provided more detailed data, but our project did not require such detailed information. However, care should be taken to ensure that questions are well defined. Pre-validation of the survey in a practice session with qualified people who will not be part of the final expert group is recommended.

2.5.2 Visualizing the data

Flow diagrams [50] and influence diagrams [61] are commonly used to visualize data. However, it would have been difficult and time-consuming to identify focal species by developing such tools during the meetings. Asking experts to complete tables of species - habitat associations provided information about a large number of species ($n = 65$) and habitats in a short period of time (2 days). Without this approach, gathering the expert data would have taken much longer. We don't believe that influence diagrams would have been useful, since they are typically used to characterize beliefs based on the relationships among system states and objectives, and we lacked sufficient information to characterize all those relationships. By focusing experts on entering data in tables, we reduced variability and increased consensus. Although we wanted consensus answers, that may not be appropriate for projects with different goals.

Although we could have used influence diagrams or flowcharts developed prior to the meetings, we wanted the experts to guide the process rather than reacting to tools that we presented. Using unfamiliar visualization tools would have required the experts to understand our process for diagramming the important relationships.

2.5.3 Online surveys

When time or money is limited, online surveys can rapidly and inexpensively collect data from experts. However, if reaching a consensus among experts is an objective, as it was for us, this would be difficult to accomplish using an online survey. The individual, anonymous nature of online surveys facilitates gathering of independent ideas and avoids groupthink, which results from inappropriate group cohesion [48], but eliminates the dialogue required to seek consensus. Online surveys facilitate quantifying values and their uncertainty even with qualitative scoring systems, but require relatively large numbers of participants.

We found the online survey program SurveyMonkey economical, easy to use and sufficiently flexible to structure our questions effectively, but it seemed designed for simpler surveys and smaller groups of respondents. If online surveys will be used to gather data from experts, their design should be modified so they will be more suitable for this type of research.

2.5.4 Implementing the results

Using experts in our planning process filled data gaps in the published literature, ensured that we had appropriately defined the problems and objectives (e.g., population goals versus specific management actions), and will increase user confidence in our final products [20] [137]. The list of focal species that we developed will be used to prioritize areas for bird conservation in the SAMBI area. However, the Southeastern United States is home to many other at-risk species, including amphibians, reptiles, and mammals [126], that were not included in our planning process. The selection process described in this chapter can be extended to include these species, and expert opinion may be even more valuable because so little published information is available about some of these species.

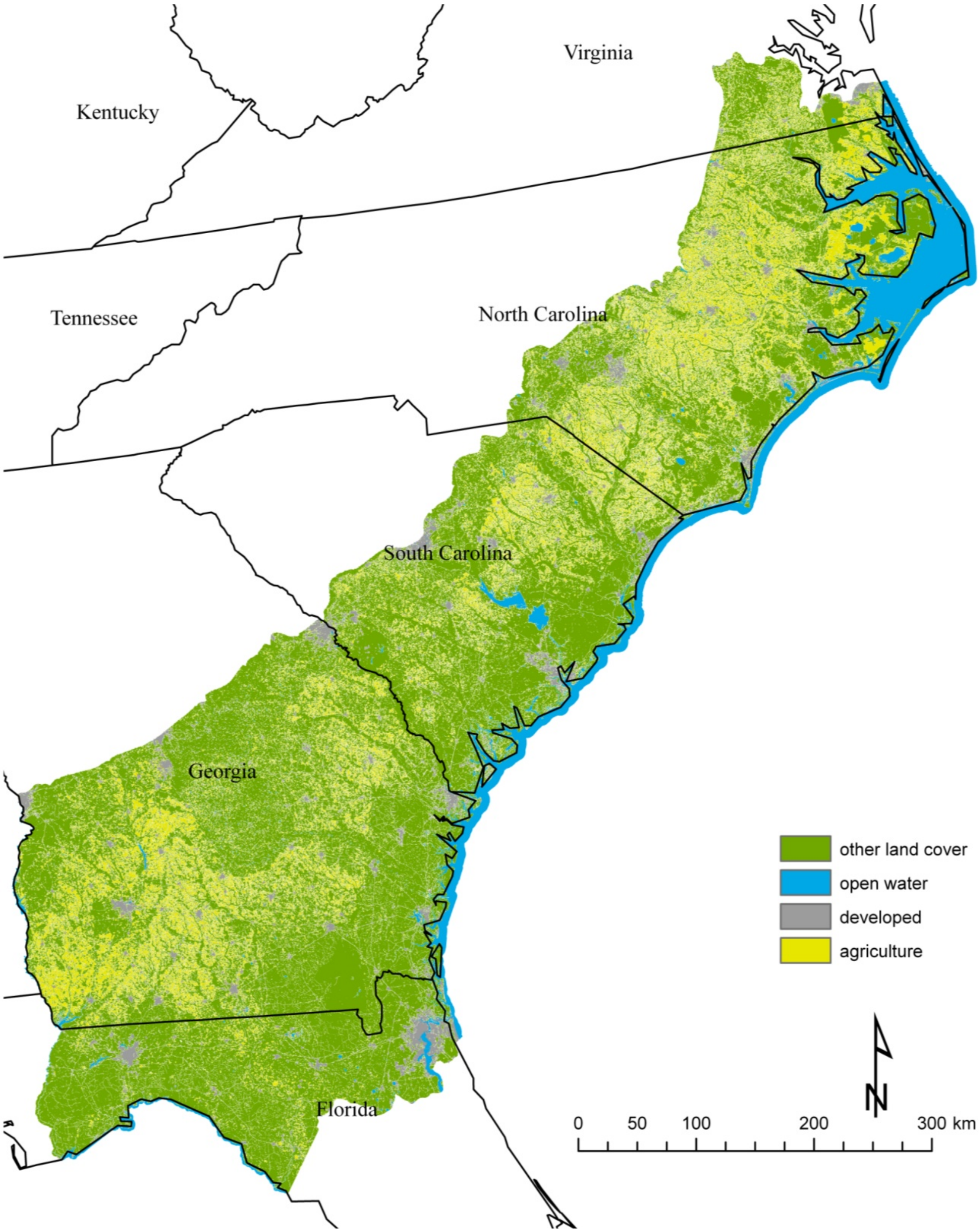

Figure 2.1: The study region in the Southeastern United States included coastal plain regions of Virginia, North Carolina, South Carolina, Georgia, and Florida.

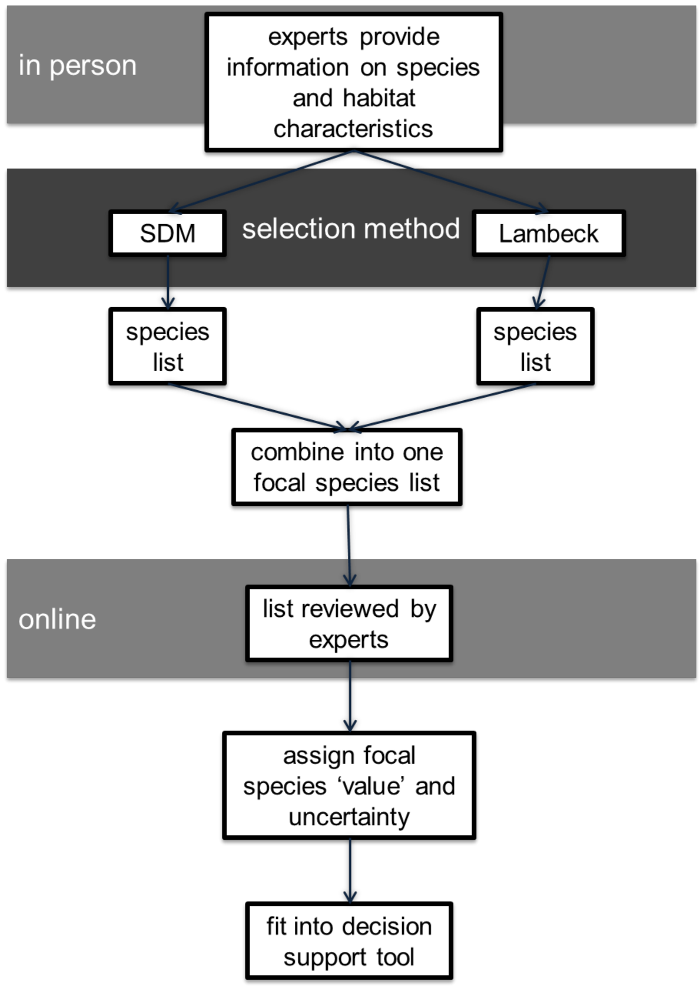

Figure 2.2: The process we used to create the list of focal species based on an elicitation of expert knowledge using two selection methods. Initially, we met the experts in person to learn their opinion of how species use different habitat characteristics. We used this information in the two selection methods to create lists of potential focal species. We then combined the two lists into a single list, which we asked the experts to review in an online meeting. We will use the results of this review to create a spatially explicit model to support bird conservation efforts.

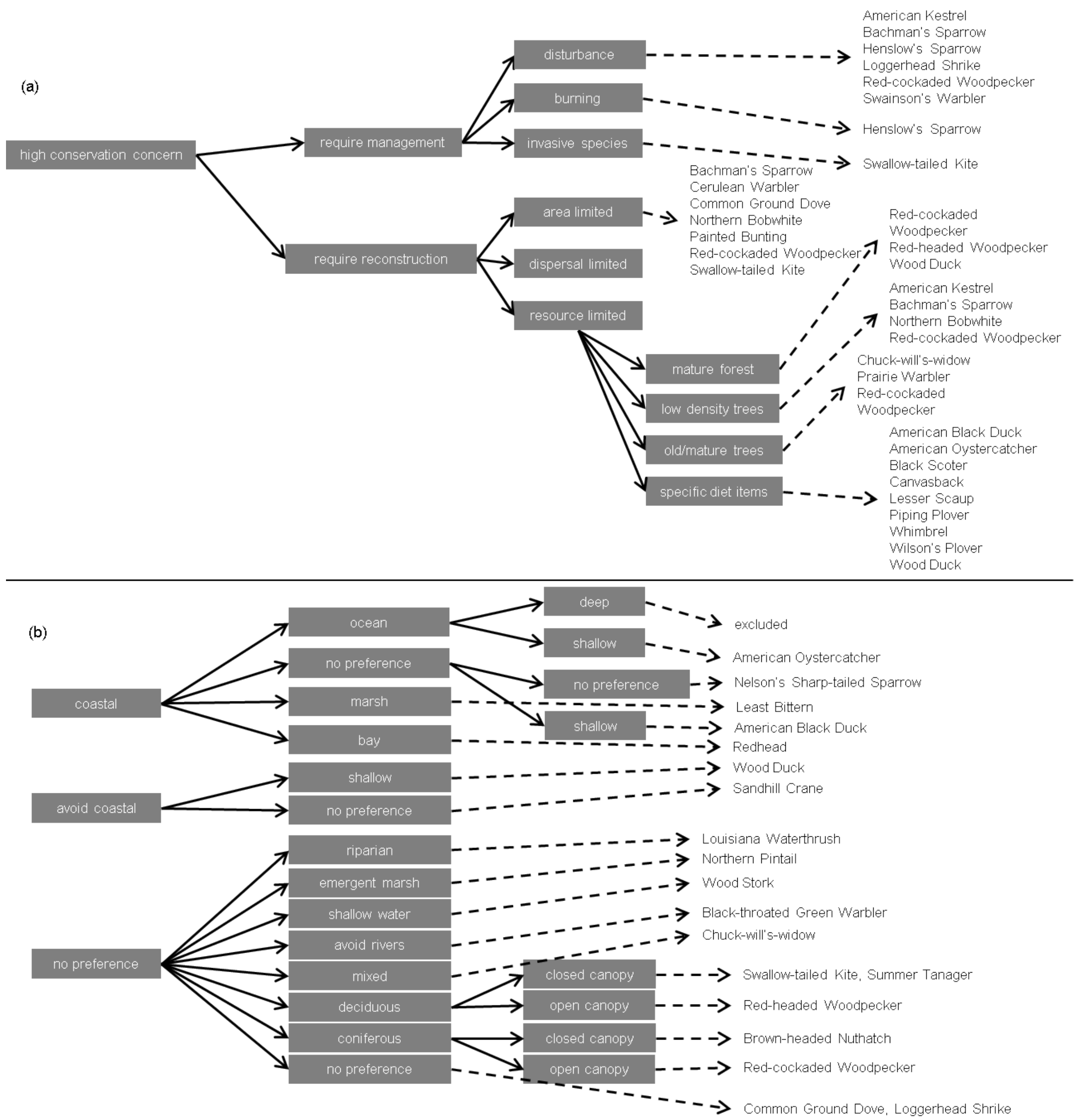

Figure 2.3: We used two different processes to select focal species using the results of our elicitation of expert opinion. (a) A process based on that of Lambeck [50]. (b) A process based on structured decision-making (SDM). Species common names are those designated in American Ornithologists' Union[1]

Table 2.1: Characteristics of the habitats used to inform the selection of focal species and to define key functional characteristics

Habitat class	Characteristic	Comments
Hydrological	coastal	use areas adjacent to coast, not necessarily marine habitat
	water type	
	water depth	
	salinity	
	presence of submerged aquatic vegetation	
	aquatic macroinvertebrates	
	turbidity	
	flooding	includes both seasonal and tidal flooding
	high-energy shore	
	low-energy shore	
Disturbance	any	
	high fire frequency	every 3 to 5 years
	growing season fires	
Vegetation	canopy cover	
	mid-story	
	understory	
	low basal area	less than 50 sq ft per acre
	old or mature trees	required for nesting or foraging
	mature forest	
	bare ground	
Other	patch size	
	social aggregation	individuals or pairs associate with others with or without overlap
	large forest patch	requires a large patch of contiguous forest
	elevation	
	urban avoidance	
	edges	between habitat types or between land and water
	large home range	
	invasive species	

Table 2.2: Example of a table used to select the focal species using structured decision-making in which experts ranked species preference for or avoidance of specific habitat characteristics. Thirteen additional habitat types and 42 associated species were similarly assessed. Scores ranged from 1 (prefer) to 5 (avoid). If experts disagreed, the range of answers was reported. Species were selected as focal species selected on Lambeck's method [50] (L), using SDM (SDM), using both methods (both), or using an online survey (online). Other species were not selected as focal species (NS). Common names conform to those in the American Ornithologists' Union standard [1]

Habitat	Species	Method	Hydrology			Structure	
			Coastal	Water type	Depth	Forest type	Canopy
Beach[a]	American Oystercatcher	both	1	1-ocean	5		
	Piping Plove	L	1	1-ocean	5		
	Wilson's Plover	L	1	1-ocean	5		
	Whimbrel	L	1	1-ocean	5		
	Least Tern	NS	2	1-ocean	4		
	Black Skimmer	NS	2	1-ocean	4		
	Royal Tern	NS	1	1-ocean			
Beach[b]	Red Knot	both					
Deep-water coastal[c]	Redhead	both					
	Black Scoter	L	1	1-ocean	1		
	Canvasback	L	1-4	1-2 open			
	Lesser Scaup	L	1	1-open	1-medium		
Inland[d]	Sandhill Crane	SDM	4				
	American Woodcock	NS			4		
Riparian[d]	Louisiana Waterthrush	SDM		1-riparian	5	deciduous	2
	Acadian Flycatcher	online		1-riparian		deciduous	1
	Cerulean Warbler	L		1-riparian		deciduous	1
Non-riparian[d]	Black-throated Green Warbler	SDM		2-not rivers		mixed	1
	Prothonotary Warbler	online		2		deciduous	

[a] breeding and non-breeding habitat
[b] migration habitat
[c] non-breeding habitat
[d] breeding habitat

Table 2.3: Example of the tabular summaries generated from our online survey to validate the selection of focal species. Experts were asked "How well did the species work as a focal species within alluvial forested wetlands?" Species groups for 11 additional habitat types were assessed and similarly summarized. Numbers represent the number of experts who chose a given score. Totals represent the sum of each score multiplied by the number of respondents who chose that score. The weighted score equals the total score divided by the number of experts who felt they had sufficient knowledge to assign a score. Common names conform to those in the American Ornithologists' Union standard [1]

Species	Very poorly	Poorly 1	Neutral 2	Well 3	Very well 4	Insufficient knowledge 5	Total score	Weighted score
Prothonotary Warbler	0	0	0	1	10	1	53.64	3.3
Swainson's Warbler	0	1	1	2	7	1	47.76	3.0
Yellow-throated Warbler	0	1	0	5	5	1	47.28	2.9
Wood Duck	0	1	2	1	7	1	46.68	2.9
Swallow-tailed Kite	0	1	2	1	5	3	37.08	2.6
Cerulean Warbler	2	1	3	4	1	1	33.60	2.1
Black-throated Green Warbler	2	1	4	3	1	1	32.64	2.0
Mallard	2	1	3	3	0	3	24.96	1.8

Chapter 3

Focal species as method to plan spatially explicit conservation priorities

3.1 Abstract

Here we present a novel method for prioritizing large areas for conservation which integrates spatial reserve design principles including prioritizing vegetation patches that are large, round and close to other patches. We compare the results of this prioritization process using three different conservation proxies because over large areas, it is impractical to model all species. For proxy conservation targets for avian conservation, we used vegetation type based on publically available data; focal species, which required additional habitat models; and expert-derived focal species values (*fsv*) were used to weight species based on how well species functioned as focal species. Three binary grids were used to develop priority surfaces based on vegetation type suitability, conservation lands, and urban. The other two prioritization methods used focal species to identify priority areas by using additional species-specific datasets potential habitat and putative source populations. We used the density of each binary grid, calculated by a two-dimensional kernel density estimator, to calculate conservation priority for each location in a regular 200 m grid across the entire SAMBI area. Density grids were combined for all associated focal species, suitability, conservation land, and urban data where appropriate. Our method produced rounded conservation areas because kernel density was calculated over an elliptical window. This was especially evident for long linear sites like those of maritime forest which showed increased conservation priority in areas that made the sites less linear and more round. Kernel density estimation also allowed increases in priority value of sites within the dispersal distance of birds from potential source populations. Using only vegetation type density to create conservation priority maps resulted in more high conservation priority areas compared to focal species prioritization

except for the most restricted vegetation types, such as those that were maritime-associated. Conservation priority surfaces created using focal species and *fsv* were very similar. The use of *fsv* should be determined by resources available to researchers because gathering the data can be done using an online survey. Using vegetation type alone to create priority surfaces required fewer data and the data are more readily available (all sourced from publically available datasets), but it did not reflect species habitat use making it problematic for conservation efforts targeted at species.

3.2 Introduction

To be effective at protecting or increasing populations or individuals, conservation efforts must maintain or increase habitat quality and quantity. However, given limited conservation resources, it is important to ensure conservation efforts are focused where they have the greatest benefit rather than concentrated where land is unimportant economically [95]. Two major decisions that must be made when conservation planning are the targets of the planning and what proxies should be used. The two broad categories of targets are species or taxa, and conservation features such as vegetation type. If the target is a single species, conservation planning can be done directly from data from the species, but when problems get more complex and involve numerous targets, it becomes more imperative to select appropriate proxies for the planning. Here we consider conservation planning over a large area and targeting avian species of concern using three different proxies: vegetation types associated with avian habitat, a suite of focal species, and focal species weighted by how well they function as focal species.

The use of focal species in conservation planning continues to be controversial. Focal species are selected for their sensitivity to conservation actions and when management actions are focused on these species, it is intended to provide protection for many other species in the ecosystem [57]. In contrast to conservation planning based on vegetation types or landforms, focal species can provide information on quantity and arrangement of conservation areas as well as allowing planning on a finer scale [102]. However, using focal species in conservation efforts has been criticized. Based on computer simulation, Andelman and Fagan [3] found focal species selected according to a number of schemes (e.g. selecting all big carnivores), did not perform any better than randomly chosen suites of species. The effectiveness of focal species has also been found to vary when the taxa of focal species differed from that of target species for conservation action [102]. For instance, selecting conservation areas based on bird species did not protect butterfly species [28], nor did protecting habitat for large mammals protect smaller mammals [12]. However, using focal species in more limited situations, such as within a realm (terrestrial, marine, or freshwater) or using vertebrate species as conservation surrogates for nonvertebrates, does appear somewhat effective [104].

