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Full Length Research Paper

Here today, gone tomorrow? Targeting conservation investment in the face of climate change

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To optimize the use of scarce resources, it is imperative to target conservation investment wisely. We discuss the impact assessment of potential climate-driven shifts in species distributions on the future conservation utility of a present-day reserve design. We provide examples using breeding bird survey data for 150 species in the eastern USA, and two predicted future species distributions models. Using present-day distributions, this study systematically selects sets of units meeting a range of conser-vation targets; 10 to 100 occurrences of each species in the reserve network. Units provide coverage to 68 – 79% of bird species in the two future scenarios. Underrepresented species fall into two principal groups, those associated with northern tree species (Balsam fir *Abies balsamea* or Paper birch *Betula papyrifera*) and those linked to temperature variables. Changes in the geography of conservation prio-rity are highlighted by a 'conservation priority surface' and compared to existing protected areas. These techniques inform adaptive conservation management strategies and encourage the geographic target-ing of long-term conservation investment.

Key words: conservation investment, climate change, diversity, systematic reserve design, species distributions.

INTRODUCTION

Recent large-scale multi-species datasets allow systematic and holistic approaches to conservation reserve design. However, successful and efficient conservation planning requires more than detailed present-day species data. Understanding the potential impact of future changes in species distribution on the implementation and impact of conservation designs is essential when optimizing conservation investment (Levitt 2005). Research into climate-driven species distributions predicts extensive changes in species richness (Currie 2001), abundance (Shoe et al., 2005), range (Walther et al., 2005), and thus regional extirpations and possible extincttions (Thomas et al., 2004; Thuiller et al., 2004). However, these broad, course-scale analyses have only recently begun to incorporate direct climatic effects on specific conservation designs. Araujo et al. (2004) and Hannah et al. (2002; 2005) demonstrated that climate change may result in loss of plant species from reserve networks in Europe and South Africa, respectively. Midgley et al. (2002) have modelled potential distributional chan-ges at the biome scale in response to climate shifts. Peterson et al. (2002) predict 'severe' turnover of local biological communities for 1,870 species of mammals, birds and butterflies in Mexico. To mitigate this effect, Hannah et al. (2007) explore options for incorporating cli-mate change effects into the selection of a minimum set reserve network. However, their use of a single conser-vation target does not reveal the sensitivity of the network design to varying levels of conservation effort. Questions remain: How can the expected temporal dynamics of spe-cies distributions (in this case, in response to climate change) be incorporated into reserve planning? Can we select regions today, using our existing level of know-ledge of present day species distributions, which will remain important centers of biodiversity into the future? And how can we best convey this information to ensure widespread integration of this information into land-use planning? Conservation efforts are often costly and time consuming, requiring large areas of land that are usually desired for other uses. The creation of additional conser-vation reserves involves a trade-off between the demands of human society and the needs

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of the ecosystem (Naidoo et al., 2006; Ferraro and Pattanayak 2006). Our understanding of which areas of land are ecologically important today must be tempered and bolstered by predictions of how that importance will develop in res-ponse to changes, both ecological and man-made. Identi-fying inexpensive areas of land that are predicted to increase in importance over time may allow the creation of more robust designs (from an ecological perspective) at a fraction of the cost. At the same time, identifying regions of diminishing importance may allow for more informed assessment when it comes to the time to select one unit over another.

This paper evaluates the impact of potential, climate-driven shifts in species distributions on the future success of a conservation reserve design based on present- day distributions. We use modern bird distribution data for 150 species to design an example of a conservation re-serve network and assess the effectiveness of this network using two predicted future climate-driven distri-butions.

A variety of techniques have been established to maxi-mize the biotic diversity contained in a reserve net-work while minimizing the total cost of implementing and main-taining the reserve (Cabeza and Moilanen, 2001; Csuti et al., 1997). A variety of site selection models have been specified for a range of conservation objectives, maximiz-ing phylogenetic diversity (Faith, 1992; Solow et al., 1993; Polasky et al., 2001; Rodrigues and Gaston 2002b), ecosystem representation (Schmidt, 1996; Pressey et al., 1997; Snyder et al., 1999) and endan-gered species protection (Dobson et al., 1997: Ando et al., 1998; Arthur et al., 2004). Metrics such as irreplace-ability (Ferrier et al., 2000) use known species distribu-tions to efficiently select complementary conservation re-serves to meet *priori* conservation targets. This type of procedure has been used in recent years to explore con-servation options (Margules and Pressey, 2000; Warman et al., 2004; Rodrigues et al., 2004; Freemark et al., 2006; Turner and Wilcove, 2006), but little has been done to examine the longer-term utility or viability of reserve designs. Implicit in the use of these methods is the assumption that reserves selected to protect present-day species distributions will remain important centers of spe-cies diversity in the future. The longer-term success of conservation effort hinges on the validity of this assump-tion.

