Spatial application of the Priority Amphibian and Reptile Conservation Areas (PARCA) Guidance in the northeastern United States

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Cooperator Science Series # 160-2024

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Contractual References:

This document (USGS IPDS # IP-164565) was developed in conjunction with the U.S. Fish and Wildlife Service with financial support from the North Atlantic Landscape Conservation Cooperative program through a Cooperative Agreement to the University of Maine with the U.S. Geological Survey Maine Cooperative Fish and Wildlife Research Unit (U.S. Geological Survey, Maine Department of Inland Fisheries and Wildlife, University of Maine, U.S. Fish and Wildlife Service and Wildlife Management Institute cooperating)..

Recommended citation:

Loftin, Cynthia, William Sutton, Kyle Barrett, and Phillip deMaynadier. 2024. Spatial application of the Priority Amphibian and Reptile Conservation Areas (PARCA) Guidance in the northeastern United States. U.S. Department of Interior, Fish and Wildlife Service, Cooperator Science Series FWS/CSS-160-2024, Washington, D.C. https://doi.org/10.3996/css78994021

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ABSTRACT:

Amphibian and reptile populations are facing rapid declines resulting from a variety of threats, including disease, overexploitation, invasive species, and habitat loss. Conservation planning for amphibians and reptiles is complicated by incomplete information about their distributions and abundances, their relative rarity and complex life cycles, and variations in land management priorities that can create inconsistencies in conservation across the landscape. The Priority Amphibian and Reptile Conservation Area (PARCA) guidance combines information about species rarity, occurrence, population viability, species diversity, and landscape integrity with expert evaluation to identify potentially important areas for amphibian and reptile conservation. We used the Maximum Entropy algorithm to model potential habitat suitability based on reptile and amphibian species occurrence data and environmental variables in the northeastern United States and combined these models with information about species richness and landscape condition following the PARCA guidance. We invited experts to review the modeled PARCA polygons and revised the draft PARCAs to incorporate their feedback. Most modeled PARCAs were retained by the experts, and some experts added areas that were not modeled. Although most experts indicated they used some of the PARCA guidance criteria in amphibian and reptile conservation in their state, there were exceptions. We compared the distribution of the draft PARCAs with existing conservation areas and evaluated whether the draft PARCAs and lands in current conservation were representative of high-quality habitats (where highly suitable or "best" habitat was indicated by a modeled value > 0.50) for the modeled species. Although most existing conservation lands included habitats predicted to be highly suitable for priority reptiles and amphibians, most species were under-represented in these landscapes, and the model-predicted best habitats for some species were not captured in any conserved lands. Combining the PARCA guidance and maps developed in this project with knowledge shared by biologists, land managers, and conservation practitioners could provide a robust approach for amphibian and reptile conservation planning.

KEYWORDS: species distribution models, species occurrence, species richness, conservation planning, maximum entropy algorithm, priority habitat

INTRODUCTION

Conservation planning may be targeted at species, habitats, landscapes, or even ecosystem services, and each approach incorporates a variety of information to develop effective plans (Bani et al. 2006, Chan et al. 2006, Buhlmann et al. 2009). For example, at the species level, up-to-date distribution and abundance information, knowledge of species' environmental requirements, connected areas of suitable habitat, and recognition of constraints that human activity places on the protected landscape can improve a range-wide conservation plan (Bani et al. 2006). Planning and implementation can be hampered by incomplete species occurrence data, limited financial resources, and inconsistencies in conservation goals across administrative boundaries. Although conservation action may be prioritized by species protection status, such as by national or global ranking, focus on priority species may be at the expense of monitoring species with less widespread conservation concern (Gaston and Fuller 2008). As a result, common species may not be documented and monitored effectively, making it difficult to track their status. Conservation efforts that focus solely on species of greatest conservation concern may under-represent biodiversity, whereas conservation that targets traditional biodiversity metrics (e.g., species richness, diversity) may overlook critical areas occupied by rare or sensitive species (Prendergast et al. 1993). To address some of the challenges inherent to conservation planning at the species level, conservation biologists may develop landscape scale plans with an expectation that such plans will capture the needs of many species and habitats (e.g., Schwenk and Donovan 2011, Baldwin et al. 2018, Duflot et al. 2018).

Area-based conservation planning may be structured around a variety of factors. Area-based plans have leveraged information on priority and common species (Buhlmann et al. 2009), ecosystem services (Chan et al. 2006), land use (Bani et al. 2006), and disturbance events that create and maintain environmental heterogeneity (Reeves et al. 1995). For example, Bani and colleagues (2006) found that indicator species and accompanying land use data offered more effective conservation plans than data on land use alone. Whereas many metrics used to inform conservation planning can be derived from existing data, expert knowledge of ecology and socioeconomic factors that affect conservation decision-making offer additional contributions to robust plans that may be supported by stakeholders (Knight et al. 2007, 2008). For example, Knight et al. (2008) identified a gap between knowing strategies for identifying conservation areas and implementing those areas on the ground and posited that closely connecting the research phase with on-the-ground practitioners or managers could help bridge the gap. Finally, plans that recognize ongoing and future environmental change may be more likely to provide resilient long-term conservation than plans that assume stationarity (Lawler 2009, Carroll et al. 2010). Plans that incorporate a variety of approaches such as species-based data, current land use, expert opinion, conservation goals and constraints, and long-term environmental and socio-economic trends, are uncommon (Naidoo et al. 2021). Nevertheless, such approaches may be more comprehensive and achievable when combining advanced distribution modeling techniques, remotely sensed landscape data, and partnerships among management agencies.