Using features like habitat or vegetation types to design conservation priorities is an alternative to using focal species. In this method, areas where vegetation types suitable for avian conservation are common, high quality, and close together are prioritized over less appropriate sites [70]. Using features like vegetation types or abiotic data like geology or climate to conserve biodiversity may not be as effective as using focal species [104]. However, data about these features are easily available for large areas whereas data for individual species may be lacking or may vary with location. Our objective was to compare focal species-based and vegetation type-based conservation prioritization using a novel method based on the density estimation of these proxies.

Conservation prioritization gives conservation practitioners a way of distinguishing among areas based on their conservation potential or value. Here we present a novel method for prioritizing large areas for conservation that integrates spatial reserve design principles including prioritizing vegetation patches that are large, round and close to other patches **??**. Current prioritization methods are limited with respect to their spatial explicitness and require extensive time and computational resources. Our method should be straightforward to calculate and yet provide detailed information about where to focus resources for conservation efforts including land acquisition, vegetation restoration and management.

3.3 Methods

3.3.1 Study site

Our study area was the Coastal Plain of the southeastern United States including the eastern portions of North Carolina, South Carolina, Georgia as well as southern Virginia and the panhandle of Florida (Fig.4.1). Based on the South Atlantic Migratory Bird Initiative (SAMBI) Plan [128], the habitats were grouped into general vegetation type categories: grasslands and associated habitats (grassland); managed and palustrine emergent wetlands (freshwater wetlands); early successional and shrub-scrub (scrub); alluvial forested wetlands; non-alluvial forested wetlands (including pocosins, and Carolina Bays); maritime forest and shrub-scrub; estuarine emergent wetlands (estuary); beaches and dunes (beach); longleaf/slash pine flatwoods and savannas (longleaf); mature open pine; hardwood/pine mixed forest (upland forest); and riparian/mixed mesic forest (slope forest).

3.3.2 Focal species selection and weights

We worked with experts to select a suite of focal species to represent the larger assemblage of avian species in the SAMBI area [72]. These experts consisted of representatives from state and federal government agencies and non-governmental conservation organizations. The list of potential focal species was based on the species of concern associated with habitats in SAMBI [128]. Experts were asked to identify and score vegetation characteristics required for each potential focal species. We created a focal species list based on expert responses including species of management concern, species that were sensitive to the landscape arrangement, and within a habitat, species with non-overlapping vegetation requirements [72].

To assess whether species should be added or removed from the focal species list and to determine focal species values, we ranked species using an online tool [118]. The tool included supporting documentation and was introduced to respondents during a conference call. We asked experts to review and rank all species of concern including those we selected as focal species. We provided criteria for evaluating whether a species was a suitable focal species. The focal species could meet one or more of the following criteria: representative of other species, well-known biology, easily sampled or observed, sensitive to disturbance, umbrella species, flagship species, habitat specialist, dietary specialist; or keystone species [13]. Our questionnaire listed species associated with each habitat category and we highlighted focal species that were included on our focal species list. The participants scored the suitability of each species as a focal species using values from 1 (would perform very poorly) to 5 (would perform very well); they could also respond that they had insufficient personal knowledge to evaluate the species. For each species, an overall focal species value (*fsv*) was calculated by averaging expert scores.

3.3.3 Spatial data

There were up to five potential binary grids (matrices) developed for identifying priority areas for conserving each vegetation type but these differed with conservation target, which were vegetation type, focal species, and focal species values. We used ArcGIS Version 9.3 (The Math Works, Natick, Massachusetts) and MATLAB Version 7.10.0.499 (Environmental Systems Research Institute, Redlands, California) to create and manipulate spatial data. The SAMBI area was divided into a regular 200 m grid (Fig. 3.1) and each grid cell was scored as a 0 (absent) or 1 (present) depending on whether specific resources or landscape characteristics were present. Three binary grids were used to develop priority surfaces based just on vegetation type (1) suitability, (2) conservation lands, and (3) urban. Both priority calculation methods using focal species used five binary grids: (1) suitability, (2) conservation land and (3) urban, as described above; and two species-specific grids created for each focal species that bred in the SAMBI region, (4) potential habitat and (5) putative source populations. The grid for potential habitat was based on range maps, land cover, ancillary data (landform, stream location, etc.), and minimum patch size requirements combined with extensive literature review and expert opinion as described by McKerrow et al. [65]. Similarly, the putative source population grid for each focal species was mapped by identifying patches of potential habitat that were large enough to support at least 200 territories [123]. Territory size was determined from literature review (Table 3.2).

We developed binary grids of suitability for the priority vegetation types using landscape characteristics and landform (Table 3.1). These data were used to exclude areas where it was considered impossible for a specific vegetation type to occur. For all vegetation types, we used landform data derived from National Elevation Dataset for Southeastern Gap Analysis Project [65]. For maritime-associated vegetation types (maritime forest, estuary, beach), their inland extent was restricted by a manually digitized boundary based on the maximum extent of existing maritime-associated habitats. Conservation lands for SAMBI were extracted from the protected areas database for the United States [98] which includes federal, state, non-governmental, and land trust lands set aside for conservation. We intersected suitability data with the PAD-US data for each vegetation type so that only suitable conservation lands were included in the prioritization for each respective vegetation type. Grassland, longleaf and mature open pine could all be managed with fire so we excluded urban areas from their conservation priority surfaces. For the urban layer we included areas categorized as developed open space, and low-, medium-, and high-intensity developed.

3.3.4 Density estimation

After we developed the binary grids for all the landscape characteristics, we calculated the density of each binary grid to calculate conservation priority for each grid cell. Areas where a given characteristic were clustered were given a high density value (Fig. 3.1). We mapped density using a two-dimensional kernel density estimator [110] in the Kernel Density Estimation Toolbox (*kdtools*[7]) using MATLAB. The estimator is used to calculate density based on probability of occurrence across a gridded space. For each observation, weight is assigned to each grid cell as a function of the distance from the observation to the center of the cell. We used a bivariate normal kernel with a fixed bandwidth which assigns weights that decline rapidly in a sigmoid fashion with distance from each observation based on the spatial distribution of all observations. For potential habitat, suitability, and conservation lands we use the normal scale rule, and bandwidth, the parameter that determines the diameter of the kernel (kernel size, h), based on the equation:

$$h = 1.0592qn^{-0.2} \tag{3.1}$$

where h is the bandwidth, n is the number of observations, and

$$q = \min(std(x), R/1.34) \tag{3.2}$$

where x is the grid point(s), std is the standard deviation of x, and R is the interquartile range of x.

To emulate colonization potential of putative source populations for each species, we used a kernel size equal to the estimated dispersal distance. We used the larger of natal or breeding dispersal distance based on published sources (see Table 3.2 for list of references), or for species without known dispersal distances, we used an allometric equation based on size and diet classification (Table 3.1) [119]. For urban areas, we used kernel size of 1200 m, which represents a distance of minimal impediment to the use of prescribed fire (Grand unpubl.). Each density dataset was scaled to a range of 0-1 by:

$$w = w/\max(w) \tag{3.3}$$

where w is the weight assigned to each grid cell, before being used in further analysis to avoid unequal weighting in the prioritization of surfaces with different numbers of density grids.

3.3.5 Modeling priorities

We calculated priority by combining the grids of densities for all associated focal species, suitability, conservation land, and urban data where appropriate (Fig. 3.2). During meetings with experts, we asked them what data layers were essential for each vegetation type [72] and we used this information to create models for vegetation types.

To calculate priority surfaces for vegetation types where experts determined fire was a limiting characteristic (Table 3.1), we used the equation:

$$Pr_i = (1 - U_i)\, S_i C_i \tag{3.4}$$

where for vegetation type i, Pr_i is the grid of priority scores (priority surface); and S_i, and C_i are the density grids for suitability and conservation lands, and U is the density grid of urban areas.

For all other vegetation types that did not include the urban layer, we used the equation:

$$Pr_i = S_i C_i \tag{3.5}$$

Pr_i was also scaled to range of 0-1 by:

$$Pr_i = Pr_i / \max(Pr_i) \tag{3.6}$$

Priority surfaces were calculated using focal species and where fire was a limiting characteristic, we used:

$$Pr_i = (1 - U_i)\, S_i \left(C_i + \sum_{j=1}^{m_i} EH_{ij} + \sum_{j=1}^{m_i} SP_{ij} \right) \tag{3.7}$$

where for vegetation type i, Pr is the grid (matrix) of priority scores; and S and C are the weights for suitability and conservation lands, $1 - U$ is the weight of the non-urban areas and for the m focal species, EH and SP are the potential habitat and putative source population weights focal species j.

For all other vegetation types that did not include the urban layer, we used the equation:

$$Pr_i = S_i \left(C_i + \sum_{j=1}^{m_i} EH_{ij} + \sum_{j=1}^{m_i} SP_{ij} \right) \tag{3.8}$$

Probability surfaces were scaled to a range of 0-1 by:

$$Pr_i = Pr_i / \max(Pr_i) \tag{3.9}$$

To weight priority surfaces by focal species value, we used the above equations with the addition of focal species value (fsv). For example, including the urban layer:

$$Pr_i = (1 - U_i)\, S_i \left(C_i + \sum_{j-1}^{m_i} fsv\, (EH_{ij} + SP_{ij}) \right) \tag{3.10}$$

3.3.6 Analysis

We made spatially-explicit comparisons of priority surfaces by subtracting one priority surface from another. Because surfaces were normed to one, areas that were not different received a score of 0, and differences scored between -1 and 1. We defined no difference between surfaces as less than 95% of pixels differing. We also compared surfaces by calculating skew and kurtosis of priority value distributions. Skewness (γ) measures distribution symmetry as follows:

$$\gamma = \sum_{i=1}^{n} \left(q_i - \bar{q}^3 \right) / (n-1)\, std^3 \tag{3.11}$$

where q is the priority score of an individual pixel and $\bar{q}$ the mean score of all pixels for a surface, n is the number of pixels and std is the standard deviation of the priority scores. A normal distribution has a value of 0, negative values indicate left-skewed distribution, i.e. a long left tail, and positive values indicated right-skew.

Kurtosis (κ) which measures peakedness is:

$$\kappa = \left(\sum_{i=1}^{n} \left(q_i - \bar{q}^4 \right) / (n-1)\, std^4 \right) - 3 \tag{3.12}$$

where q is the priority score of an individual pixel and $\bar{q}$ the mean score of all pixels for a surface, n is the number of pixels and std is the standard deviation of the priority scores. A normal distribution has a kurtosis value of 0 (more accurately known as excesses kurtosis), more peaked distributions (leptokurtotic) having positive values and less peaked distributions, negative values.

3.4 Results

3.4.1 Focal species selection

There were 53 experts who participated in the elicitation meetings and 15 who provided our species rankings. We did not remove any species from the focal species list based on the ranks, but we added 11 species to our model based on the expert scores. As the initial focal species list was 31 species, our prioritization process used a total of 42 species (Table 3.1) [72].

3.4.2 Distribution of priority scores

For priority surfaces created using vegetation types, the maritime-associated vegetation types (beach, estuary, and maritime forest) and the non-alluvial forested wetlands had positive values for skew ($\gamma > 1$; 3.3) indicating that a small number of sites were given high priority ($Pr > 0.75$). Grassland was the only vegetation type to show a left skew ($\gamma > -1$) and the rest of the vegetation types were normally distributed ($1 < \gamma < -1$). All vegetation types had positive kurtosis values indicating distributions more peaked than normal, with beach, maritime forest and estuary having the most highly peaked distributions ($\kappa > 10$; Fig. 3.4).

The distribution of priority scores was highly skewed ($\gamma > 4$) and leptokurtotic for narrowly distributed vegetation types (beach, estuary, and maritime forest) for priority surfaces of both weighted and unweighted focal species. For vegetation types that were less restricted, slope forest, upland forest, grassland, and wetlands distributions demonstrated moderate skewness ($1 < \gamma < 4$) and less leptokurtosis than narrowly distributed vegetation types, and for vegetation types with a relatively wide distribution across the SAMBI, skewness was low ($\gamma < 1$) and they were mesokurtotic. Overall for all vegetation types except beach, priority surfaces created using focal species values were less symmetrical and more peaked than surfaces created without *fsv*.

3.4.3 Priority maps

Generally, using only vegetation type density to create the conservation priority maps resulted in more high priority areas except for the most restricted vegetation types, those that were maritime-associated. Beach (Fig. 3.6), estuary (Fig. 3.7), and maritime forest (Fig. 3.10) showed very similar distributions regardless of the method used to create the priority surfaces (Fig. 3.18 and 3.19), although there were slightly more mid-priority areas when only vegetation type density was used. The area of highest priority occurred along the coast from Brunswick, Georgia to Charleston, South Carolina. High priority areas for wetlands (Fig. 3.16 and 3.20) were also found in this area when focal species densities were used to create the priority surfaces. In contrast, when vegetation type density alone was used, the priority of the interior of SAMBI increased significantly and the highest priority area occurred around the Osceola National Forest and the Okefenokee National Wildlife Refuge on the Florida-Georgia border.

The highest priority areas of alluvial forested wetland for all methods were concentrated in 6 regions along the lower Roanoake River; Waccamaw, Little, and Great PeeDee drainage; Cooper River; confluence of the Congaree and Wateree Rivers; middle and lower Savannah River; and the lower Altamaha River (Fig. 3.5). Only a small percentage ($< 2\%$) of the

SAMBI was of high conservation priority (Pr >75th percentile) for alluvial forested wetland bird habitat using focal species; however using just vegetation type, there was a much greater percentage of the area which was high priority. High priority areas for nonalluvial forested wetlands (Fig. 3.11), slope (Fig. 3.14) and upland forest (Fig. 3.15) systems occurred in association with alluvial forested wetland vegetation type when priority surfaces were created using focal species. Conversely, using only vegetation type density to create the priority surfaces for these vegetation types resulted in much more broadly distributed and more numerous high priority areas.

In comparison, moderate priority ($0.25 < Pr < 0.75$) grassland conservation areas were common (> 97%) and widely distributed (Fig. 3.8). This was due to the relatively widespread occurrence of suitable areas for grassland conservation across the SAMBI. However, using focal species compared with only vegetation type density produced very different priority surfaces. Using focal species, the highest priority regions ($Pr > 0.75$) occurred in interior portions of northeast Florida from south and east of Valdosta, Georgia to northwest of Gainesville, Florida. Using only vegetation type, most of SAMBI region including northern areas which were of low priority using focal species, was high priority with only urban areas standing out as unsuitable. The distribution of priority areas for scrub was also widely distributed and compared with grassland, extended farther north in SAMBI using focal species (Fig. 3.13) and was lower priority using only vegetation type.

The highest priority ($Pr > 0.75$) areas for longleaf conservation were concentrated in northern Florida and along the Georgia-Florida border south of Thomasville, Georgia when the priority surface was created using focal species (Fig. 3.9). There were more high priority areas for longleaf when only vegetation type density was used to create the priority surface and the highest priority areas were situated around Apalachicola National Forest in Florida and in Francis Marion National Forest in South Carolina with more moderate priorities throughout North and South Carolina.

Moderate priority areas for conservation of open pine systems were widespread because suitable areas were widely available. Using focal species, the highest priority areas also fell along the Georgia-Florida border south of Thomasville, Georgia (Fig. 3.12). When only vegetation type density was used, the highest priority areas were much farther inland along the fall line that separates the coastal plain and Appalachian ecoregions. There were also high priority open pine conservation areas around the national forests in Florida (Apalachicola and Osceola), and South Carolina (Francis Marion) and the Okefenokee National Wildlife Refuge.

Priority surfaces created using focal species values were similar to those without except priority values were generally lower (Fig. 3.17, 3.18, 3.19, and 3.20).

3.5 Discussion

One of our objectives was to integrate principles of conservation We used kernel density estimation to provide a single approach to address conservation area size, shape, and connectivity which allowed us to integrate principles of conservation biology into a spatially explicit conservation planning process. Kernel density estimation prioritized large patches of appropriate sites because it considered the neighborhood around each pixel so areas with a high density of appropriate sites had the highest priority. Larger, denser patches minimize edge and maximize core area, and both are desirable characteristics for reserve design [22] [57]. Our method produces rounded shapes because kernel density is calculated over an elliptical or circular window, which smoothed the resulting surface. This was especially evident for long linear sites like those of maritime forest which showed increased conservation priority in areas that made the sites less linear and more round, although they still remained restricted to areas adjacent to the ocean. Kernel density estimation also allowed us to increase the priority value of sites within the distance a bird could move through varying the kernel size. We used the dispersal distance of birds as the distance over which connection between patches was important. Birds have relatively large dispersal distance, especially the focal species we considered (all greater than 11,000 m except Red-cockaded woodpecker; Table 3.2) but our method could be modified for other species for which connectivity is a more limiting factor in designing conservation reserves by setting kernel size at a smaller distance.

3.5.1 Proxies for conservation

Of the three prioritization methods, conservation priority surfaces created using focal species without *fsv* provided the best reflection of species habitat requirements. Vegetation type densities alone did provide somewhat comparable priority surfaces for vegetation types that were least constrained with respect to suitable sites, for example non-alluvial forested wetlands. The priority surfaces calculated with *fsv* were very similar to those created without, suggesting gathering information to calculate focal species values may not be an effective use of resources. However, the focal species selection process [72] could be easily combined with the online ranking tools we used to gauge focal species values. Our process split the expert elicitation process into a resource-intensive two day set of in person meetings and a follow-up online survey that took less than an hour to complete. The online ranking process could be used alone to delineate a focal species suite by selecting the top ranked species for further modeling, as well as being used to calculate *fsv*. Having the entire process online would require much less time and money although the difference in participation rates between the in person and online parts of our process suggest there may be a participation problem with a solely online survey.

The difference between using focal species or vegetation type as the proxy in conservation prioritization was much greater than between using *fsv* or not. This difference was most pronounced in wide-spread habitats that were not restricted in their site requirements and in habitats which had species with restricted ranges, for example grasslands, open pine and slope and upland forests. The maritime-associated vegetation types were restricted in suitable sites that conservation surfaces based on focal species vegetation type density were in the same locations; however, skew for beach and estuary showed much higher values when focal species were included. For vegetation types associated with rivers (alluvial forested wetlands, slope and upland forests), there were substantial differences between priority surfaces created using vegetation type and focal species proxies. Most noticeably focal species based priority surfaces had small areas of high priority for these habitats along rivers, while the surfaces created with vegetation types had generally moderate priority over the entire region. For these vegetation types, the priority maps with the focal species are more reflective of species habitat requirements and therefore species conservation, than the priority maps without the focal species. Similarly, priority surfaces for grasslands and open pine habitat had lower conservation values in northern regions using focal species, In this case, both focal species for both vegetation types were at their northern range limits within the SAMBI extent and areas north of their ranges were of less value than areas within their range.

Which priority surface stakeholders should use in their decisions is best determined by examining the stakeholder objectives. If stakeholder goals are to conserve wildlife, it is important to use focal species in the conservation prioritization process because the resulting surface better represents species habitat requirements by integrating species-specific landscape preferences. On the other hand, if a more general objective of vegetation or habitat conservation is preferred, priority surfaces based on vegetation type density could be used. Although there were differences between priority surfaces calculated using focal species or vegetation types, the areas of highest conservation priority are similar between the methods for most habitats. The exception was riparian-associated habitats for which using vegetation type density only provided a poor model of conservation priorities because high priorities were not associated with rivers. Although using vegetation type alone to create priority surfaces requires less data and the data are more readily available (all sourced from publically available datasets), it does not necessarily reflect species habitat use well enough. This problem only occurs with some vegetation types, but unless it is known ahead of time which vegetation types would be affected, we suggest conservation planners use focal species to create priority surfaces.

3.5.2 Comparison with other conservation prioritization methods

Previous work on conservation prioritization methods can be broken down into two broad categories: optimization and heuristic processes. Optimization method considers all possible arrangements of sites and selects the solution that best meets the objective [33]. Common objectives include every species represented at a minimum of number of sites or conserve the most species in protected sites with the least cost. Heuristic methods vary but their general process is to select a site that best fulfills the objective, then select another site that compliments that initial selection, and continue to select sites until the objective has been met [69]. So for example, at the first step the site with the rarest species is selected; that site is then taken out of consideration and the site with the next rarest species is selected, etc. MARXAN (http://www.uq.edu.au/marxan/) is a popular heuristic algorithm that is used to select the minimum number of sites or minimum total area needed to represent all biodiversity for a specific cost. Heuristic methods often overestimate the number of sites compared to the optimal solution but optimization is difficult or impossible to apply to large or complex problems [96] [133].