This paper is presented to further critically discuss issues regarding the identification and management of areas for longer-term conservation and protection, using species distributions today in comparison to those in the future. The paper further introduces a conservation prio-rity metric that is equivalent to the averaged optimacity metric (Wilhere et al., 2008) defined as the proportion of times a unit is selected for conservation across a range of conservation targets (from minimum to maximum degrees of conservation effort). This metric represents a unit's contribution to the reserve network, given its local species assemblage and the regional distribution of species, as a function of the degree of conservation effort available in a given planning region. A unit selected for conservation at low levels of conservation effort contains more unique species than a unit that is selected only at higher levels of conservation effort that is, adding only redundancy to the reserve network. Few conservation efforts are enacted wholesale; this metric provides a visualization of the trade offs between low-effort, representational reserves and more intensive coverage of species distributions.

Priority surfaces may be calculated for present day and future species distributions. By comparing the difference between present-day conservation priorities and potential future priorities, areas of expected change or stability can be identified; these latter areas of persistent and irreplaceable biodiversity should be considered critical components of long-term conservation action. It is also important to identify regions that consistently provide little or no unique biodiversity, drawing attention to areas that may benefit from conservation action other than protect-tion. This triage process may help to guide conservation managers towards regions of long-term importance that may be occluded by existing present-day community pat-terns.

METHODS

The analysis uses three species incidence datasets generated by Mathews et al . (2004), documenting the present and potential future distribution of 150 bird species in the eastern United States. These data have previously been used to evaluate the effect of distribution size on the extinction risk as a result of climate change (Schwartz et al., 2006). The first dataset contains species distributions aggre-gated from breeding bird survey (BBS) data from 1981 - 1990, generalized to the county grain for the conterminous United States east of the 100th meridian. The remaining two datasets comprise predicted future distributions. Mathews et al. (2004) produced the two future bird species distributions using two general circulation model climate scenarios and future tree species distributions (Prasad and Iverson 1999). In the future, it would be useful to expand the extent of the study to include all of North America as continuous and fine-scale tree species distributional data for other regions becomes available. Prasad and Iverson's (1999) work provides predictions of tree cover change across the country, a key component in modelling many avian distributions. The British Hadley Center for Climate Prediction and Research model (Mitchell et al., 1995) and the Canadian Climate Center model (CCC) (Boer et al., 2000: Kittel et al., 2000) comprise 2 x CO_2 climatic pre-dictions spanning the spectrum of potential climate change for the years 2070 to 2099 for a set of eight temperature and precipitation variables. The Hadley scenario predicts relatively grea- ter preci-pitation increases across the continent, while the CCC scenario predicts greater temperature increases. Mathews et al. (2004) used a regression tree approach to model species incidence functions using contemporary climate and tree species variables. The 150 species included in these data sets are those for which the models explained more than 50% of the observed variation in present-day BBS incidence-by-county (ranging in total r^2 from 50.9 – 91.0%, with a mean value of 73.3%). Incidence is defined as the proportion of within-county BBS surveys in which the species occurs. Any species with an incidence > 0.05 was considered to occur within a given county and all further analysis focuses on the resulting Boolean occurrence data. This paper assigned the occurrence

rence information of the county to the centroid of each county polygon, generating the 2121 'planning units' used in our analysis.

This paper uses the C-Plan software package (New South Wales NPWS 2002) to summarize these species distributions using the irreplaceability metric (Ferrier et al., 2000). This method quantifies the unique contribution a unit makes towards pre- specified conservation targets; the species composition of a unit is weighted against the relative rarity of each species and the stringency of the targets. Units containing many highly endemic species will be assigned greater irreplaceability scores than units containing few or very common species. A value of 1, or completely irreplaceable, indicates that the unit contains species that cannot be found elsewhere that is, unless this unit is included in a conservation design, some aspect of the preset conservation targets cannot be met. Lower irreplaceability values indicate that other units within the study region contain comparable species, resulting in greater flexibility in the selection of the reserve network. However, this metric is dependent on the particular species targets chosen for the analysis; at low targets, few units are necessary for the reserve network to meet its *a priori* species goals. At higher targets, proportionately more units are necessary, and units are more often selected to provide redundancy to the network. This study examines a range of 10 potential conservation targets, ranging from 10 occurrences of each species within the reserve network (low conservation effort, smaller total reserve area) to 100 occurrences (high conservation effort, equivalent to protecting every instance of the rarest species in the study). Three reserve network sets are constructed by iteratively selecting a reserve network for each of the 10 conservation targets (10 - 100 units per species). By processing each of the three data sets (Present-day, Hadley and CCC) using the C-Plan software, three continuous irreplaceability maps are produced for the study region and a corresponding set of minimum-set reserve networks (10 for each dataset). Minimum sets were chosen by ranking units by their irreplaceability score and then selected one by one, by rank and breaking ties by preferentially selecting units with greater total richness. While many additional constraints might be introduced into this selection procedure, this method is straightforward and suitable for the demonstration purposes of this article. Each selected unit is then scored with regards to its conservation priority using the number of times a unit is included across a range of conservation targets, divided by the total number of targets, a metric that is equivalent to average optimacity (Wilhere et al., 2008).

A high priority unit (averaged optimacity approaching 1) contains endemic species and is included at low levels of conservation (10 occurrences of each species within the reserve) while a low priority unit (averaged optimacity approaching 0) will only be necessary to conserve at high levels of conservation effort (targets approaching 100 occurrences of each species) and provides supplementary coverage to more widespread species; null values indicate that a unit does not contain irreplaceable biodiversity and is never required at any conservation target.

The efficacy of the present-day reserve network to conserve species in the future by comparing how well it covers the Hadley and CCC species distributions is evaluated. It is assumed in this study that bird species will successfully disperse over time to track changes in climate; individual species' climatic envelopes are also assumed to remain constant over this time. For a reserve network selected to meet a given conservation target in the present-day (for example, 10 occurrences per species within the reserve), how many species meet these targets in the future distributions? An effective reserve network is one that maintains a high proportion of species at the conservation target levels for which it was designed. Finally, we evaluate the correlation between shifts in priority and changes in species composition, using the Bray-Curtis distance metric.

For visualization purposes, we use a kriging interpolation (Bailey and Gatrell, 1995; Jiguet et al., 2005 spherical semivariogram method) to produce a smooth conservation priority surface across the study region for each dataset. This approach was considered more appropriate than using county polygons (from which the predicted-futures data is based), as this work was intended to be used as a regional guide to direct further monitoring and conservation effort, rather than as a reserve network design *per se.*

The potential effects of climate change on the results of systematic conservation planning techniques using two difference maps created by subtracting each future priority surface from that of the present-day surface are highlighted. These maps highlight regions of increasing or decreasing conservation priority under climate change. The range of shifts in priority between the two climate scenarios, both in terms of magnitude and in geographic extent is then compared. Using the recent Commission for Environmental Cooperation's North American Environmental Atlas of Protected Areas (C.E.C. 2008), the average conservation priority within existing protected areas to that found outside established reserves are compared.

RESULTS

Present-day reserve designs failed to provide any future protection to 19 – 26% of species (Figure 1; 28 in Hadley, 38 in CCC, 27 in common, 39 in all; Table 1), 18 of which were extirpated from the CCC distribution. The CCC-based predictions showed these extirpated species moving northward and out of the study regiondriven by shifts in balsam fir (Abies balsamea) or paper birch (Betula papyrifera; 9 species) and temperature averages from January and July (9 species).

Of the remaining 21 species lacking coverage by the present-day reserve set, 61% had distribution models dominated by correlations with balsam fir and paper birch and 66% were impacted by climatic temperature variables (Mathews et al., 2004). The 39 "at risk" species had a significantly lower mean present-day incidence than species meeting conservation targets (two-tailed unequal variance T-test, n_1 = 39, n_2 = 111, = 0.05, p = 0.000; Levene's test for Equality of Variance, F = 70.311, p = 0.000). Both predicted future distributions showed reductions in mid-rarity species and increases in the proportion of both common and rare species (Figure 2). Correlation was low between shifts in conservation priority and changes in species composition, as meas-ured by the Bray-Curtis distance metric. Pearson correlation coefficients of 0.106 (Present-CCC) and - 0.025 (Hadley-CCC) (= 0.05, p = 0.001) indicated no consistent trend. Regions with high changes in conservation priority do not necessarily show great changes in species composition. Likewise regions with consistent priority may still display changes in the community composition, albeit amongst spe-cies with similar degrees of endemism.