Our prioritization method is significantly different from optimization and heuristic prioritization methods because it remains in a spatial context and is able to integrate several principles of conservation reserve design. It has proved difficult to integrate spatial criteria into either optimization or heuristic methods [133] [33]. Rules can be set to minimize distance between sites [82]; maximizing the number of adjacent sites selected [75] or minimize perimeter length to increase compactness of selected sites [63], but applying multiple rules increases the complexity of the calculations for the solution. The output of optimization and heuristic methods also do not give the conservation value of sites that were not selected for conservation. Our output evaluates all sites on the landscape, like optimization methods, but gives a conservation priority value for all sites, unlike optimization.

3.5.3 Complications

Our priority surfaces may overestimate conservation value to species because priority areas are often a mixture of land cover types, although the ratio of appropriate to inappropriate habitat is correlated with the priority value, i.e. areas with high conservation priority have higher proportion of suitable habitat than low priority areas. This is because kernel density estimation does not require all pixels of similar priority levels to be one vegetation type. However, some vegetation types can be considered complimentary habitats rather than incompatible habitats. For example, in our project grassland is distinct from open pine but the undergrowth species use may be contiguous between these vegetation types, with grassland lacking the scattered pines of open pine habitat. Therefore, grassland mixed with open pine habitat should still have high conservation value for open pine species. Moreover, our prioritization method is based not just on prioritization of current habitat (i.e. existing habitat grids) but also on the potential to restore habitat in areas where it does not occur but the site is suitable for restoration (i.e. suitability grids).This apparent overestimation of conservation value is actually a reflection of the potential of a site rather than just current conditions.

Our process places higher priority on sites that are within or immediately adjacent to existing patches of suitable habitat, unless the areas under consideration in low priority areas are large enough to be of higher total value. We did not attempt to estimate this relationship, but, sensitivity analysis could determine the threshold sizes at which parity between levels of conservation priority occur. Further research should focus on the effects of patch size as they relate to species requirements and priorities.

Over 85% of the land in the Southeastern US is privately owned [17] so stakeholders, which in our project did not include private landowners, are restricted to acquiring land that is available for purchase or easement and for which they have sufficient resources to buy. Restoration and management of existing patches of habitat can be done on both publically owned and privately owned lands through cooperation with landowners, but is again limited by time and monetary resources. All of these factors limit the actions available to our stakeholders with respect to conservation. For this reason our prioritization method is particularly useful since it compares the full extent of the region so comparisons can be made even among moderate or low priority areas. We did not delineate polygons of highest conservation priority to create a set of ideal reserve sites but a set of conservation areas could be drawn by arbitrarily selecting a priority level or patch.

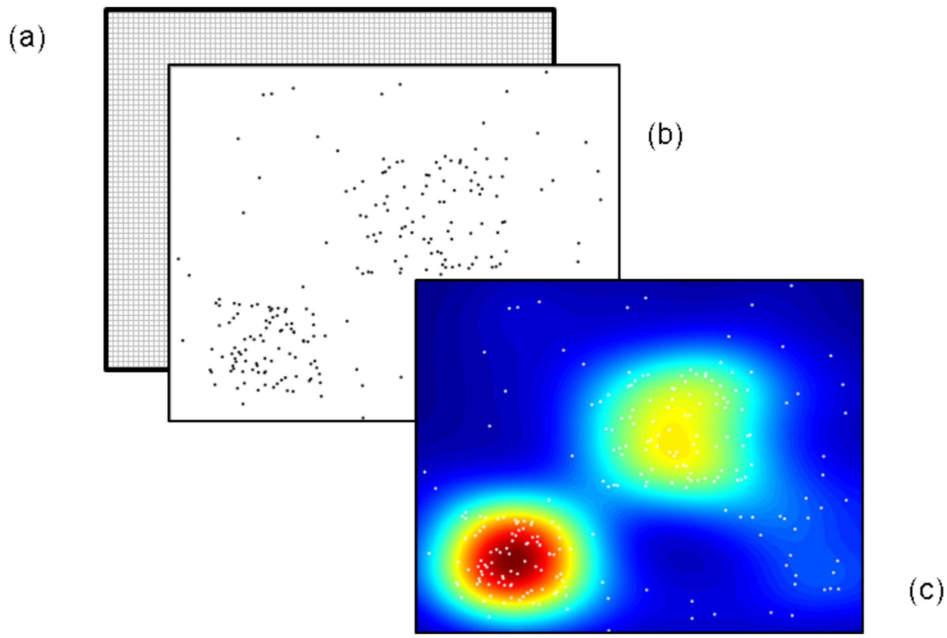

Figure 3.1: Priority surfaces start with (a) gridded space in which (b) resources are found and (c) kernel density estimation is used to calculate the density of these resources

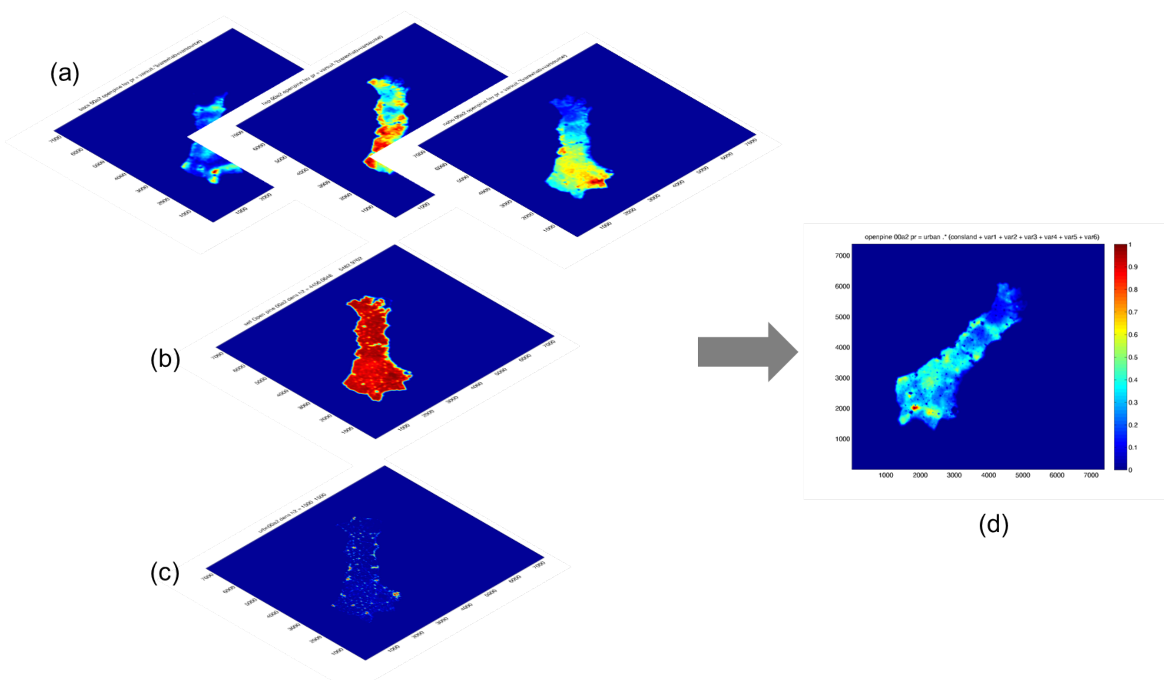

Figure 3.2: Density maps of (a) focal species and (b) suitable sites are combined and (c) urban areas are subtracted in order to create a priority surface for a fire-dependent vegetation type

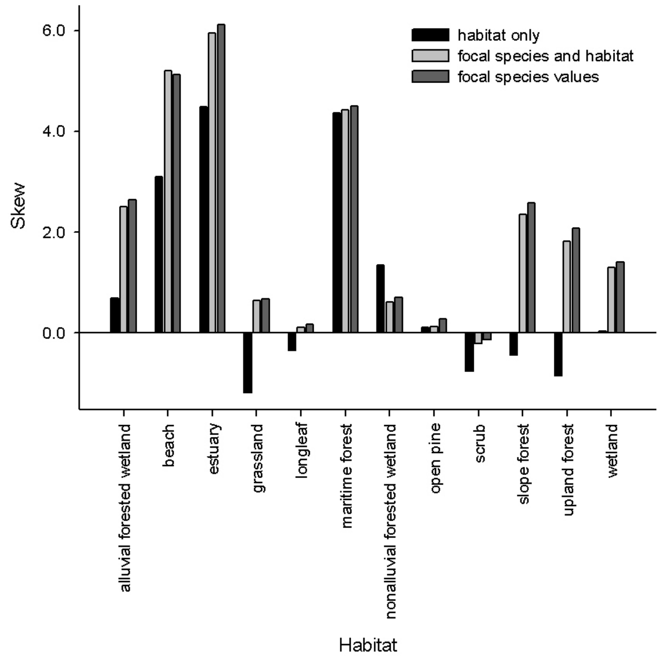

Figure 3.3: Skew for conservation priority values of vegetation types in SAMBI

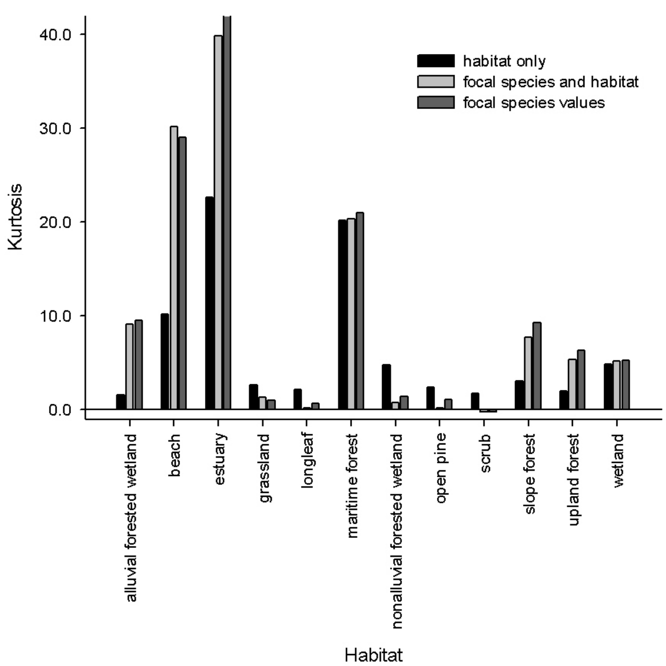

Figure 3.4: Kurtosis for conservation priority values of vegetation types in SAMBI

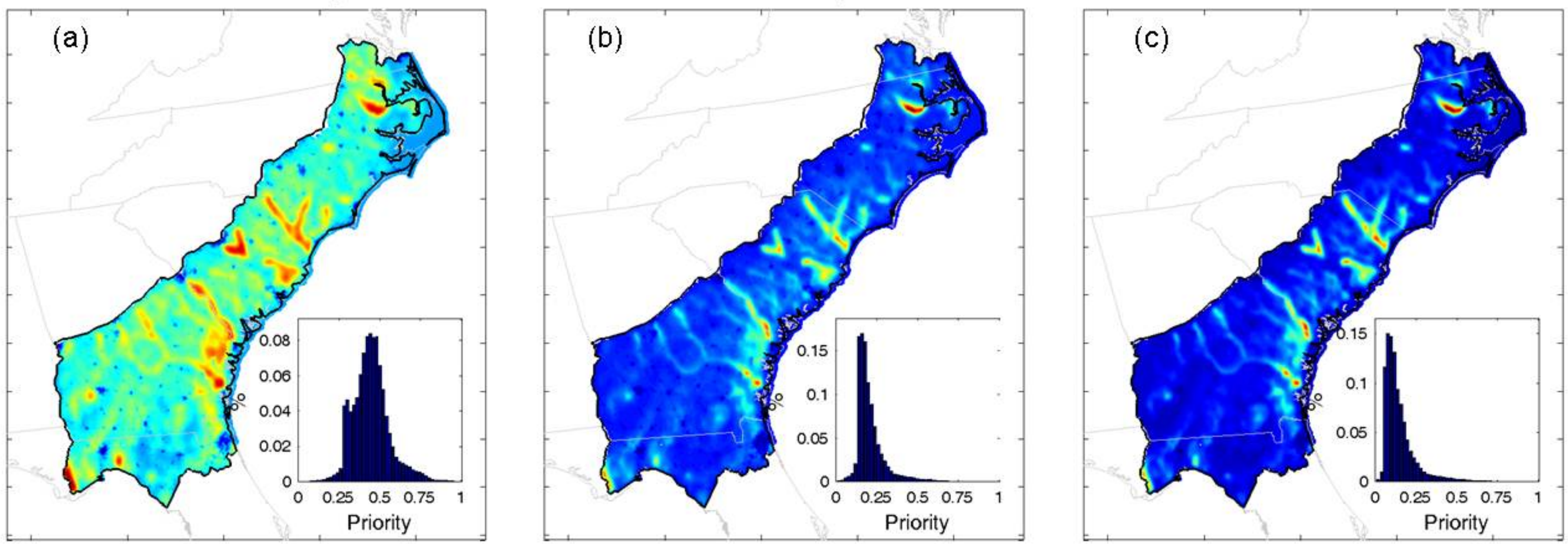

Figure 3.5: Alluvial forested wetland conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