The Hadley-scenario displayed much greater temporal shifts in conservation priority (- 0.991 to 0.885) than the CCC-scenario (- 0.297 to 0.265), although both scenarios shared similar spatial distributions across the region (Figure 3). Substantially more variation in priority existed between the present-day and Hadley predictions (standard deviation 0.43) than between the present-day and CCC (standard deviation 0.13; Figure 4). The correlation (Pearson correlation, = 0.05, p = 0.01) between the present and Had-

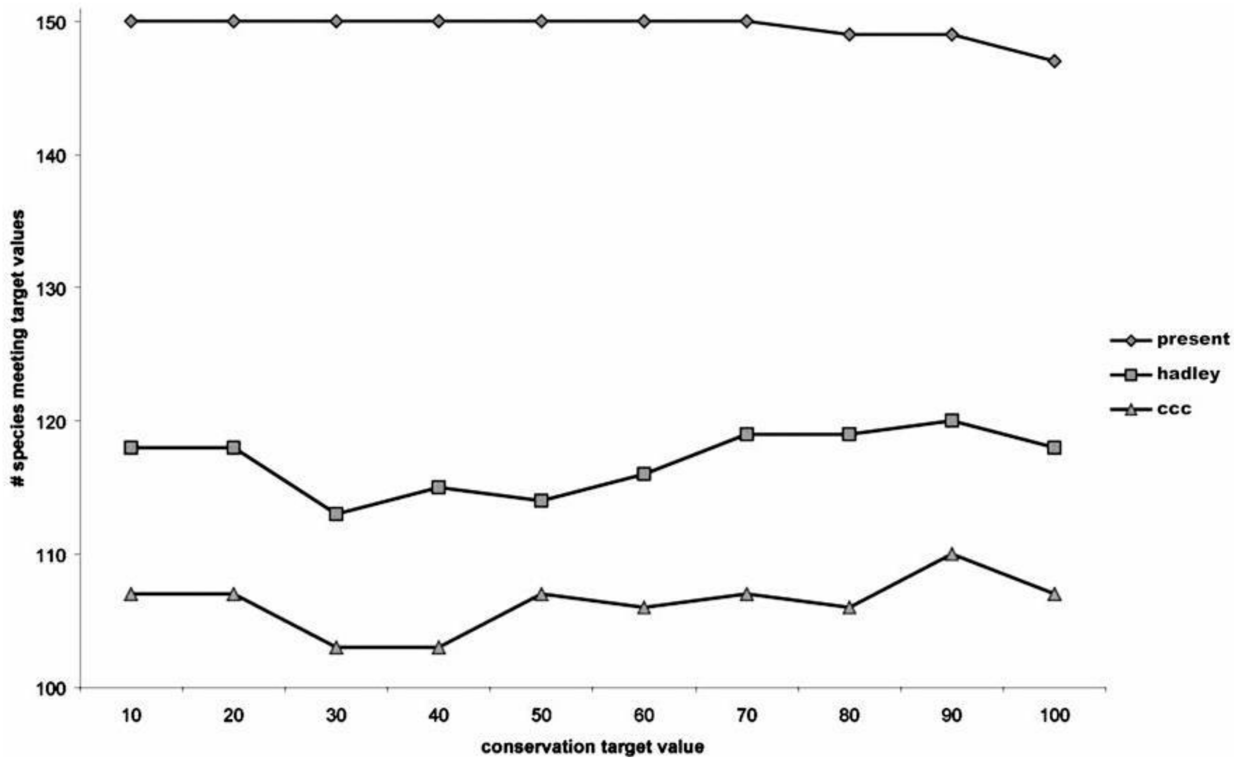

Figure 1. The number of species meeting conservation targets under a present-day reserve design, at varying levels of conservation effort. The present-day scenario (diamond points) contains some species that occur in less than 80 counties, and so cannot reach higher levels of conservation. The Hadley (square points) and CCC (triangular points) show consistent patterns of species coverage across all levels of targets.

ley priority values (r = 0.10) was substantially lower than that between present and CCC priority values (r = 0.92). The average priority values within the CEC protected area network were not significantly different (> 0.05) than values seen outside the existing network. Each sce-nario shows a similar distribution of priority within and outside the protected areas. Areas within existing pro-tected areas do show a higher mean priority (0.363) than those outside of protected areas (0.176), but the variance in the data precludes a significant result.

Despite this difference, the spatial distribution of areas with no priority (those areas not selected for conservation in any scenario) was consistent between scenarios; large central and south-eastern portions of the study area con-tain no irreplacable units (Figure 4). This result closely tracks that of high-intensity agricultural land-use and extensive urban development in the study region.

DISCUSSION

These results suggest that present- day species distribu-tions are a reasonable starting point for reserve design in important for conserving biodiversity using the present-day distribution remained important centers of conserva-tion importance in our two potential futures. Although the specific species composition varies, regions containing important or rare species today continue to do so under climate change. This suggests that geography and land cover may be limiting factors on the distribution of overall biodiversity, while climate may play a stronger role in determining the specific assortment of species found within a given location.