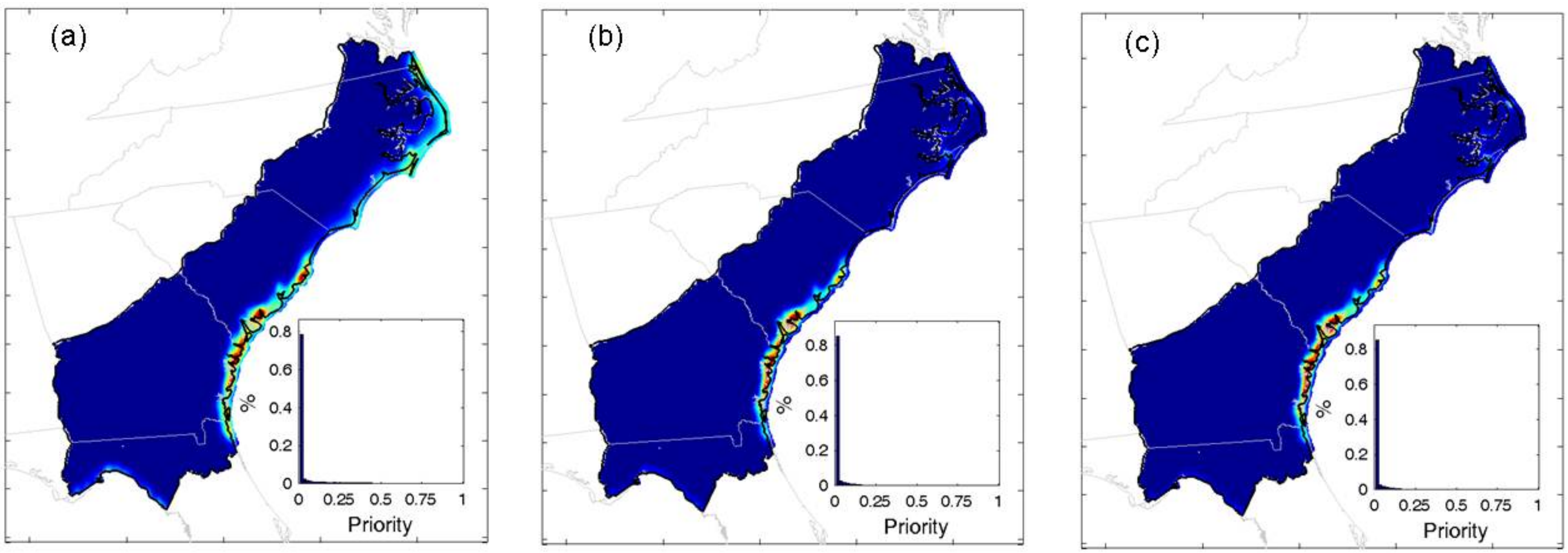

Figure 3.6: Beach conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

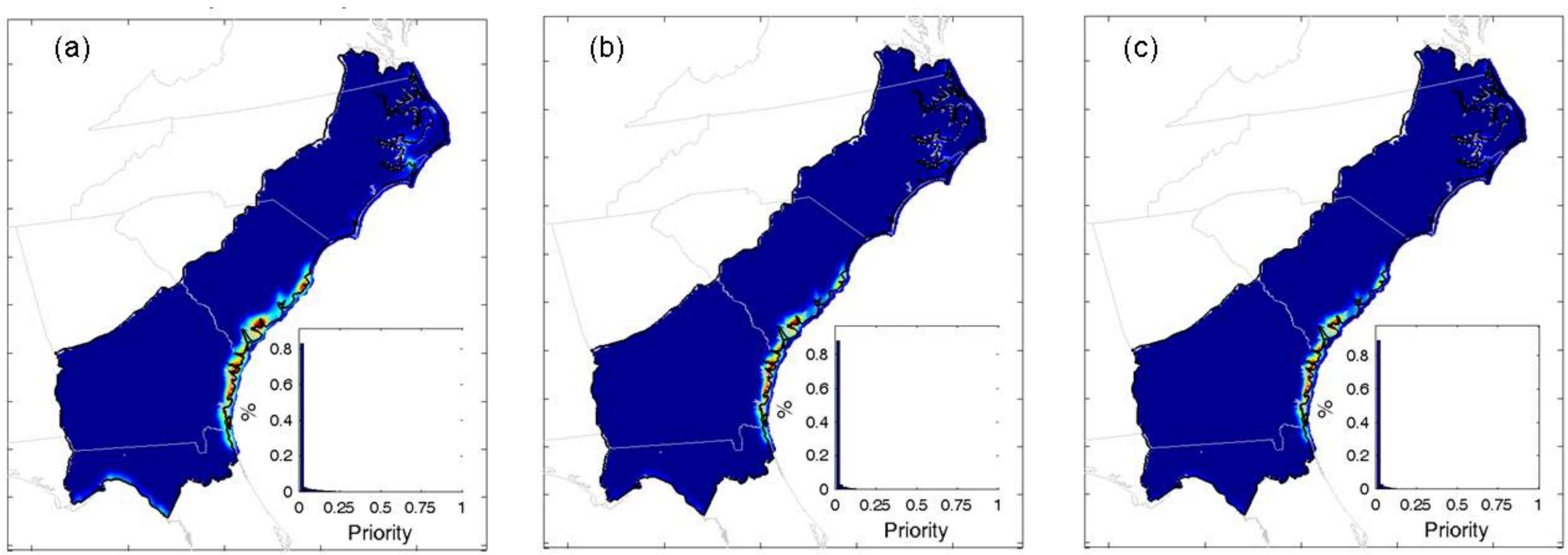

Figure 3.7: Estuary conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

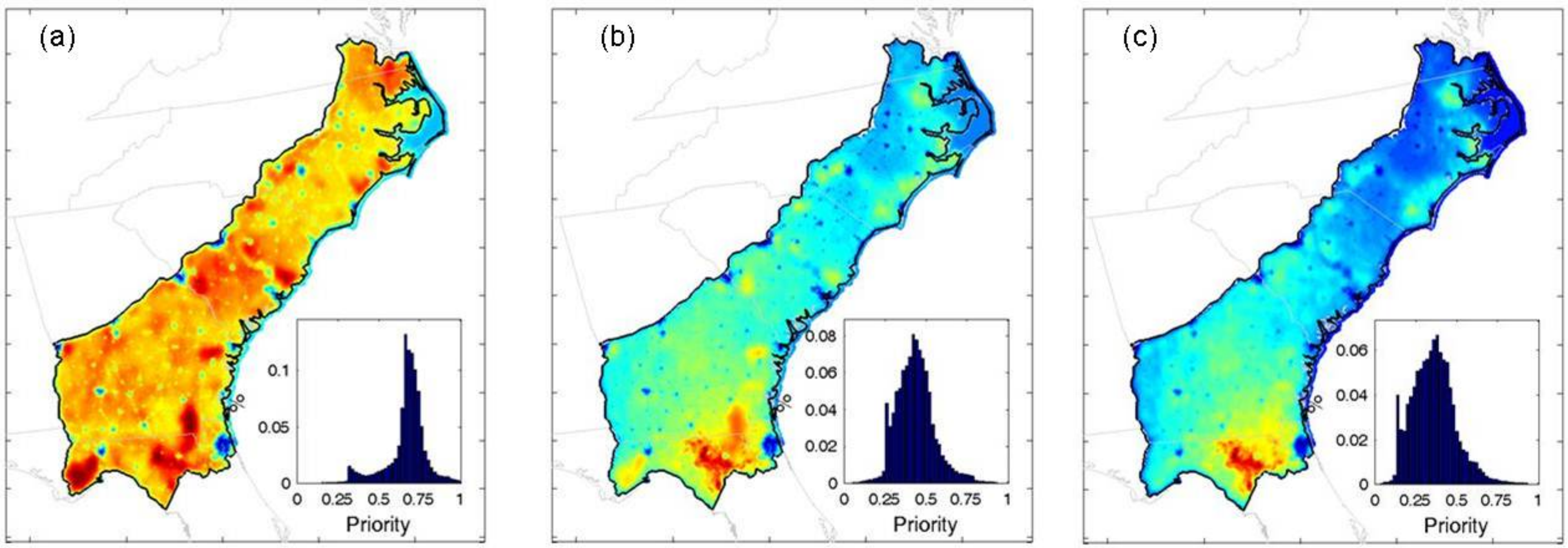

Figure 3.8: Grassland conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

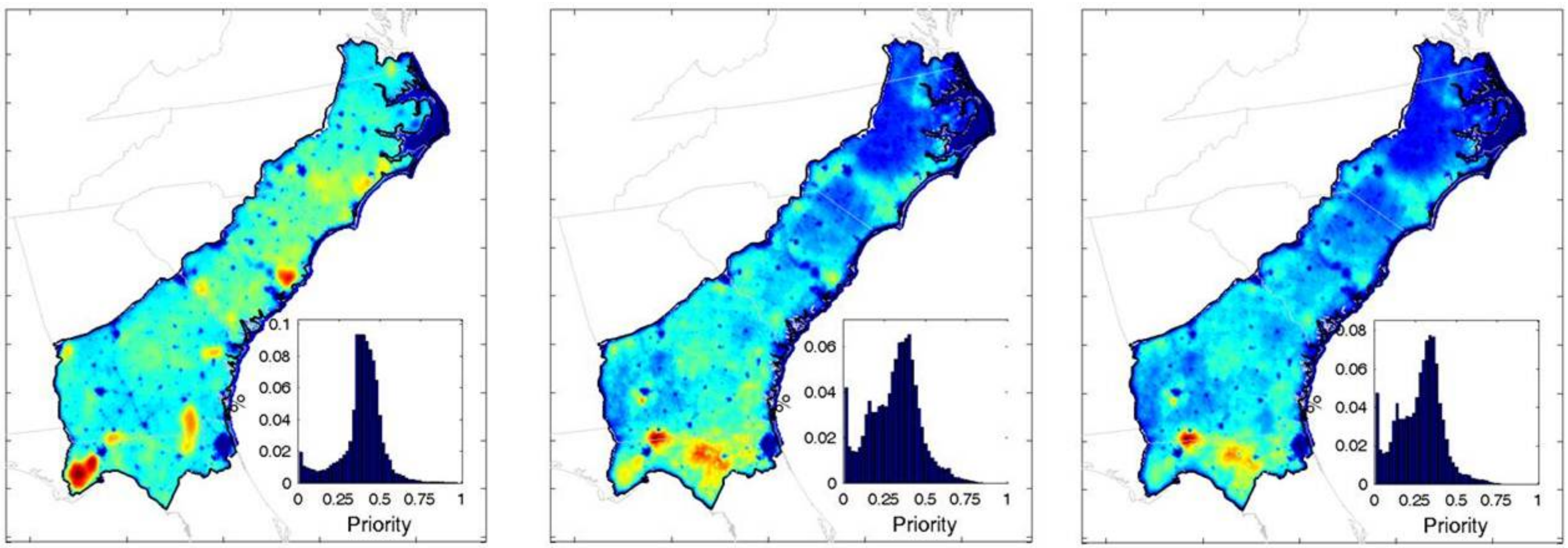

Figure 3.9: Longleaf conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

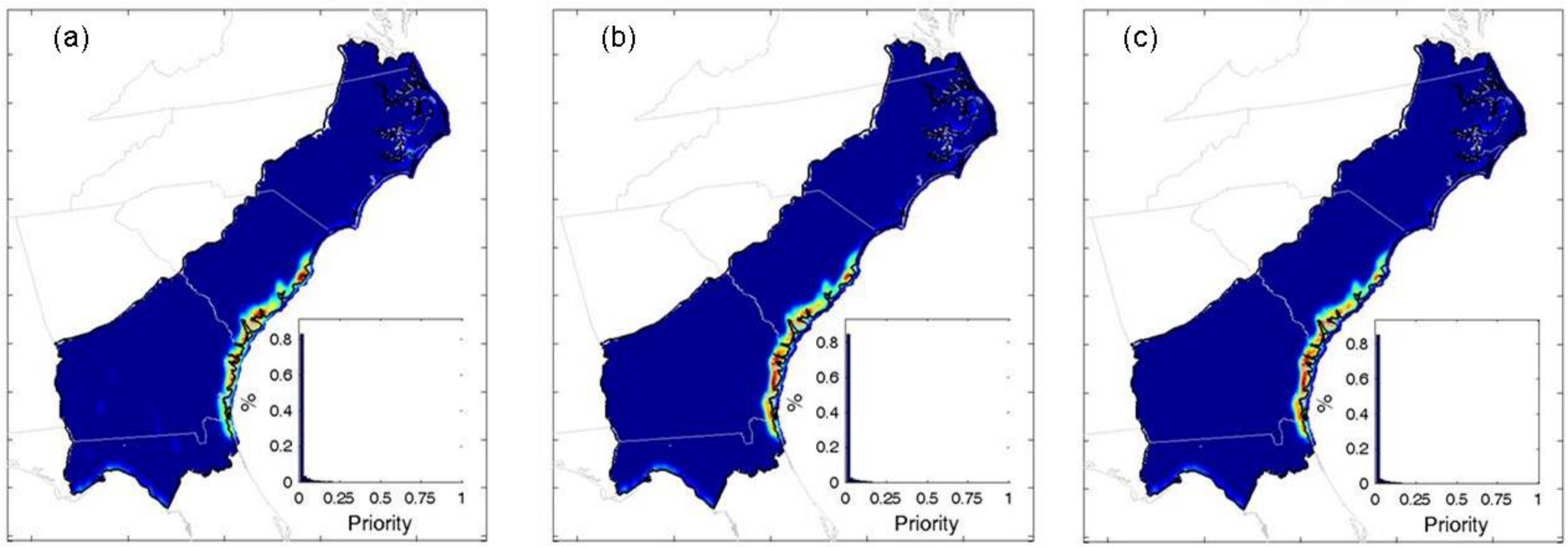

Figure 3.10: Maritime forest conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

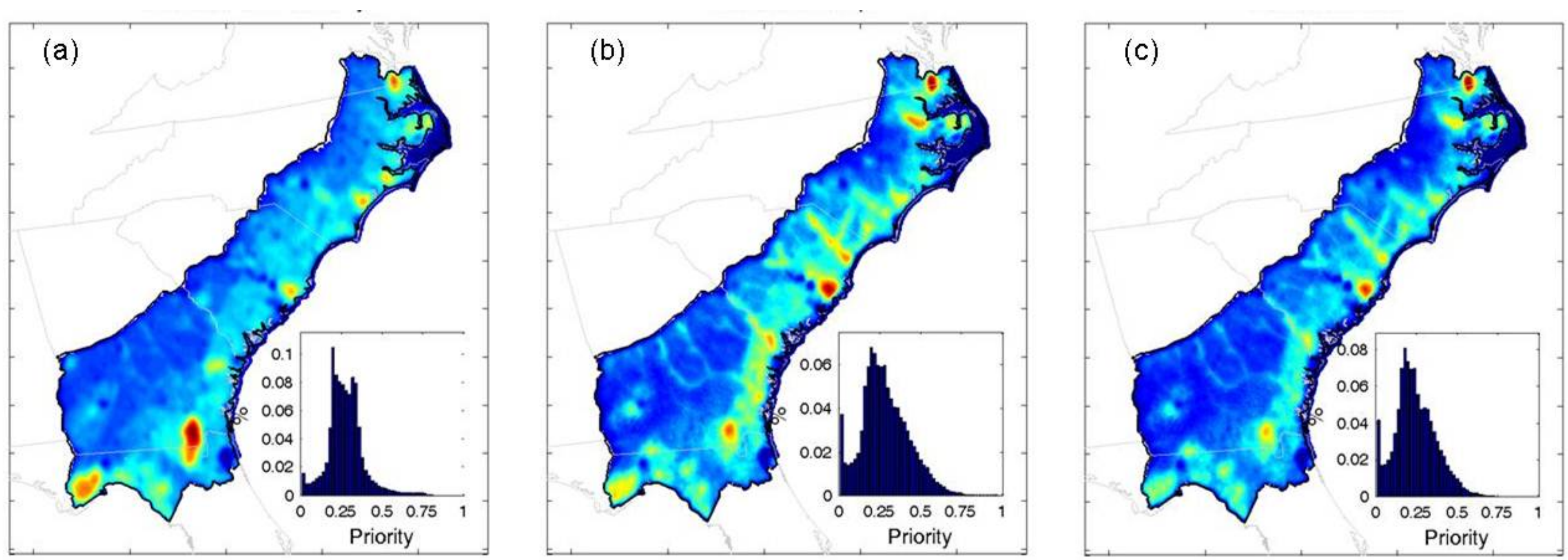

Figure 3.11: Non-alluvial forested wetland conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

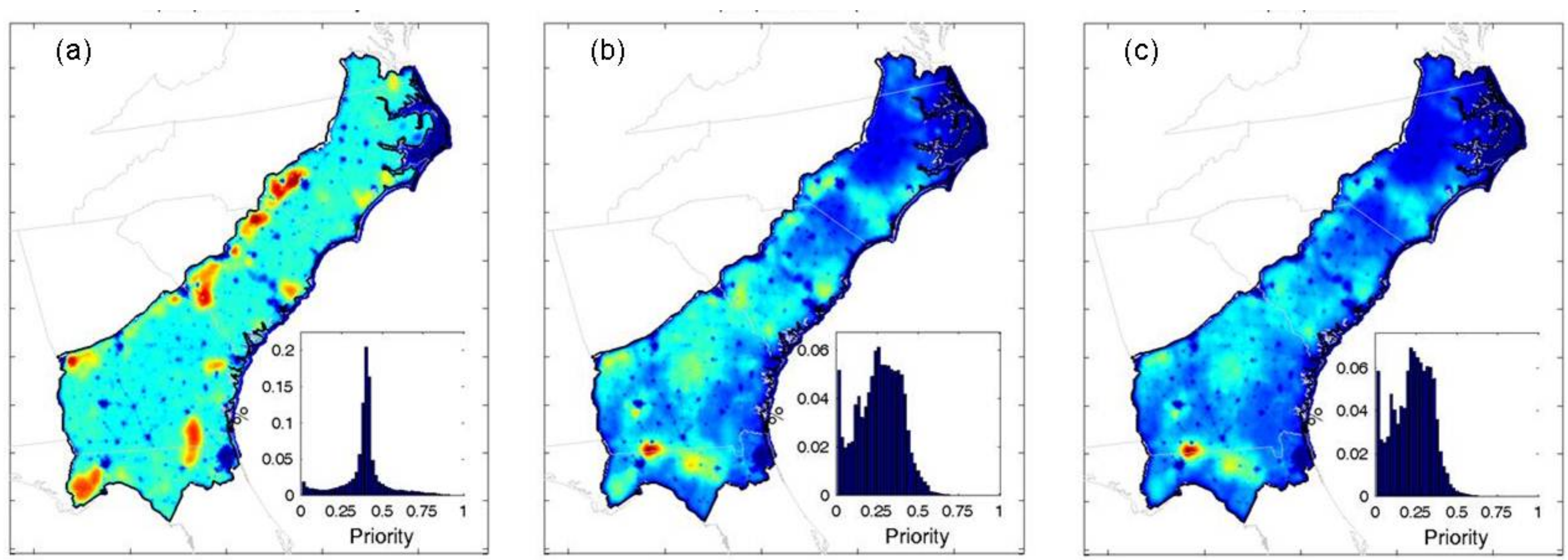

Figure 3.12: Open pine conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

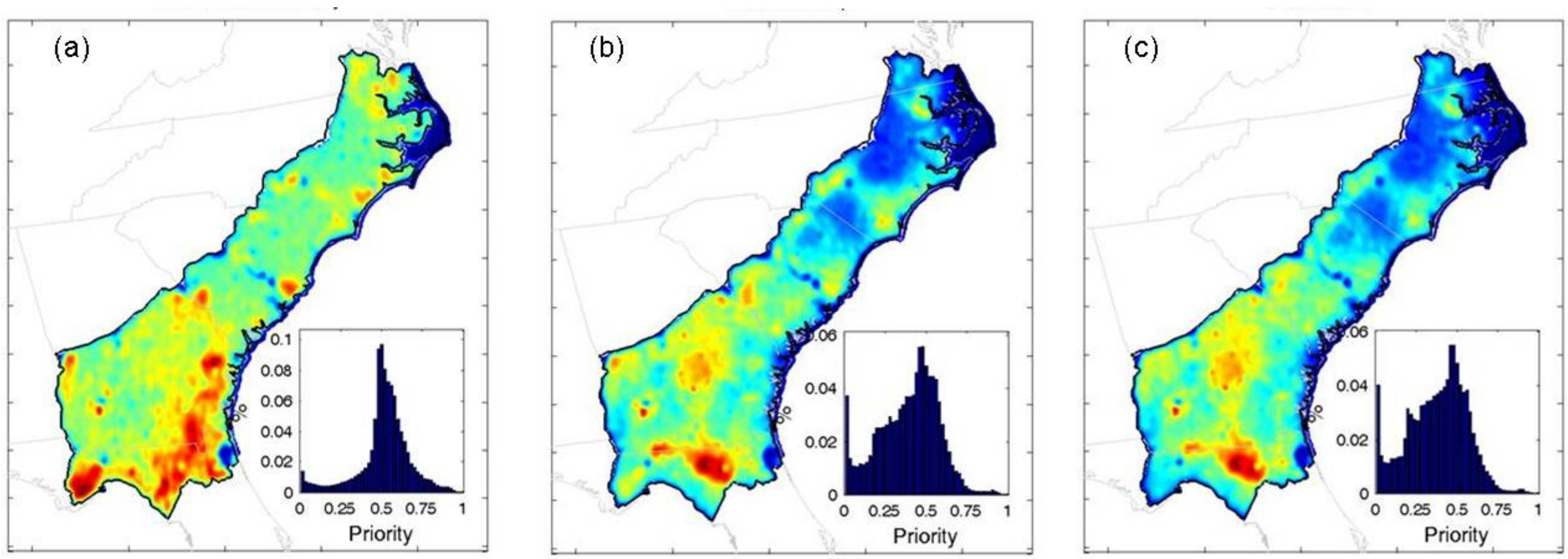

Figure 3.13: Shrub-scrub conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

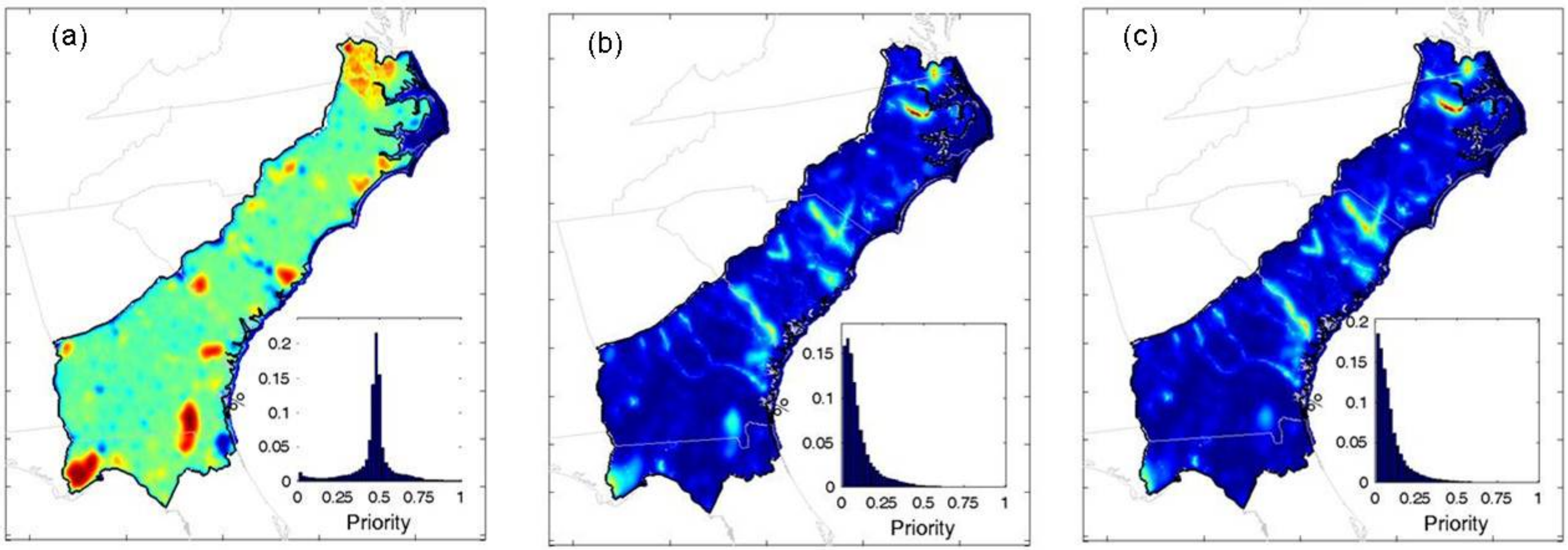

Figure 3.14: Slope forest conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

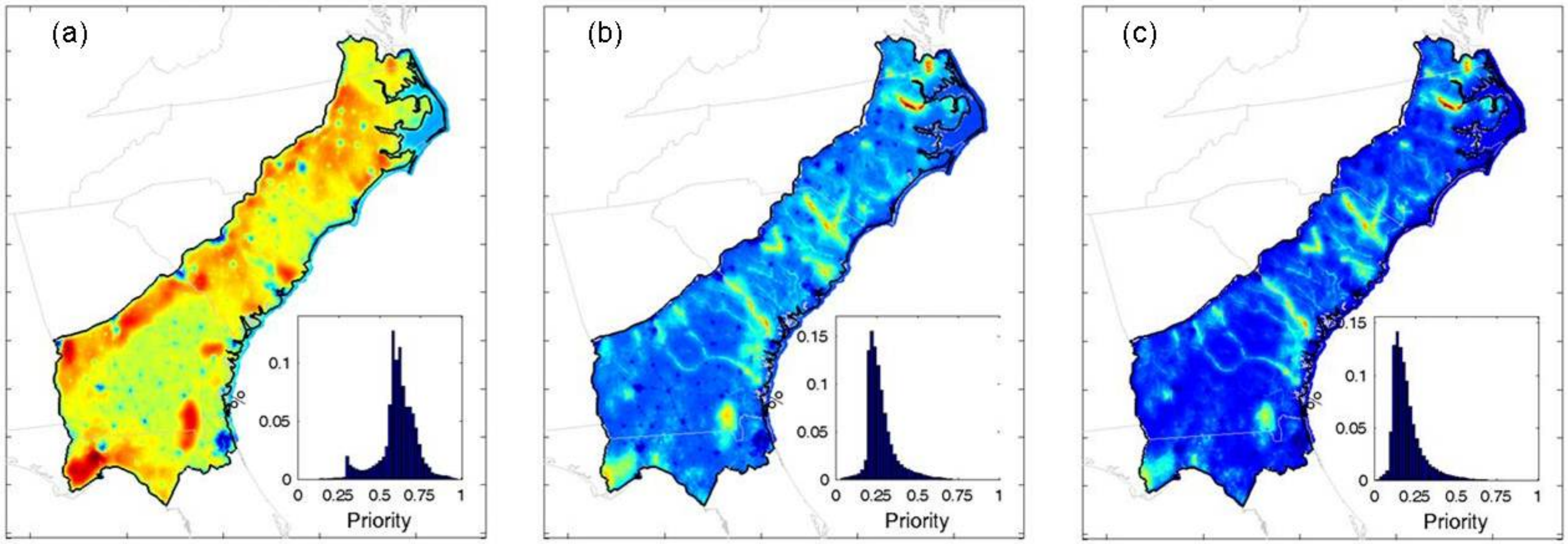

Figure 3.15: Upland forest conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

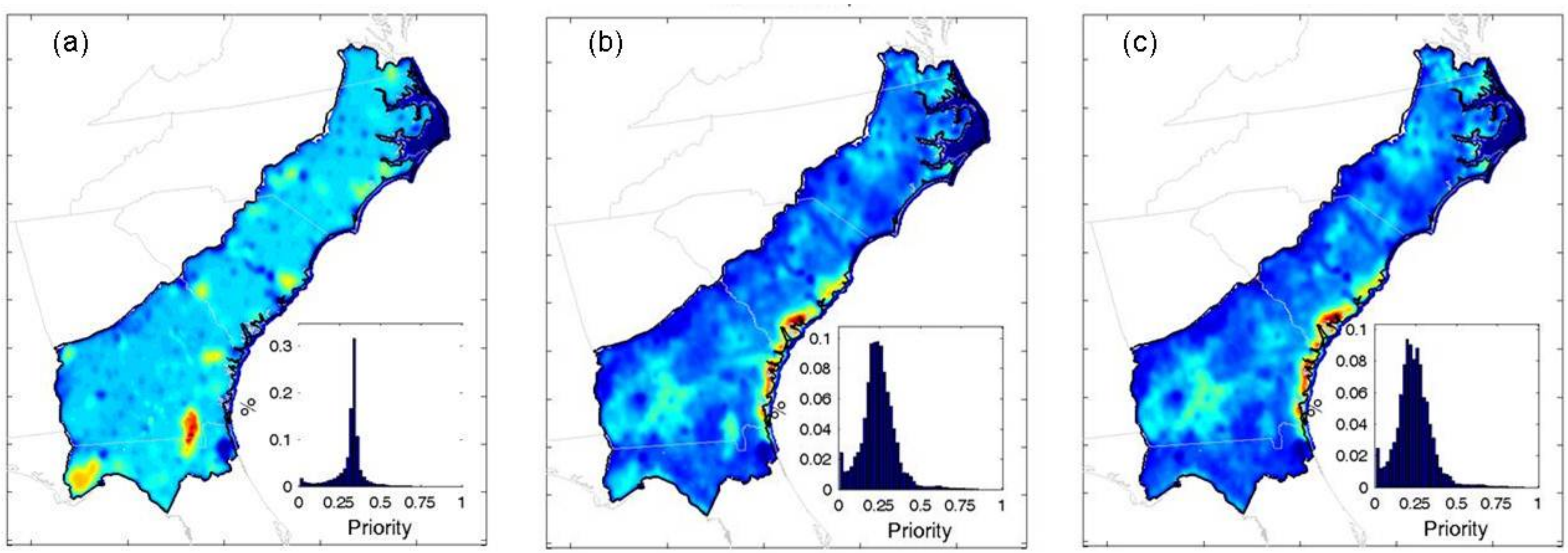

Figure 3.16: Wetland conservation priority surfaces (warmer colors indicate higher priority) for each vegetation type using (a) only density of vegetation types; (b) densities of vegetation types and focal species; (c) densities of vegetation types and focal species using focal species values. Inset histograms are distribution of priority values for each surface

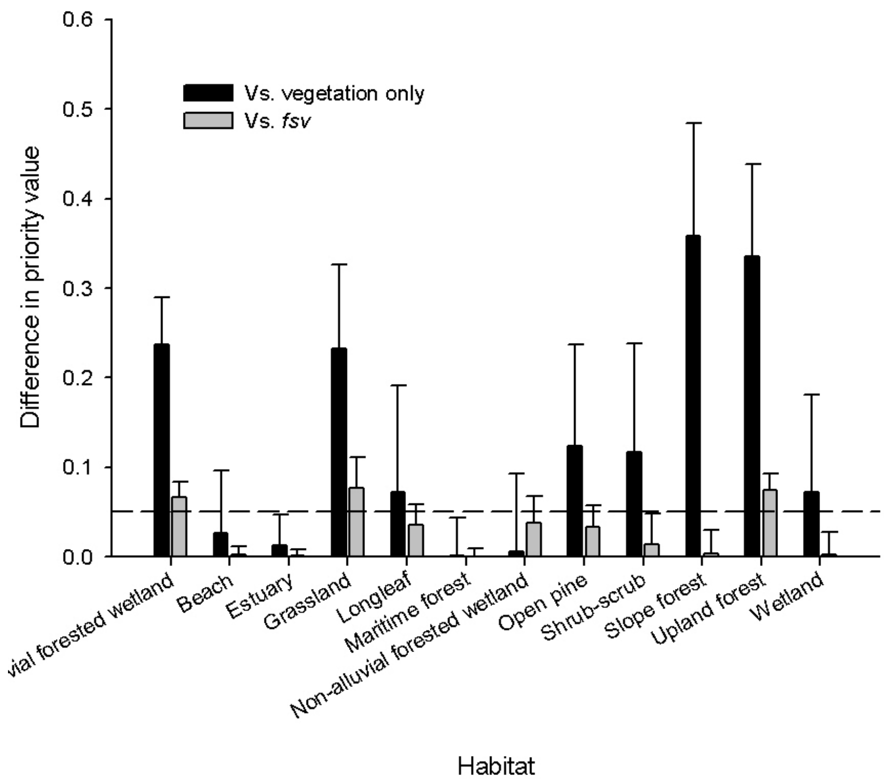

Figure 3.17: Difference between priority surfaces created using vegetation only and focal species (black bars with standard deviation); and focal species and *fsv* (gray bars with standard deviation). Dashed line is 0.05 difference and bars below this line we have defined as not significantly different.

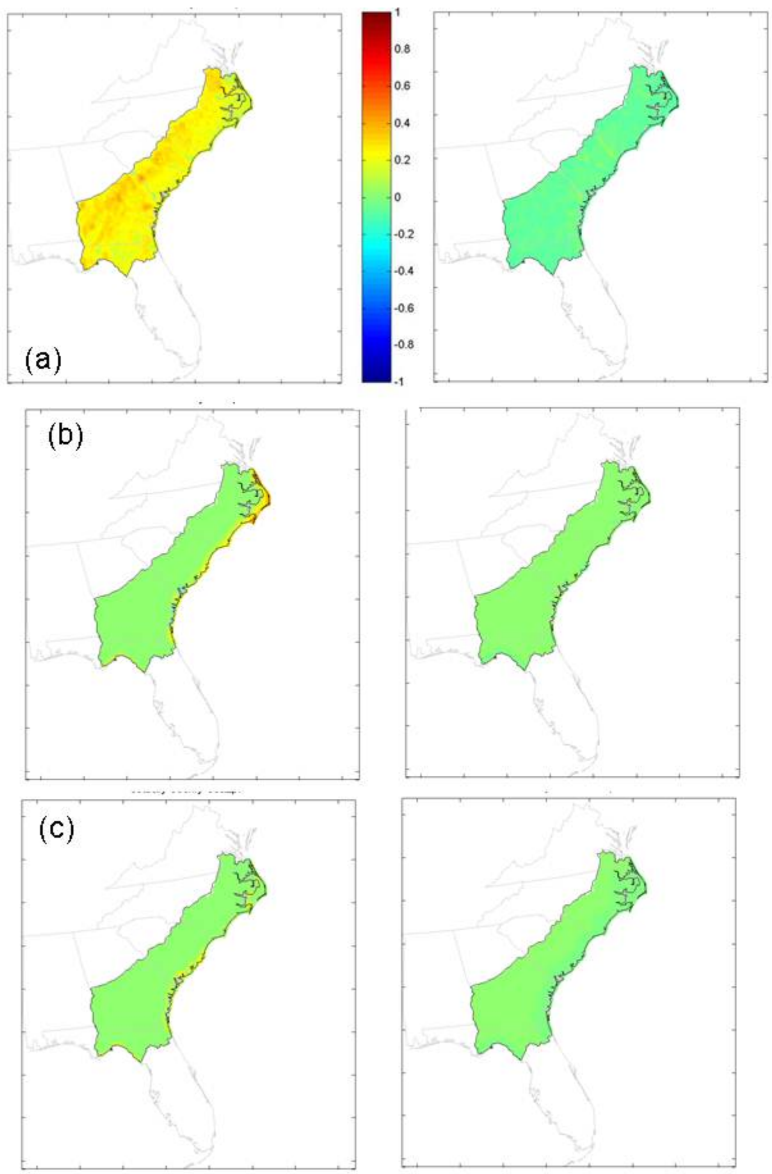

Figure 3.18: For (a) alluvial forested wetland, (b) beach, (c) estuary, and (d) grassland, difference between priority surfaces created using (left) vegetation only and focal species; and (right) focal species and *fsv*. Warm colors are where conservation priority was lower for (left) focal species compared with vegetation only and (right) *fsv* compared with focal species. Cool colors are where priorities were higher.

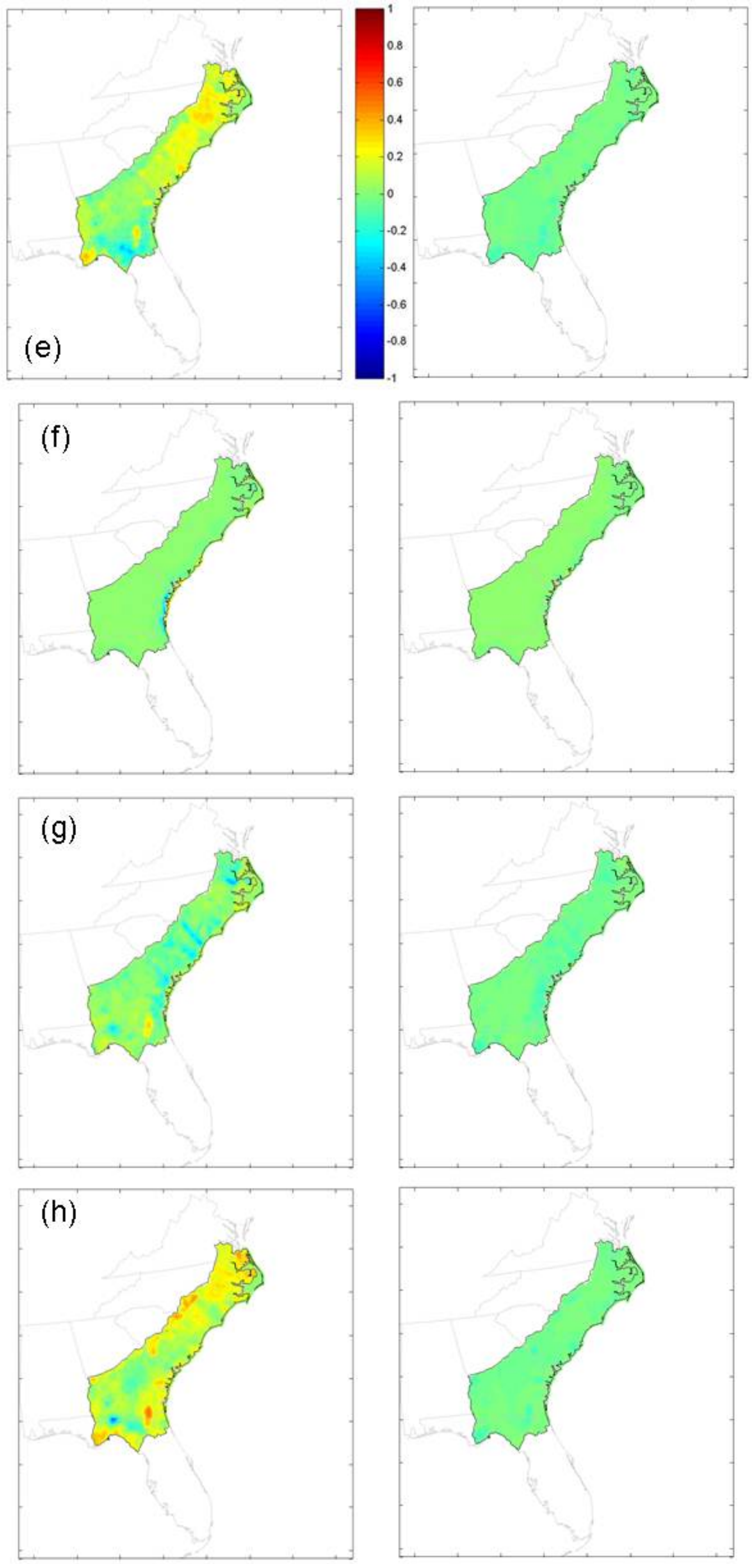

Figure 3.19: For (e) longleaf, (f) maritime forest, (g) non-alluvial forest wetland, and (h) open pine, difference between priority surfaces created using (left) vegetation only and focal species; and (right) focal species and *fsv*. Warm colors are where conservation priority was lower for (left) focal species compared with vegetation only and (right) *fsv* compared with focal species.

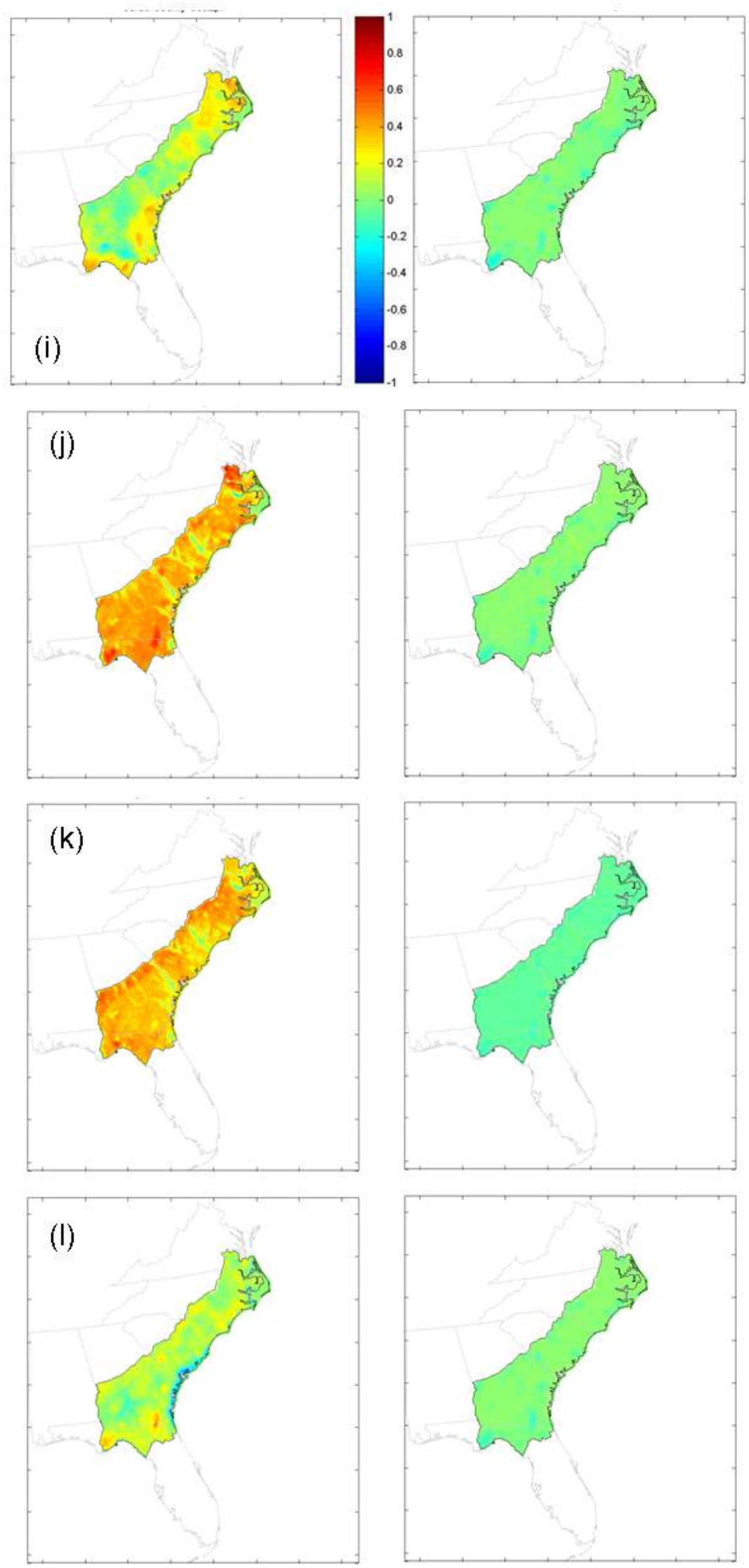

Figure 3.20: For (i)shrub-scrub, (j) slope forest, (k) upland forest, and (l) wetland, difference between priority surfaces created using (left) vegetation only and focal species; and (right) focal species and *fsv*. Warm colors are where conservation priority was lower for (left) focal species compared with vegetation only and (right) *fsv* compared with focal species.

Table 3.1: Landforms associated with general vegetation types of the Southeastern United States (slope and relative elevation) and whether fire was important to management of the vegetation type. All vegetation types also excluded open water (streams, lakes, and oceans). Y = included in model.