Although the predicted future distributions used in this analysis were the best available for the study region, these results need to be used with caution in relation to guiding conservation action. The refinement of predictive datasets (Iverson and Prasad, 2002) is an ongoing pro-cess and revisions need be incorporated as they become available. However, the urgency of the conservation need demands that the process begins with using data at hand.

It is expected that species with restricted present-day ranges will likely be under -represented in the future. Small disjunct populations of endemic species (especially those existing at the edges of their present ranges) may find their unique niche-space vanish as climate shifts over the region. Special attention will be needed to iden-tify these remnant populations and to determine whether to act to preserve them (through remediation) or to shift focus to new areas (potentially beyond present planning regions) to track range changes. This assumes that populations are sufficiently capable of dispersing to newly

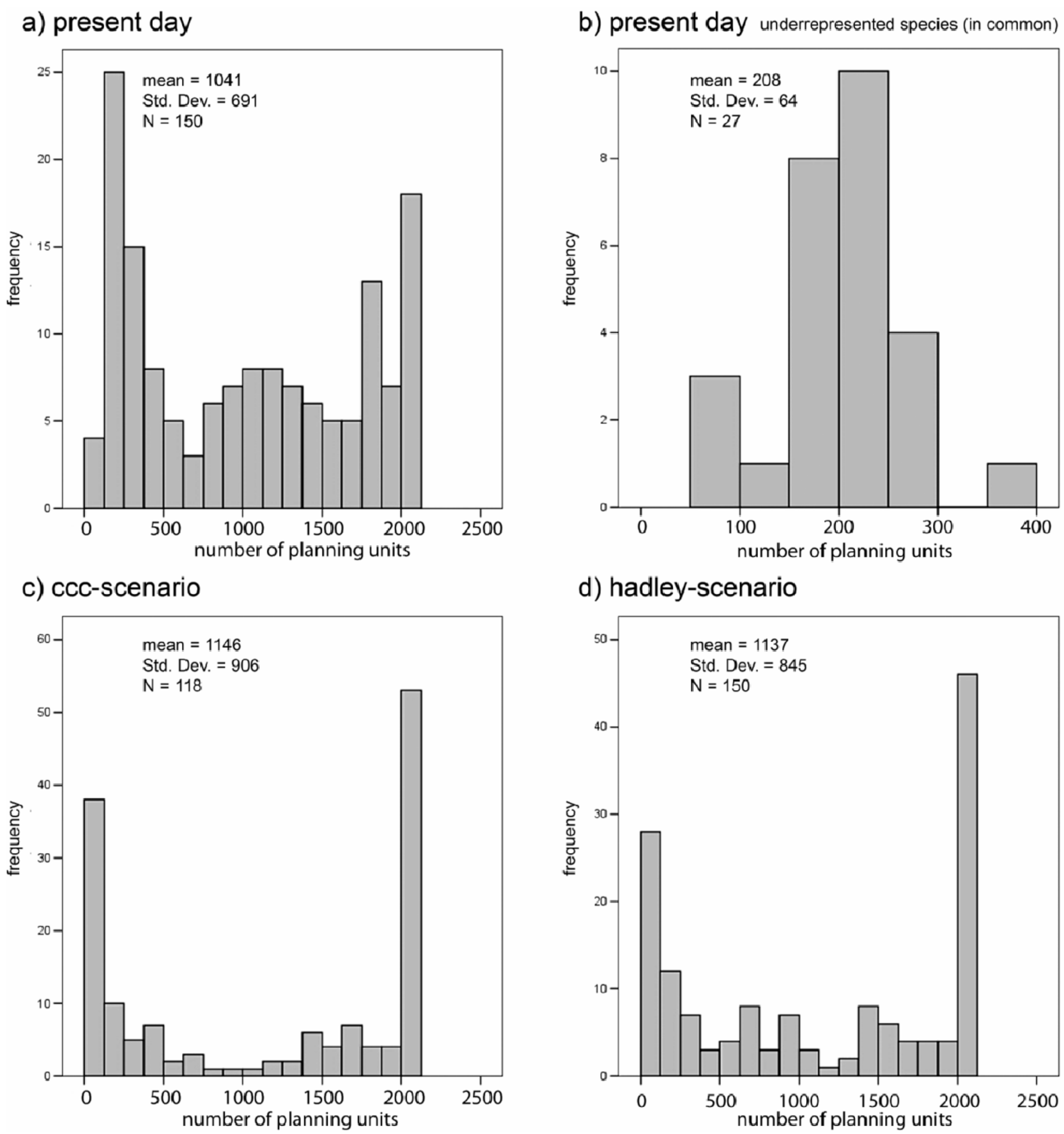

Figure 2. The frequency of species incidence across the 2121 planning units in the study area a) the present day distribution of all 150 species; b) the present day distribution of the 27 species underrepresented in both the CCC and Hadley scenarios; c) the CCC-scenario distribution of the 118 remaining, non-extirpated species; and d) the Hadley-scenario distribution of all 150 species.

appropriate areas and very much depends on the hostility of the human-dominated landscape. Williams et al. (2005) present potential techniques for tracking these dispersal requirements.

Some under-represented species in our dataset show high associations with specific forest communities, particularly balsam fir and paper birch. Identifying these associations will allow the proactive designation of areas of future importance and preservation of habitat with the potential to maintain populations that may presently live elsewhere. Existing present-day reserves provide a nucleus of coverage; these can be modified in response to the changes in conservation priority expected over time and evident in this study's findings and those of others (Parmesan, 2006). The configuration of present-day reserves with respect to potential future reserves may encourage the effective dispersal of communities in response to changing environmental conditions. Without the explicit consideration of these potential avenues of dispersal, areas may become isolated by intensive land use and preventing existing populations from dispersing to optimal habitat over time.

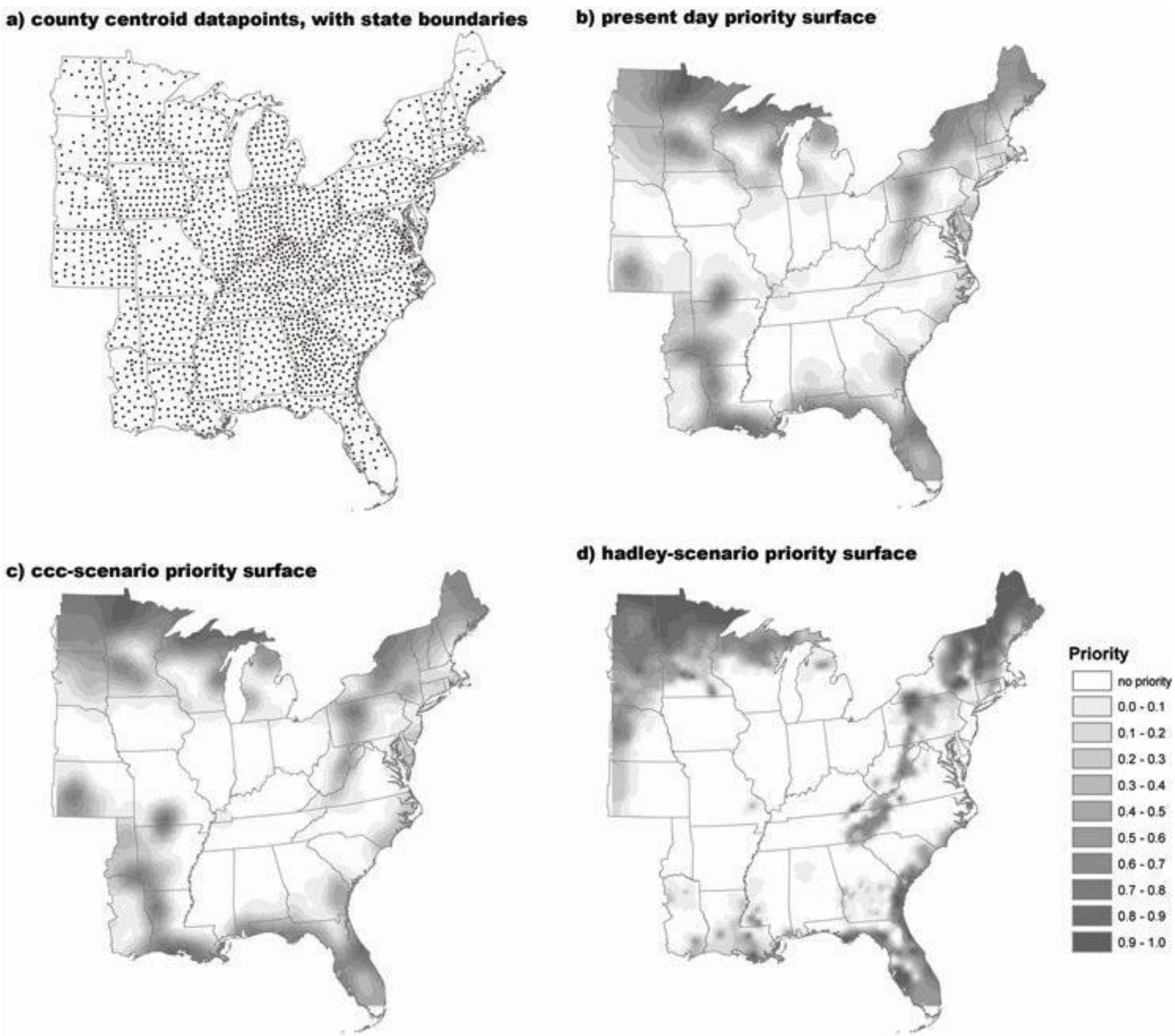

Figure 3. County-centroids (a) for the study region. Interpolated conservation priority values for (b) the present-day, (c) CCC and (d) Hadley species distributions. A high priority region (approaching 1) contains rare or endemic species and is required immediately at low levels of conservation (10 occurrences of each species within the reserve) while a low priority (approaching 0) indicates that area will only be necessary to conserve at high levels of conservation effort (targets approaching 100 occurrences of each species).

It is important that attention be focused on those regions with high future potential. Large human-dominated tracts of land, with little or no conservation value today, have little potential in the future; without extensive remediation and management they are unlikely to develop into into centers of biodiversity. Protecting high priority areas today will minimize ongoing species loss and give time to identify the high priority areas of the future. In particular, present-day low priority regions with predicted increased future priority require monitoring and landuse planning to prevent erosion of their conservation potential. Hannah et al. (2007) have demonstrated an approach for incorporting climate change considerations into present-day network design in order to minimize the "cost of waiting". However, design methods which explicitly incorporate future predictions require rigorous validation of the predictive models, to ensure that uncertain model outputs do not override existing certain ties. The emergence of new tools for financing, facilitating and implementing regional and landscape-scale conservation such as external revolving loan funds (McBryde et al., 2005); hold significant potential to increase the pace and scope of adaptive land conservation in the face of climate change. A synthesis of these methods will guide design considera-