	Steep slope	Slope crest	Upper slope	Flat summit	Plateau flat	Side slope	Ravine	Dry flat	Moist flat	Slope bottom	Fire
Slope	$> 25^o$	$6 - 25^o$	$6 - 25^o$	$< 6^o$	$< 6^o$	$< 6^o$	$6-25^o$	$< 6^o$	$< 6^o$	$< 6^o$	
Elevation		highest	high	highest		mid	low	mid	mid	low	
Vegetation type											
Alluvial forested wetlands	Y					Y	Y		Y	Y	
Beach	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Estuary									Y		
Grassland	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Longleaf	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Maritime forest	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Non-alluvial forested wetland	Y	Y	Y	Y	Y				Y	Y	
Open pine	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Shrub-scrub	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Slope forest	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Upland forest	Y	Y	Y		Y	Y	Y	Y	Y	Y	
Wetland	Y				Y	Y					

Table 3.2: Territory size and dispersal distance for focal bird species. Dispersal distance was based on the maximum distance of published adult (A) or natal (N) dispersals or calculated (C) using an allometric equation [119]. We did not use either territory size or dispersal distance for wintering species. Focal species value (fsv) was derived from expert input

Species	Territory size (m^2)	Dispersal distance (m)	Type dispersal	Reference	fsv	Habitat
Acadian flycatcher	16,300	1,000	A	[131]	2.5	upland forest
Empidonax virescens					3.1	slope forest
American black duck	30,000	300	A	[53]	2.8	wetland
Anas rubripes					2.5	estuary
American kestrel	1,000,000	38,800	N	[112]	2.6	longleaf
Falco sparverius						
American oystercatcher	1,000	20,000	A	[76]	2.1	beach
Haematopus palliatus						
Bachman's sparrow	25,000	21,000	C	[24]	0.9	scrub
Peucaea aestivalis					2.0	longleaf
					1.7	open pine
Black-throated green warbler	14,000	13,000	C	[73]	1.3	allufor
Dendroica virens					1.7	nonallufor
Brown-headed nuthatch	28,000	19,000	C	[134]	1.6	nonallufor
Sitta pusilla					2.1	longleaf
					2.0	open pine
Cerulean warbler	10,400	1,000	A	[35]	1.4	allufor
Dendroica cerulea					1.2	upland forest
					1.2	slope forest
Chuck-will's-widow	70,000	54,000	C	[115]	1.4	nonallufor
Caprimulgus carolinensis						
Common ground dove	4,200[a]	100,000	N	[9]	1.4	maritime forest
Columbina passerina						
Field sparrow	7,600	20,000	C	[11]	1.9	scrub
Spizella pusilla						

Species	Territory size (m^2)	Dispersal distance (m)	Type dispersal	Reference	fsv	Habitat
Henslow's sparrow	1,800	20,000	C	[39]	1.6	grassland
Ammodramus henslowii					1.3	scrub
					1.4	longleaf
Hooded warbler	6,250	14,000	C	[14]	1.9	slope forest
Wilsonia citrina						
Kentucky warbler	22,100	500	A	[62]	1.3	upland forest
Oporornis formosus						
King rail	$4{,}000^b$	31,000	C	[87]	1.9	wetland
Rallus elegans						
Least bittern	97,000	44,000	C	[88]	1.7	wetland
Ixobrychus exilis						
Least tern	3	80,000	A	[124]	1.8	beach
Sternula antillarum						
Loggerhead shrike	80,000	70,000	N	[136]	1.5	grassland
Lanius ludovicianus					1.9	scrub
					1.3	longleaf
Louisiana waterthrush	16,000	4,000	N	[60]	1.3	upland forest
Parkesia motacilla					1.8	slope forest
Nelson's sharp-tailed sparrow	$22{,}000^c$	20,000	A	[108]	1.9	estuary
Ammodramus nelson						
Northern bobwhite	16,187	100,000	N	[10]	1.6	grassland
Colinus virginianus					2.0	scrub
					1.8	longleaf
					1.8	open pine
Northern parula	4,000	11,000	C	[71]	1.5	nonallufor
Parula americana					1.5	maritime forest
Northern pintail	wintering				1.7	wetland
Anas acuta						

Species	Territory size (m^2)	Dispersal distance (m)	Type dispersal	Reference	fsv	Habitat
Painted bunting	20,000	8,000	A	[55]	2.0	maritime forest
Passerina ciris						
Piping plover	280^d	600,000	A	[?]	2.2	beach
Charadrius melodus						
Prairie warbler	15,000	3,400	A	[77]	1.8	scrub
Dendroica discolor					1.3	maritime forest
					1.6	longleaf
					1.4	open pine
Prothonotary warbler	10,000	3,900	N	[85]	2.2	allufor
Protonotaria citrea					1.6	nonallufor
Red knot	wintering				1.9	beach
Calidris canutus						
Red-cockaded woodpecker	800,000	5,400	N	[46]	1.3	nonallufor
Picoides borealis					2.0	longleaf
					1.9	open pine
Red-headed woodpecker	30,000	1,040	A	[113]	1.4	nonallufor
Melanerpes erythrocephalus					1.6	longleaf
Redhead	wintering				1.0	estuary
Aythya americana						
Saltmarsh sharp-tailed sparrow	wintering				1.9	estuary
Ammodramus caudacutus						
Sandhill Crane	920,000e	45,000	C	[120]	1.0	grassland
Grus canadensis						
Seaside sparrow	5,100	1,600	A	[91]	1.9	estuary
Ammodramus maritimus						
Summer tanager	100,000	22,000	C	[103]	n/a	
Piranga rubra						
Swainson's warbler	14,000	15,400	N	[4]	1.9	allufor
Limnothlypis swainsonii					1.3	upland forest

Species	Territory size (m^2)	Dispersal distance (m)	Type dispersal	Reference	fsv	Habitat
					1.8	slope forest
Swallow-tailed kite	12,000,000	140,000	C	[66]	1.6	allufor
Elanoides forficatus						
Wood duck	125,000	3,800	N	[38]	1.9	allufor
Aix sponsa					1.7	nonallufor
Wood stork	3	340,000	C	[19]	1.5	wetland
Mycteria americana						
Yellow-throated warbler	22,800	13,000	C	[64]	1.9	allufor
Dendroica dominica					1.3	maritime forest

[a] [101]
[b] [47]
[c] [109]
[d] [16]
[e] [8]

Chapter 4

Conservation priorities in an uncertain future

4.1 Abstract

We targeted avian conservation in the Southeastern United States in partnership with the Atlantic Coast Joint Venture, because bird abundance in the United States has been declining for over half a century. This is likely a result of habitat changes due to urbanization and forest management. Global climate change is expected to lead to warming temperatures and changes in precipitation that should further affect bird habitat. We wanted to provide a tool to enable stakeholders to conserve species and habitats that are currently present and to integrate future habitat conditions to allow species to respond to climate change. Our conservation prioritization method was developed for use over a large geographic area extending from southern Virginia through northern Florida. It also allowed us to abide by principles of conservation biology and conservation reserve design, including prioritizing larger areas over smaller ones, and preferentially selecting areas in close proximity to one another. We designed conservation priority areas for two habitats, open pine and maritime forest, that are expected to respond to different aspects of climate change, increased fragmentation and sea level rise, respectively. Land cover projections were developed for years 2000 to 2100 at 10-year time intervals for three global climate change models, specifically the a2, a1b, and b1 climate scenarios. We included five binary spatio-temporal grids to prepare habitat priority maps: (1) potential habitat and (2) putative source population distributions for each of the focal species; (3) suitability models for each habitat; (4) conservation lands; and (5) urban areas. For both open pine and maritime forest habitats, differences between priority surfaces created with discounted or summed future conditions affected how valuable areas were to conservation but not where those areas were within the region, and surfaces did not differ

significantly between climate scenarios. Similarities among alternatives of future conditions may be a result of scale because changes due to climate change may have a strong local, but weak regional effect. Having six similar alternatives is helpful because it suggests a set of consistent conservation priorities that can be relied upon to conserve bird populations in the South Atlantic Migratory Bird Initiative region. As additional information is gathered relating to climate-change-driven land cover changes, the alternatives may diverge which makes repeating the modeling process very important.

4.2 Introduction

Adding new protected areas or extending current protected areas is key to enable species to adapt to climate change [32]. Modeling future land use/land cover given various climate change scenarios and integrating this information into conservation prioritization plans should increase population persistence as species respond to climate change. Without integrating these future conditions, suitable habitat may shift out of protected areas where species may become vulnerable to land use changes. For example, if a habitat is expected to shift northward, prioritizing habitat conservation towards the northern edge of the habitat's range should allow species to shift their range as the habitat shifts.

A major obstacle to implementing conservation goals occurs when researchers design solutions and practitioners do not understand the solution, interpret the solution as too prescriptive or researchers simply fail to address problems useful to practitioners [52] [93]. This is particularly the case with dynamic problems that are mathematically complex and difficult to implement [90] such as the effect of climate change on species and ecosystem persistence. Alternatively, simple target-based approaches with management actions applied in a highly controlled system are problematic because these models are too simple and do not address real world complexity [27]. The trade-off then is between conservation planning using complex mathematical solutions that are difficult to interpret and implement, and oversimplifying the problem which reduces effectiveness. We propose a new method of conservation prioritization that is simple to use compared with traditional optimization or heuristic methods and integrates a number of biological and spatial objectives in a multi-species context.

It is important to both conserve what is currently present, in terms of species, habitats and ecosystems, and to plan for coming conservation challenges. We targeted avian conservation in the Southeastern United States in partnership with the Atlantic Coast Joint Venture, because bird abundance in the United States has been declining for over half a century, likely a result of habitat changes [125] [78]. In the Southeastern U.S., urban areas are growing at the expense of forests [30] and short-term projections suggest urbanization will continue to reduce forest area and increase fragmentation [129]. In the long term, climate change is expected to lead to changes in precipitation and temperature patterns [44]. In the Southeastern US, future precipitation trends are uncertain but temperatures are expected to warm by 2-3C degrees in the next 100 years [44]. We predicted a warmer climate would lead to land cover changes that would shift terrestrial birds northward and would shift coastal species inland with rising sea levels. The conservation prioritization models based on resulting species distributions would therefore also shift northward and inland. In order to allow species to respond to climate change, we must integrate future conservation priorities with current priorities.

Conservation prioritization should combine information about species and habitat requirements over large geographic extents based on principles of conservation biology, including prioritizing larger areas over smaller ones, and preferentially selecting areas in close proximity [22]. Prioritization should integrate future land use/land cover conditions under different climate scenarios to provide conservationists with tools for determining how important various areas are to conservation now and in the future. Finally, such tools should be developed in collaboration with stakeholders to ensure the result is a tool that will be useful.

We examine two avian habitats that are expected to be affected by climate change: open pine and maritime forests under three climate scenarios. Open pine forest is an important habitat for several endemic bird species in the Southeastern US including Red-cockaded Woodpecker (*Picoides borealis*), Bachman's Sparrow (*Peucaea aestivalis*), and Brown-headed Nuthatch (*Sitta pusilla*). Open pine forests are similar to longleaf pine (*Pinus palustris*) forests in that they have an open canopy and a grassy ground layer from which shrubs are excluded by fire. These open canopy pine forests historically dominated the Southeastern US but have been much reduced since European settlement. In open pine forests, climate change is expected to increase fire and insect outbreak frequency leading to more fragmentation. Maritime forest is a coastal habitat that is important for migratory neotropical songbirds such as Bicknell's Thrush (*Catharus bicknelli*), as well as providing breeding habitat for species of concern including Painted Bunting (*Passerina ciris*), Common Ground Dove (*Columbina passerina*), and Prairie Warbler (*Setophaga discolor*). Maritime forest is already much reduced from its historic extent due to human development along the coast and climate change will add additional stress to the habitat through increased sea levels. Because these two habitats will respond differently to climate change, we can compare how conservation priorities may shift over time due to different processes.

4.3 Methods

4.3.1 Study site

The study area was the Coastal Plain of the Southeastern United States including the eastern portions of North Carolina, South Carolina, Georgia as well as a small part of southern Virginia and part of the panhandle of Florida (Fig. 4.1). Our project focused on conservation of sustainable bird populations in this region in maritime forest and mature open pine forest. Using species at risk associated with these two habitats, a suite of focal species were selected by experts (Table 4.1) [72].

4.3.2 Future land cover

We developed data from land cover projections for 2000-2100 at 10 year time intervals for three different climate change scenarios [65]. The three scenarios, a2, a1b and b1, differed in regards to energy sources, global population size and economic growth [43]. The a2 scenario was the worst case scenario of the three we considered. It simulated a continuously increasing global population, a slow switch to more efficient technology, and continued reliance on fossil fuels [43]. The best case scenario was b1 under which the global population peaks mid-century and the economy switches to clean energy sources and there is a general focus on sustainability. The other scenario, a1b, predicts some development of alternative sources of energy, a population peaking at mid-century and a balance between the use of fossil and non-fossil fuels. We use land cover projections computed by collaborators at North Carolina State University. They used SLAMM (http://www.slammview.org/) to model sea level rise, SLEUTH (http://www.essc.psu.edu/SLEUTH/) to model urbanization and VDDT (http://essa.com/tools/vddt/downloadvddt/) to model land change probabilities. Downscaled climate change effects were used to determine how much sea levels would rise each decade and to modify the insect outbreak and fire-related disturbance frequency in the land cover modeling.

Our objective was to develop a method for prioritizing habitat conservation across very large landscapes incorporating current landscape conditions and predictions of future landscapes based on the presumption that the configuration, size, and proximity of conserved areas affects the sustainability of targeted populations. We included up to five binary spatio-temporal datasets (grids) used to prepare habitat priority maps: (1) potential habitat and (2) putative source population distributions for each of the focal species; (3) suitability models for each habitat; (4) conservation lands; and (5) urban areas. The SAMBI region was divided into a regular 200 m grid and grid squares were evaluated for each dataset description. For example, if protected areas occurred in a grid square, that square would get a value of one in the conservation grid. We used ArcGIS Version 9.3 (Environmental Systems Research Institute, Redlands, California) and MATLAB Version 7.10.0.499 (The Math Works, Natick, Massachusetts) to create and manipulate spatial data.

4.3.3 Datasets

In our analysis, we used three binary grids based on habitat (1) suitability, (2) conservation land, and (3) urban area. We developed binary maps of suitability of locations for open pine and maritime forest habitats using land cover projections, landscape characteristics, and landform. These data were used to exclude areas where it was considered impossible for a specific habitat type to occur. For open pine, we used time-invariant landform data derived from National Elevation Dataset (NED) for Southeast Gap Analysis Project [65]. However, we developed suitability maps for each time step for maritime forest based on projected land cover because of expected changes in sea level and ensuing coast lines and the low thematic resolution of NED. Maritime forest was restricted to its inland extent by a manually digitized boundary at each time step based on the maximum extent of any existing maritime-associated habitat which also included estuary and beach habitats.

Two binary grids were created for each focal species that bred in the South Atlantic Migratory Bird Initiative (SAMBI) [128] region at each time step. Maps of potential habitat were based on range maps, land cover, ancillary data (stream location, elevation, etc.), and minimum patch size requirements determined by extensive literature review and expert opinion as described by McKerrow [65]. Once future land covers were created, potential habitat models for species were applied at each time step. Putative source populations of each focal species were mapped by identifying patches of potential habitat that were large enough to support at least 200 territories [123] (Table 4.1).

Conservation lands for SAMBI were extracted from the protected areas database for the United States (PAD-US) [98], which includes federal, state, non-governmental, and land trust lands set aside for conservation. We intersected suitability data with the PAD-US data for each habitat so that only suitable conservation lands were included in the prioritization for each respective habitat. This grid was calculated once for all time steps.

Because land cover projections incorporated urban growth, urban areas were extracted from the land use projections for each time step. We excluded areas mapped as developed open space, low- medium- and high-intensity developed lands.

4.3.4 Density estimation

We mapped density of each binary layer using a two-dimensional kernel density estimator [110] in the Kernel Density Estimation Toolbox (kdtools [7]) using MATLAB. The estimator was used to calculate density based on probability of occurrence across a gridded space. For each observation, weight was assigned to each grid cell as a function of the distance from the observation to the center of the cell. We used a bivariate normal kernel with a fixed bandwidth which assigns weights that decline rapidly in a sigmoid fashion with distance from each observation. The weights were summed across all observations resulting in a smoothed surface that reflects the two-dimensional density of resources. For potential habitat, suitability, and conservation land grids we used the normal scale rule, and bandwidth, the parameter that determines the diameter of the kernel (kernel size, h), based on the equation:

$$h = 1.0592qn^{-0.2} \tag{4.1}$$

where h is the bandwidth, n is the number of observations, and

$$q = \min(\text{std}(x), R/1.34) \tag{4.2}$$

where x is the grid point(s), std is the standard deviation of x, and R is the interquartile range of x. We divided the grid of weights by the density of a binary grid indicating the extent of terrestrial areas in order to avoid underestimating density on the edges of our study area and large waterbodies [68]. To emulate colonization potential of putative source populations for each species, we used a kernel size equal to the estimated dispersal distance (Table 1). We used the larger of natal or breeding dispersal distance, or for species without known dispersal distances, an allometric equation based on size and diet classification [119]. For urban areas, we used kernel size of 1200 m, which represents a distance of maximal impediment to the use of prescribed fire (Grand unpubl.). Each density grid was scaled to range of 0-1 by:

$$w = w/\max(w) \tag{4.3}$$

where w is the weight assigned to each grid cell before being used in further analysis to avoid unequal weighting in the prioritization.

4.3.5 Modeling priorities

We calculated priorities for each habitat in each time step by combining the grids of weights for all associated focal species, suitability and conservation lands data, and urban data where appropriate. During meetings with experts from state and federal government and non-governmental organizations, we asked which data were essential for habitat function [72] and we used this information to create models for both habitats. For mature open pine, where experts determined fire was a limiting characteristic, we used the equation:

$$Pr_{it} = (1 - U_{it})\, S_{it} \left(C_i + \sum_{j=1}^{m_i} EH_{ijt} + \sum_{j=1}^{m_i} SP_{ijt} \right) \tag{4.4}$$

where for habitat i in time t, Pr_i is the grid of priority scores (priority surface); and S_i, and C_i are the density grid for suitability and conservation lands, U is the density grid of the urban areas and for the m_i focal species, EH_i and SP_i are the potential habitat and putative source population weights focal species j.

Maritime forest did not include the urban grid and was thus:

$$Pr_{it} = S_{it}\left(C_i + \sum_{j=1}^{m_i} EH_{ijt} + \sum_{j=1}^{m_i} SP_{ijt}\right) \tag{4.5}$$

Pr_it was also scaled to range of 0-1 by:

$$Pr_{it} = Pr_{it}/\max(Pr_{it}) \tag{4.6}$$

To incorporate the effects of climate and urban growth as expressed in the land cover projections, we summed the priority surfaces for each time step in an undiscounted fashion:

$$Pr_{it} = \sum_{t=1}^{T} Pr_{it} \tag{4.7}$$

or we applied a 4% per year discounting rate:

$$Pr_{it} = \sum_{t=1}^{T}(Pr_{it}(1+0.04)^{10}) \tag{4.8}$$

This process reduced the value of future land cover conditions and give them less influence in our conservation plans. The discounting rate was based on the 30-year United States government treasury bond rate [6].

4.3.6 Analysis

To evaluate the differences between priority surfaces, we subtracted one grid from another. Because surfaces were normed to one, areas that were not different received a score of 0, and differences scored between -1 and 1.

We also compared distributions of the priority values of the surfaces using skew (γ):

$$\gamma = \sum_{i=1}^{n}\left(q_i - \bar{q}^3\right)/(n-1)\, std^3 \tag{4.9}$$

where q is the priority score of an individual pixel and $\bar{q}$ the mean score of all pixels for a surface, n is the number of pixels and std is the standard deviation of the priority scores.

A normal distribution has a value of 0, negative values indicate left-skewed distribution, i.e. a long left tail, and positive values indicated right-skew.

To look at the shape of the distribution curves of the priority surfaces , we also used kurtosis (κ):

$$\kappa = \left(\sum_{i=1}^{n} \left(q_i - \bar{q}^4 \right) / (n-1)\, std^4 \right) - 3 \tag{4.10}$$

where q is the priority score of an individual pixel and $\bar{q}$ the mean score of all pixels for a surface, n is the number of pixels and std is the standard deviation of the priority scores. Skewness measured symmetry of the distribution where a normal distribution equaled 0, negative values indicated left skewed distribution, i.e. a long left tail, and positive values indicated right skew. A left skewed distribution would indicate less high priority habitat than with a normal distribution. Kurtosis measured peakedness with normal distribution having a value of 0, more peaked distributions (leptokurtotic) having positive values and less peaked distributions, negative values. A highly peaked distribution would suggest more areas with mid-value priority for conservation.

4.4 Results

We produced a total of 363 priority maps for 11 species every 10 years from 2000 through 2100 for three different climate scenarios. In all climate scenarios (Fig. 4.2), high priority open pine habitat occurred near large patches of existing forest: in northern Florida in the region of Apalachicola National Forest, near Oconee National Forest in Georgia, along the coast of South Carolina near Francis Marion National Forest and inland near the Coastal Plain/Piedmont boundary in South and North Carolina in the area of Uwharrie, Pisgah and Sumter National Forests. The highest priority areas for maritime forest occurred along the coast of South Carolina, around Hilton Head, and Georgia, around Cumberland Island National Seashore and Jekyll Island State Park (Fig. 4.3).

4.4.1 Projected priority surfaces

We produced 6 priority surfaces for each habitat by combining the projected priorities for each climate scenario by both discounting and summing future conditions (Fig. 4.4 and 4.5). For open pine, there was more area of moderate conservation priority when future priorities were integrated compared with the initial priority surface, with the discounted priority surface having slightly more high priority areas than the summed surface (Fig. 4.8). Maritime forest, on the other hand, was more restricted in extent and the difference between the discounted and undiscounted priority surfaces were minimal as was the difference between the initial and summed or discounted surfaces. The differences between climate scenarios for both habitats were minimal (Fig. 4.7).

Spatially, the largest change in priority values between the initial and final time step priority surfaces for open pine was in northern Florida with the western area decreasing in priority while the eastern regions increased (Fig. 4.6). Over time, maritime forest increased in priority along the Gulf Coast of Florida and in coastal areas near the Virginia/North Carolina border. The coastal region of the Carolinas showed large decreases in priority likely due to sea level rise.

4.4.2 Habitat priorities

The distribution of priority scores for maritime forest at each time step was highly right-skewed ($\gamma \leq 3.2$) and leptokurtotic ($\kappa \geq 11.1$) indicating a small number of sites were given high ($Pr > 0.75$) priority (Fig. 4.9). For open pine, which had a relatively wide distribution across the SAMBI region, skewness was low ($\gamma \leq 1.0$) and the distribution was similar to normal distribution ($-0.5 \geq \kappa \geq 1.3$). For both habitats, there was minimal difference in skewness or kurtosis between climate scenarios.

4.5 Discussion

Our results illustrate the difficulties associated with prioritizing areas for conservation based on predictions of future conditions in the SAMBI region. Priority areas were shifted, more so for open pine habitat than maritime forest. However, the overall effect of climate change on the distribution of priority areas in both habitats was not very different compared to priorities based on 2000 (recent) land cover. This was particularly true when we discounted to allow for uncertainty in the prediction of future landscapes.

Modeling the response of ecosystems in the southeastern US to global climate change is difficult for several reasons. Future climate trends in this area are not as clear as those in other areas of the US, making down-scaling the global climate models difficult. The IPCC predicts slightly warming temperatures over the next 30 to 40 years [43], but models do not agree on the direction of precipitation trends. This disagreement among the climate predictions is problematic to models that are based on the effects of temperature and precipitation patterns on mortality and growth rates of vegetation [84]. However, the vegetation models that were used to create our predicted land cover data were based on pest outbreaks and fire frequency, not changes due directly to precipitation even though the rates of tree pest and disease outbreaks are expected to increase due to changes in temperature or precipitation [84].

Additionally, the time frame over which we are considering land cover changes may be too short for Southeastern ecosystems to show major changes. Loblolly pine trees have an average longevity of over 150 years [117] so our 100 year timeframe represents less than one generation of unharvested trees. Although it is unlikely major range shifts due to climate change could occur quickly, catastrophic events like introduced pest species or hurricanes could result in major mortality and succession could be significantly affected by climate changes [43]. The process used by our colleagues at NCSU to model future conditions does rely on these catastrophic, although highly unpredictable events, to affect forest conditions.

Birds, unlike vegetation, could be more likely to show range shifts in response to climate change within the next 100 years and many of the focal species we used in our modeling are at or near their northern range limits in the SAMBI region [24] [9] [55] [134] [46]. Bachmans Sparrow, Brown-headed Nuthatch, Red-cockaded Woodpecker, Common Ground Dove and Painted Buntings should therefore be expected to increase their density or extend their range northward if the resources they depend on are affected by temperature [58] [59]. Nevertheless, these species will probably not respond to climate change solely through temperature; it is much more likely their responses will be through interactions between species including predator/prey dynamics, phenology, pest and disease susceptibility [84]. Because we only used models based on predicted patterns of potential habitat on the landscape, we cannot address all processes that may have influence species abundance or distribution.

The process of creating prioritization surfaces can help stakeholders better define their objectives [29] [89]. With maritime forest prioritization, stakeholders realized priority surfaces created for maritime forest are insufficient to plan conservation areas at a small scale. Areas of high conservation priority occur along the coast of Georgia and South Carolina, but finer scale prioritization is needed to identify specific parts of the coast. For example, it may turn out that sheltered bays have the most amount of maritime forest and other maritime-associated habitats of high conservation priority, but that requires smaller scale modeling of sea level rise than our project could address. The process of prioritization for open pine habitat has also led stakeholders to question the effects of conservation lands on the prioritization values. Conservation lands are included directly in our modeling processes as a grid, as well as indirectly as the location of large tracts of existing habitat and putative source populations. Stakeholders worried conservation priorities were limited to areas adjacent to already established conservation areas and were required to better define the role of the prioritization surfaces is it important to acknowledge how important current protected areas are for conserving species or should existing protected areas be excluded from the prioritization surface?

There is often pressure to produce the best single answer to conservation problems but providing stakeholders with a range of answers illustrates the range of uncertainty in the system. We produced a series of possible alternatives to the question of where conservation priorities occur under different climate change scenarios. The IPCC [45] considers all climate scenarios equally sound and discourages averaging among scenarios. The three climate scenarios we modeled, therefore, gave us three alternatives for future conditions. We also modeled summary priority surfaces using two different methods, either discounting future condition or summing without discounting. This gives stakeholders six alternatives for conservation planning. Surprisingly however, the differences among these alternatives were not pronounced. The differences between priority surfaces created using discounted or summed future conditions affected how valuable areas were to conservation but not where those areas were within the SAMBI region, and our priority surfaces did not differ significantly between climate scenarios. This similarity may be a result of scale because changes due to climate change, specifically sea level rise and fire or insect outbreaks, may have a strong local, but weak regional effects.

Adaptive resource management is a cyclical process [42] and allows managers to make decisions in situations with a high degree of uncertainty, such as global climate change [5]. Our project will be used in an adaptive management context and therefore, we do not want to suggest which alternative priority surface is best, only that the decision support tools we produced can help in the next stage of the process. When additional information becomes available about the effect of climate change or about stakeholder objectives, this information can be integrated into our process and new decision support tools can be developed. Our priority surfaces are forecasts of future conditions in the form of tools to allow stakeholders to make better decisions [67].

While there are many sources of uncertainty in our models of conservation priority areas in the Southeastern US, it is important to avoid using uncertainty to prevent conservation actions [32]. Our results showed conservation priority surfaces changed in intensity so values of areas changed over the time, but at large scales, areas of high conservation priority remained of high priority regardless of their exact conservation value. The consistency of relative priorities gives confidence the areas we highlight as high priority will remain vital for conservation into the future.

> "If we wait decades for certain knowledge of climate-change effects, land-use change will have already dictated the conservation landscape, and the scope for adapting to climate change will be minimal. Conversely, if we act now, we will have to act in the face of considerable uncertainty. Dealing intelligently with uncertainty in a landscape with considerable space to make choices seems our best option. Acting intelligently will therefore require taking some risks and convincing society and policy makers that risks are worth taking. The alternative is letting uncertainty become an excuse for inaction." [32]

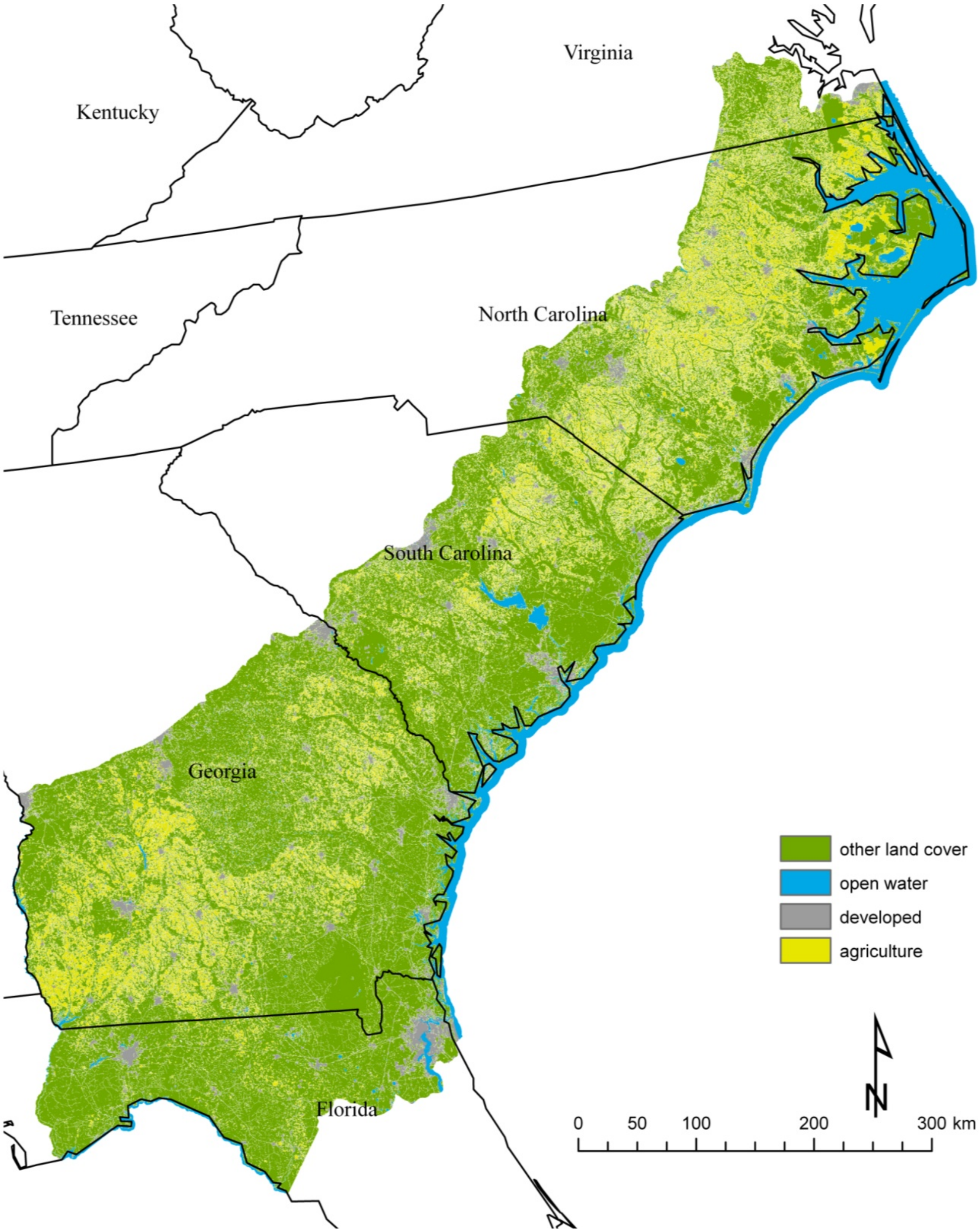

Figure 4.1: The study region in the Southeastern United States included coastal plain regions of Virginia, North Carolina, South Carolina, Georgia, and Florida.

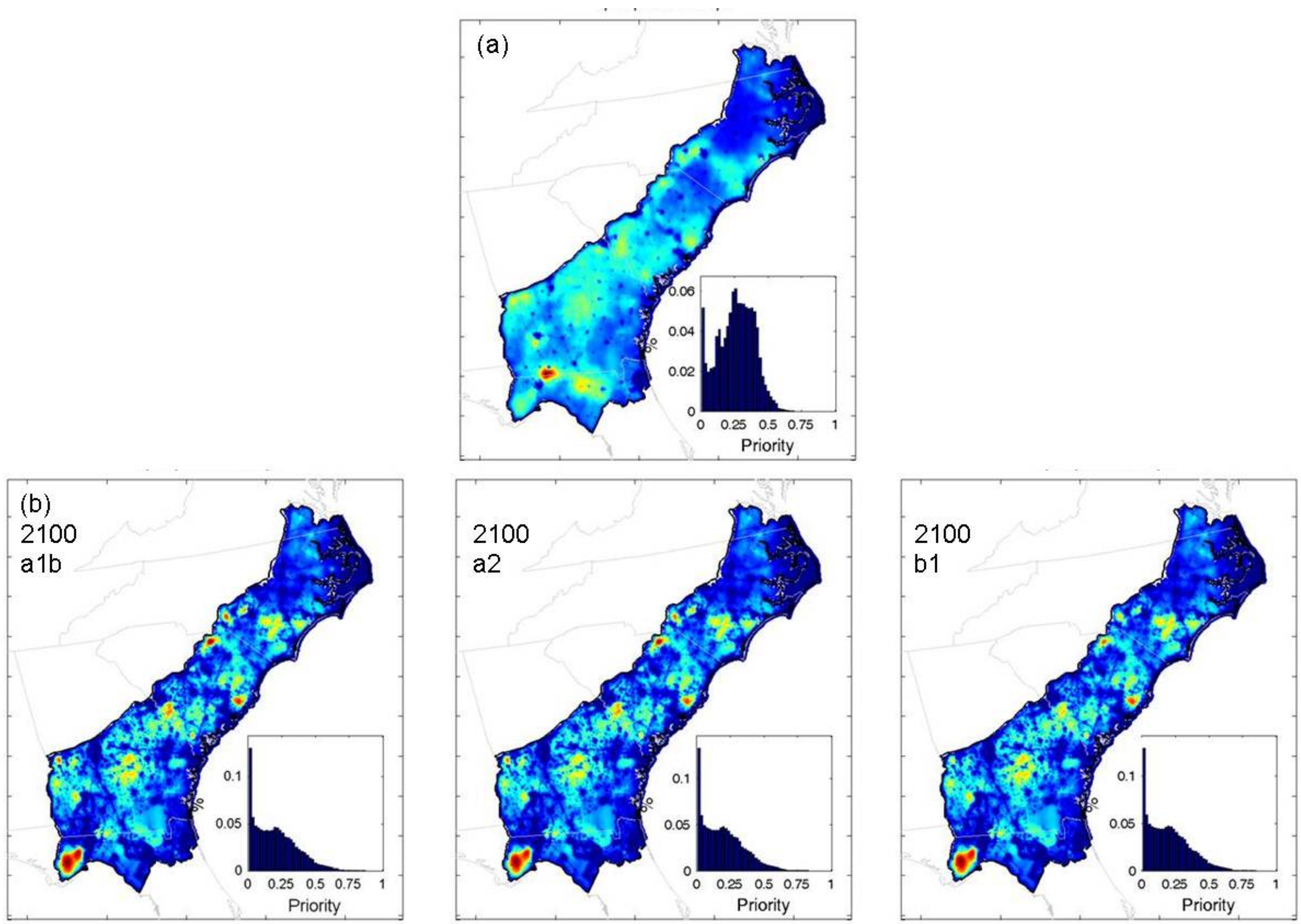

Figure 4.2: Conservation priority surfaces for open pine forest in the Southeastern US showing different years and climate scenarios: (a) conservation priorities for initial conditions (2000); (b) conservation priorities projected to 2100 under climate scenarios a1b, a2 and b1. Inset figures show distribution of conservation priority values. Warm colors indicate areas of high conservation priority and cool colors indicate lower priority.

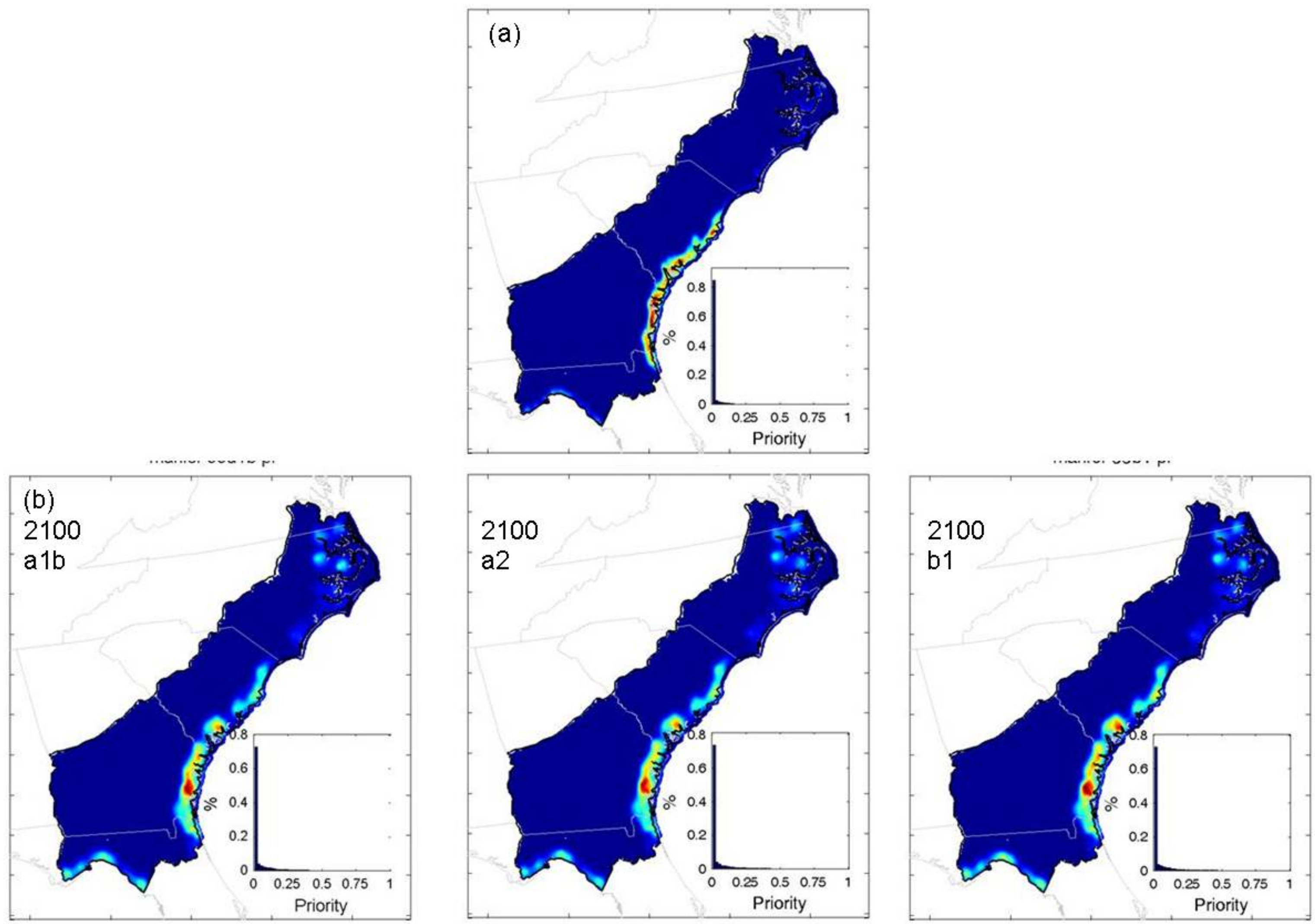

Figure 4.3: Conservation priority surfaces for maritime forest in the Southeastern US showing different years and climate scenarios: (a) conservation priorities for initial conditions (2000); (b) conservation priorities projected to 2100 under climate scenarios a1b, a2 and b1. Inset figures show distribution of conservation priority values. Warm colors indicate areas of high conservation priority and cool colors indicate lower priority.

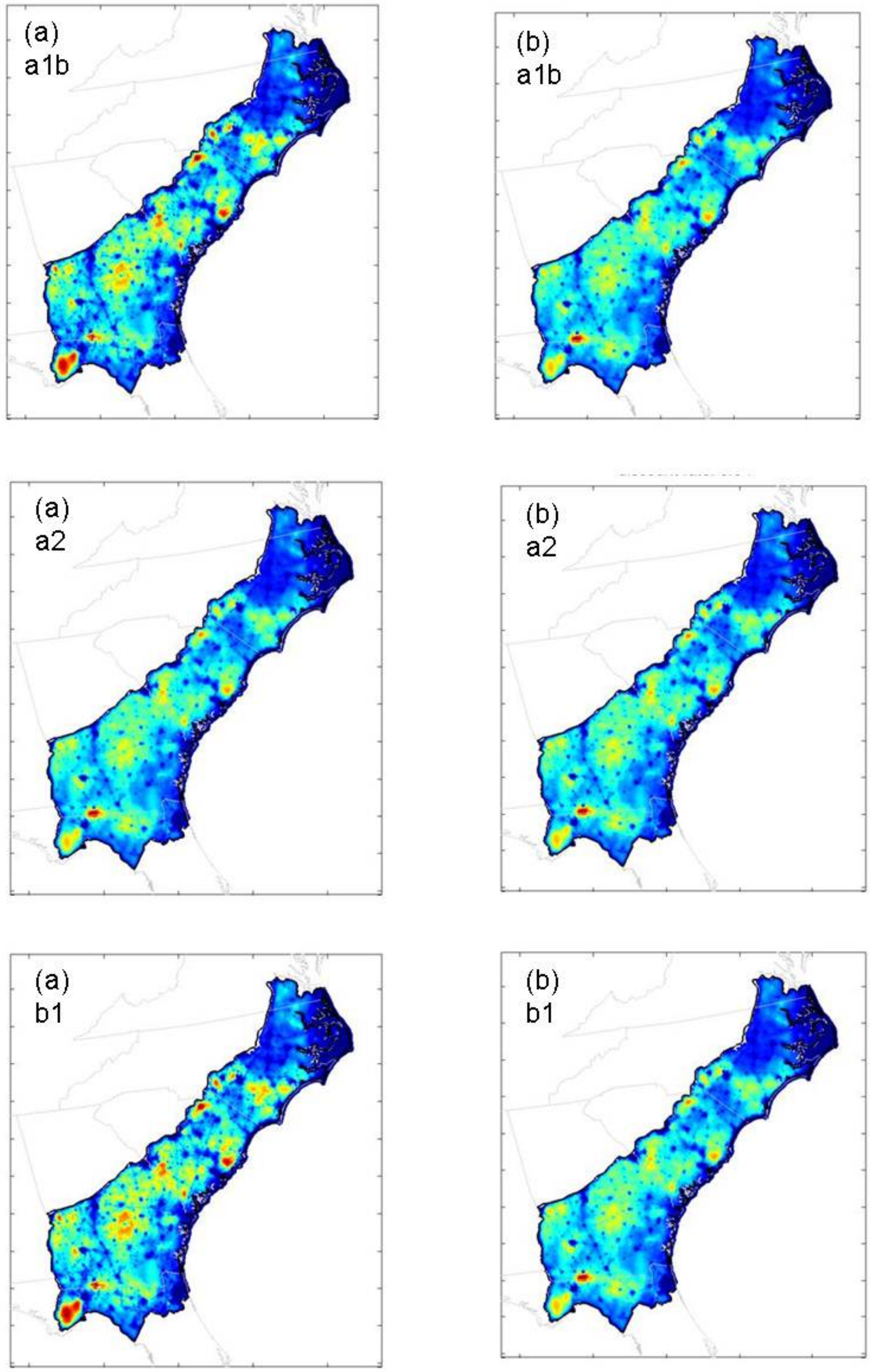

Figure 4.4: Open pine final conservation priority surface including land cover from all years (2000-2100), for climate scenarios a1b, a2 and b1; (a) summed and (b) discounted by 4% per year. Warm colors indicate areas of high conservation priority and cool colors indicate lower priority.