Table 1. Summarized species occurrence information (for 39 underrepresented species) by AOU code number and common name, detailing the number and proportion of units (N = 2121) each species occurs in, for the present-day, Hadley and CCC distributions. Underrepresented species are those species that fail to meet any conservation targets in a future scenario (% Coverage = 0 for either scenario).

Species		Current		Hadley			CCC		
AOU #	Common Name	# units	% units	# units	% units	% coverage	# units	% units	% coverage
1900	American Bittern	242	11	27	1	0	0	0	0
2210	American Coot	167	8	12	1	0	0	0	0
770	Black Tern	194	9	17	1	0	0	0	0
6620	Blackburnian Warbler	250	12	18	1	0	0	0	0
6540	Black-throated Blue Warbler	232	11	73	3	0	49	2	0
6670	Black-throated Green Warbler	433	20	305	14	100	254	12	0
1400	Blue-winged Teal	365	17	97	5	0	132	6	0
5100	Brewer's Blackbird	183	9	5	0	0	0	0	0
7260	Brown Creeper	213	10	137	6	50	96	5	0
5610	Clay-colored Sparrow	184	9	3	0	0	0	0	0
6120	Cliff Swallow	903	43	268	13	100	116	5	0
70	Common Loon	128	6	8	0	0	0	0	0
5670	Dark-Eyed Slate-colored Junco	246	12	51	2	0	27	1	0
5140	Evening Grosbeak	90	4	7	0	0	0	0	0
6420	Golden-winged Warbler	288	14	174	8	100	124	6	0
2881	Gray Partridge	194	9	51	2	0	2	0	0
7590	Hermit Thrush	254	12	138	7	50	96	5	0
4670	Least Flycatcher	397	19	168	8	100	6	0	0
5830	Lincoln's Sparrow	71	3	22	1	0	0	0	0
6570	Magnolia Warbler	197	9	49	2	0	4	0	0
6790	Mourning Warbler	243	11	21	1	0	0	0	0
6550	Myrtle Warbler	197	9	22	1	0	0	0	0
6450	Nashville Warbler	206	10	65	3	0	0	0	0
6750	Northern Waterthrush	208	10	57	3	0	8	0	0
5170	Purple Finch	291	14	111	5	0	69	3	0
7280	Red-breasted Nuthatch	230	11	22	1	0	0	0	0
540	Ring-billed Gull	288	14	87	4	20	1	0	0
3000	Ruffed Grouse	354	17	174	8	100	123	6	0
7240	Sedge Wren	358	17	132	6	60	70	3	0
2140	Sora	179	8	6	0	0	0	0	0
7580	Swainson's Thrush	95	4	22	1	0	0	0	0
5840	Swamp Sparrow	481	23	183	9	100	27	1	0
7560	Veery	467	22	216	10	100	148	7	0
5580	White-throated Sparrow	206	10	22	1	0	0	0	0
2300	Wilson's Snipe	292	14	42	2	0	0	0	0
7220	Winter Wren	220	10	57	3	0	8	0	0
4020	Yellow-bellied Sapsucker	264	12	65	3	0	0	0	0
4970	Yellow-headed Blackbird	242	11	92	4	0	13	1	0
6410	Blue-winged Warbler	668	31	336	16	0	244	12	50

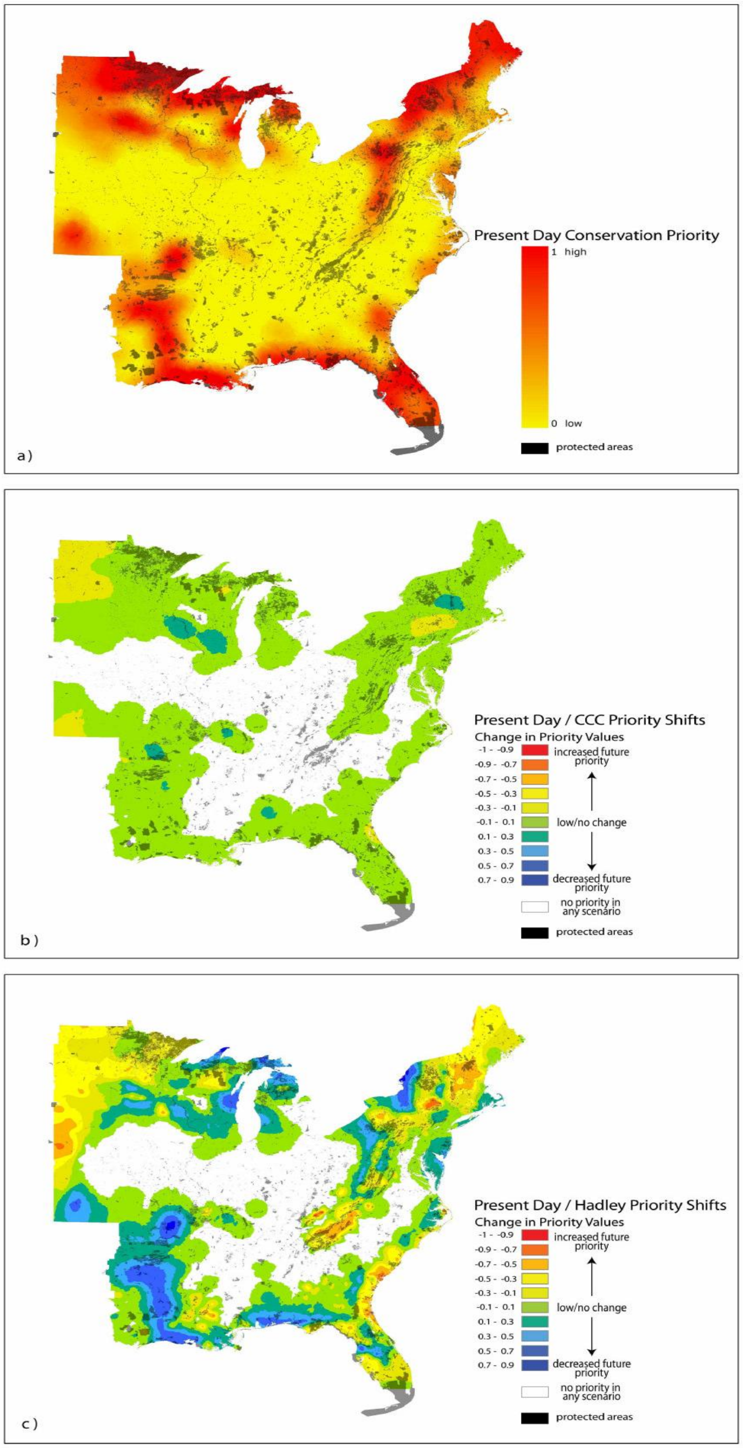

Figure 4. (a) Priority map for present -day species distributions, overlain with existing protected areas according to the CEC (2008) . Priority-change surfaces generated by the subtraction of the CCC (b) and Hadley (c) predicted conservation priority surfaces from the present day priority surface (see supplemental data for original priority surfaces). Difference values near 0 show no change in priority over time. Negative differences show areas of increasing priority over time, while positive values indicate areas of decreasing priority over time. Null (white) values indicate regions with no conservation priority in any scenario. The Hadley comparison indicates finer-scale variation of greater magnitude than in the CCC case.

tions for years to come.

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