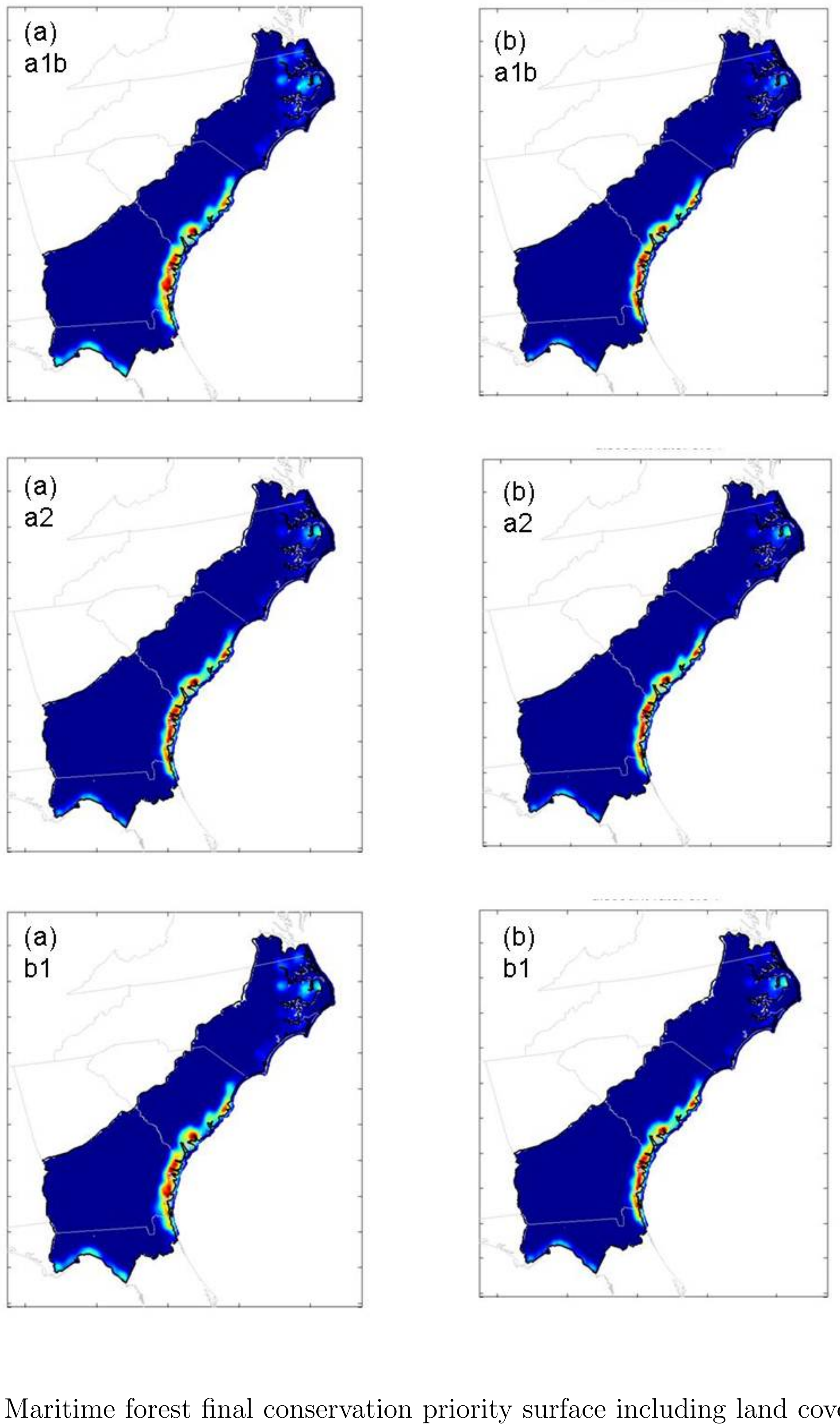

Figure 4.5: Maritime forest final conservation priority surface including land cover from all years (2000-2100), for climate scenarios a1b, a2 and b1; (a) summed and (b) discounted by 4% per year. Warm colors indicate areas of high conservation priority and cool colors indicate lower priority

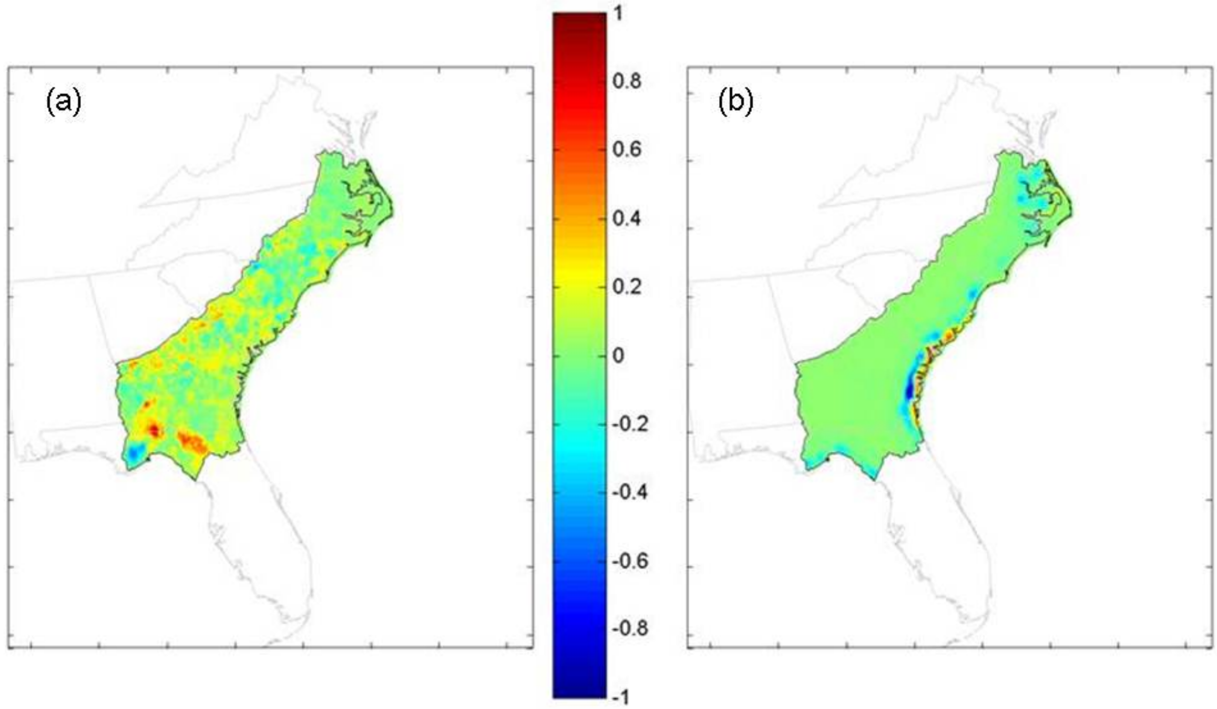

Figure 4.6: Difference between initial conservation priorities and those of 2100 for (a) open pine and (b) maritime forest for climate scenario a2. Warm colors indicate where conservation priority increased over time and cool colors where priorities decreased. Green designates no change in priority values.

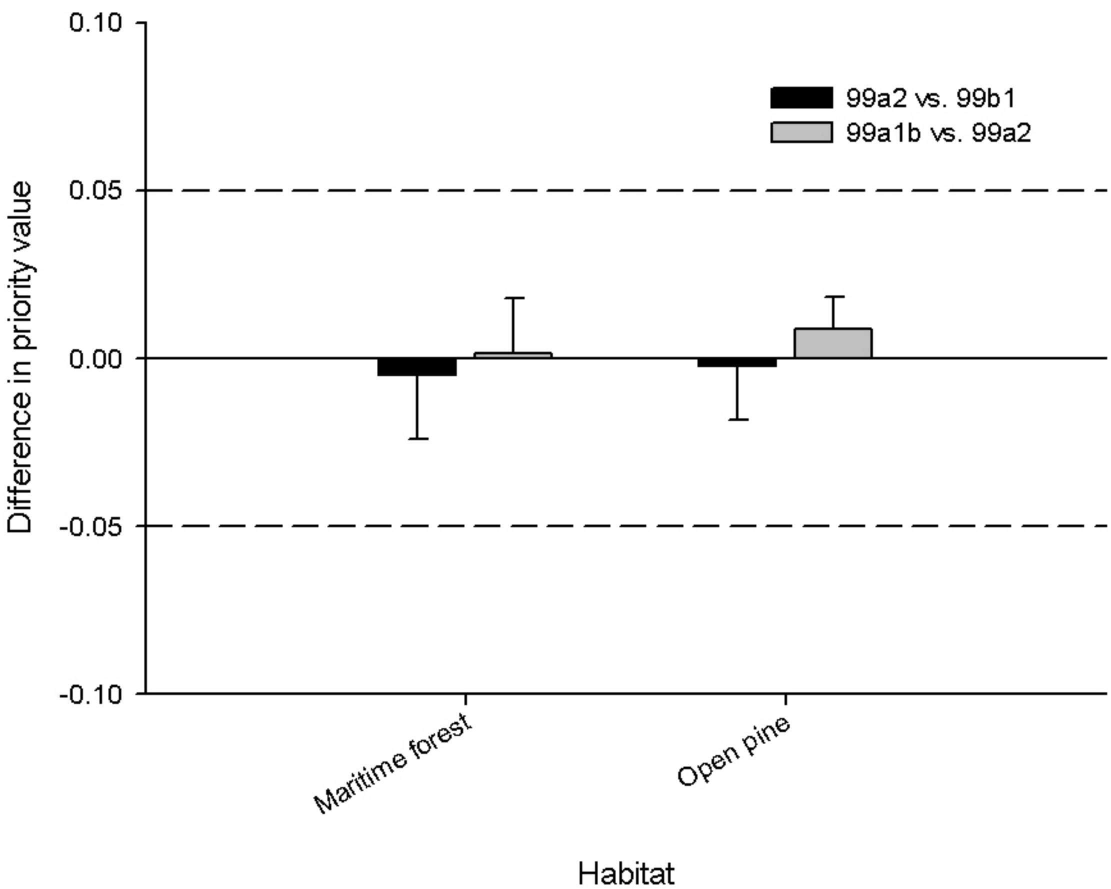

Figure 4.7: Difference among open pine and maritime forest priority surfaces for climate scenarios, a2 (worst case scenario), b1 (best case scenario), and a1b (middle way) Reference line indicates less that 5% difference between the surfaces which we have defined as no significant difference.

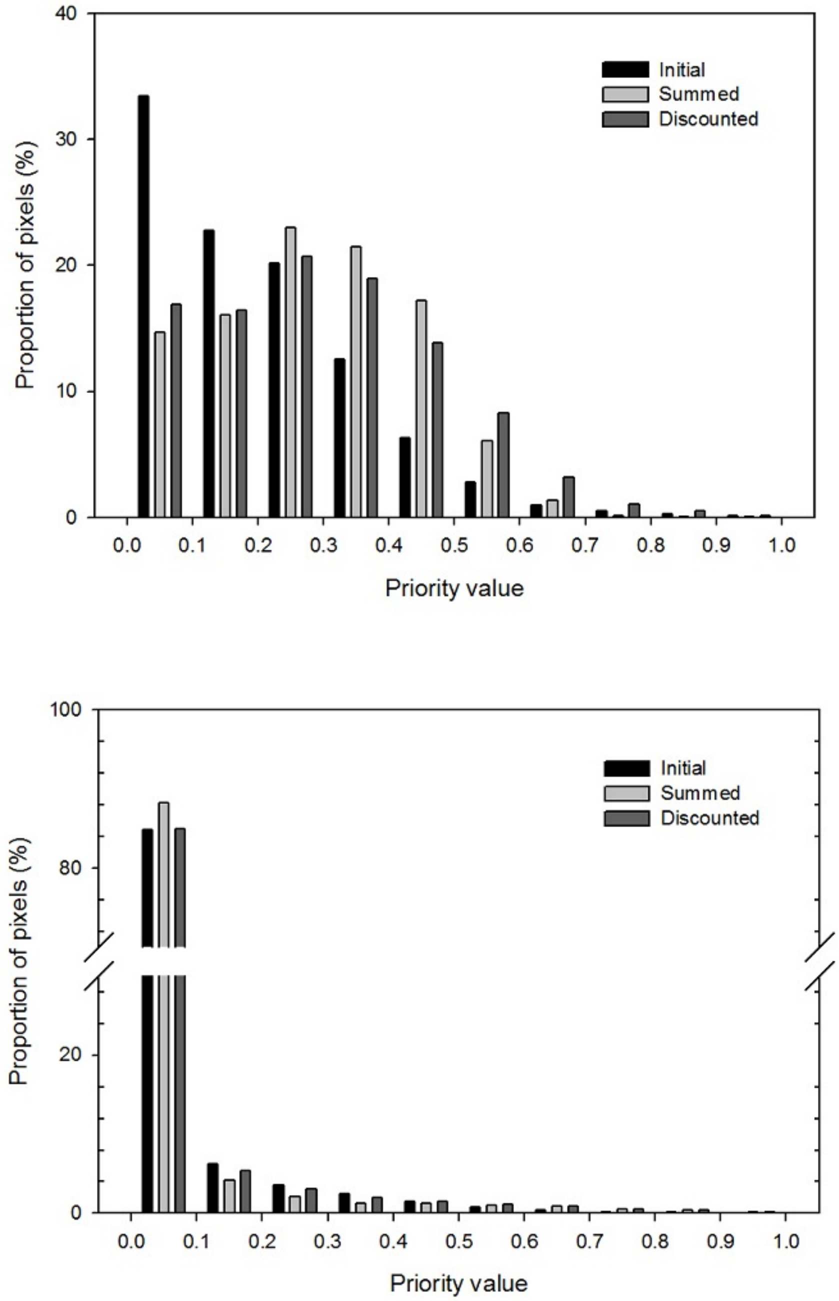

Figure 4.8: Distribution of priority values for open pine (top) and maritime forest (bottom) habitats in 2000 (Initial), summed across 100 years (Summed), and with a 4% annual discount (Discounted) under a2 climate scenario.

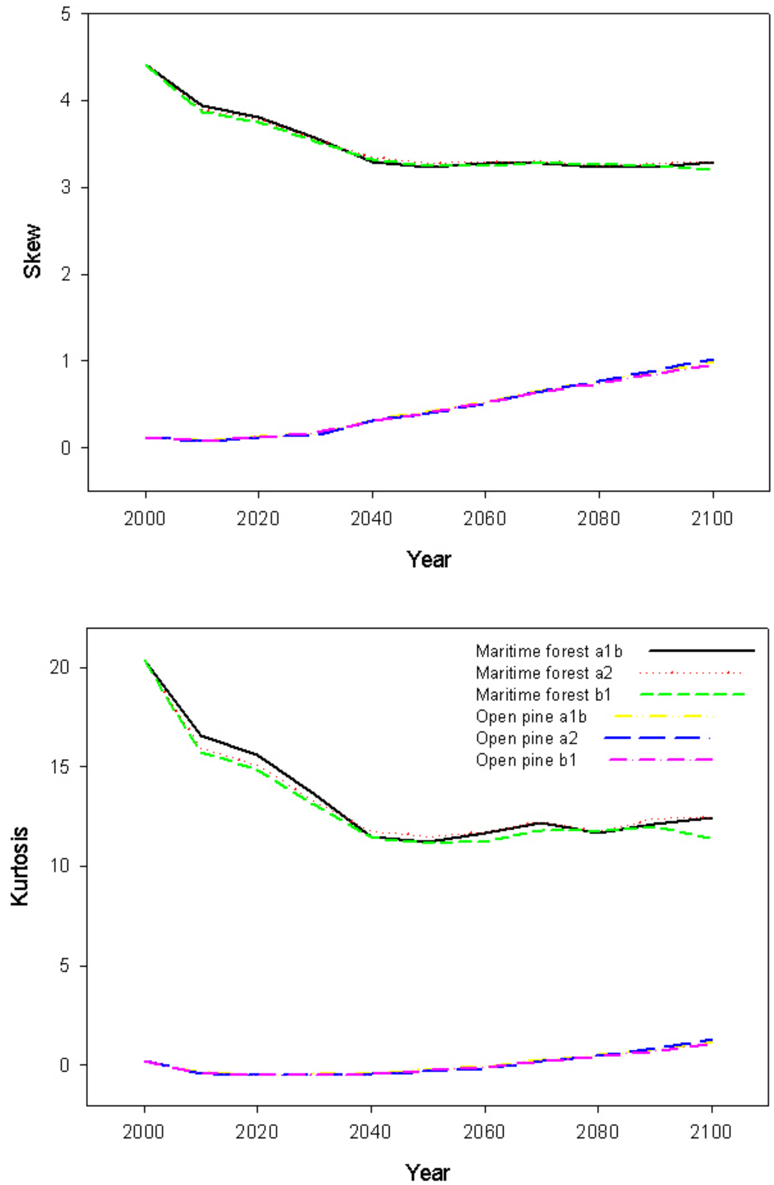

Figure 4.9: Skew (top) and kurtosis (bottom) of priority scores for open pine (yellow, blue, and pink curves) and maritime forest (black, red, and green curves) by year of land cover projection under a2, a1b, and b1 climate scenarios. Both habitats show positive values of skew which indicates long right tails and little area of high conservation priority, but maritime forest had higher skew values. Comparatively, while maritime forest has large positive kurtosis values which indicate highly peaked distribution of priority values, open pine has kurtosis values around zero which indicates a normal distribution. There was little variation among climate scenarios so curves largely overlap.

Table 4.1: Habitat association, selection method, territory size, and dispersal distance for focal bird species for spatially-explicit conservation prioritization process in the Southeastern United States. Focal species were selected using structure decision making (SDM), Lambecks process (Lambeck), both selection methods (both) or using an online survey (online). Territory size was based on published literature. Dispersal distance was based on the maximum distance of published adult (A) or natal (N) dispersals or calculated (C) using an allometric equation [119]

Habitat	Species	Latin name	Selection method	Territory size	Dispersal distance	Type of dispersal	Reference
Open pine	Bachman's sparrow	*Peucaea aestivalis*	Lambeck	25,000	21,000	C	[24]
	Brown-headed nuthatch	*Sitta pusilla*	SDM	28,000	19,000	C	[134]
	Field sparrow	*Spizella pusilla*	online	7,600	20,000	C	[11]
	Northern bobwhite	*Colinus virginianus*	Lambeck	16,187	100,000	N	[10]
	Red-cockaded woodpecker	*Picoides borealis*	both	800,000	5,400	N	[46]
Maritime forest	Common ground dove	*Columbina passerina*	both	4,200	100,000	N	[9]
	Northern parula	*Parula americana*	online	4,000	11,000	C	[71]
	Painted bunting	*Passerina ciris*	Lambeck	20,000	8,000	A	[55]
	Yellow-throated warbler	*Dendroica dominica*	online	22,800	13,000	C	[64]
Both	Prairie warbler	*Dendroica discolor*	Lambeck	15,000	3,400	A	[77]

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