Species occurrence data may provide incomplete information about a species' geographic distribution because of limited survey effort, extent, or time since surveys were conducted. Species distribution modeling (SDM) approaches extrapolate correlations between species occurrences and associated environmental data (which also may be limited in accuracy and precision) to predict habitat suitability of non-surveyed or data deficient areas (Elith et al. 2006). This modeling method also is used to predict future habitat suitability where environmental conditions may be altered by dynamic forces such as landscape development or climate change

(Beaumont et al 2016). Predictions may be weighted by species conservation status to enhance the perceived value of a location that potentially hosts a priority species. Although species distribution modeling provides habitat suitability predictions for individual species, multiple species' models combined with biodiversity assessments and evaluation of anticipated landscape change offers a dynamic, multi-species conservation planning approach. Resolution and extent of species occurrence data can affect the modeled surface accuracy, and integration of expert knowledge in development of SDMs can reduce uncertainty and improve model reliability (Mainali et al. 2020). Additionally, expert opinion can bridge gaps created by decision making that reflects differences in conservation goals and cultural values across spatial scales (Crawford et al. 2020). For example, expert feedback about factors affecting conservation implementation locally versus those that reflect state or regional priorities can be incorporated to guide conservation actions informed by SDMs. Ultimately, conservation planning based on accurate predictions about species occurrence, land use trends, and expert knowledge of factors affecting decision-making can improve plan accuracy and practicality that supports conservation goals.

Amphibians and reptiles (herpetofauna) may benefit from large-scale conservation planning, as many species are experiencing rapid population declines attributed to emerging pathogens, pollution, overexploitation, habitat fragmentation and loss, and invasive species (Gibbons et al. 2000; Stuart et al. 2004; Grant et al. 2020). Although global declines in both reptiles and amphibians generally can be attributed to these factors, mechanisms of local loss can be complex and may be inconsistent owing to environmental variation and scale-dependent effects. For example, many stream salamander species have experienced declines owing to habitat loss; however, even within individual species populations, responses can vary regionally from causes that are not apparent (Barrett and Price 2014). Conservation efforts that focus solely on priority herpetofauna may be ineffective, owing to incomplete occurrence datasets that under-represent current and historical distributions, uncertainty about species sensitivities to environmental change, lack of public support for reptile and amphibian conservation, and slow progress and insufficient resources for land conservation that connects priority areas (Tingley et al. 2016, Olson and Pilliod 2022). Return on the conservation investment may be enhanced by engaging a variety of partners in habitat-centered planning strategies that sustain natural ecosystems in protected areas that are integrated within the human-affected landscape and that also capture species and taxonomic groups in additional to herpetofauna (Olson and Pilliod 2022).

The Priority Amphibian and Reptile Conservation Areas (PARCA) system aims to identify habitat for priority herpetofauna species conservation throughout the United States (Sutherland and deMaynadier 2012). PARCAs combine species rarity, occurrence, and population viability, species diversity, and landscape integrity and may be evaluated by expert knowledge in a non-regulatory framework that complements existing landscape conservation. The goal of the PARCA criteria is to identify "…exceptionally important targets for reptile and amphibian conservation --- places with significant populations of rare, diverse, and unique species assemblages embedded in landscapes capable of supporting viable populations" (Sutherland and deMaynadier 2012). Applying the PARCA criteria to identify habitat for potential conservation requires information about recent species occurrence, conservation status, population viability, species richness, and landscape condition. Expert opinion may bridge species data gaps, as well provide evaluation of proposed PARCAs that span state boundaries to regional scales. Ultimately, amphibian and reptile conservation informed with PARCAs could be implemented at the local scale in protected area networks in an iterative process, as new surveys provide additional occurrence data and information on habitat condition to improve knowledge about species distribution and status and land use dynamics.

The goal of this project was to spatially apply the PARCA System Criteria and Implementation Guidance (Sutherland and deMaynadier 2012) to amphibian and reptile species occurrence data and environmental variables to predict and map habitat clusters (i.e., proposed draft PARCAs) of potentially suitable habitat for these species in the northeastern United States (Figure 1). Our approach combined information about species occurrence, habitat preference, and richness with habitat condition and feedback from practitioners who could use the PARCA system criteria in future conservation efforts. We compared co-occurrence of draft PARCAs and areas managed for conservation. Additionally, we evaluated whether draft PARCAs were representative of high quality or best habitats for species with limited distribution as well as evaluated PARCAs for species that are more widely distributed.

METHODS

PARCA modeling process

Occurrence data preparation

We modeled distributions of highest conservation priority reptile and amphibian species (Table 1) in the northeastern United States with occurrence records and environmental covariates. We acquired species locality datasets from state agency biologists (Maine, New Hampshire, Vermont, New Hampshire, New York, New Jersey, Massachusetts, Connecticut, Pennsylvania, Maryland, Virginia, Rhode Island) and the District of Columbia and online species record databases (Vertnet, www.vertnet.org; Biodiversity Information Serving Our Nation, BISON, https://www.gbif.us/). We restricted the records to 1990-2013 for state- and District of

Columbia-provided data (the end date determined by records available at the time the study was begun), while also extending the record search back to 1950 for online resources for species with uneven point spread or small numbers of points. We reviewed, edited, and compiled the datasets for content accuracy and consistency (e.g., in species names, geographic location format and projection) and completeness, and species with insufficient point numbers or extreme unevenness (e.g., severe clustering) were removed from the occurrence datasets. We converted the compiled occurrence data spreadsheet file into a shapefile and then subset the file by species to evaluate the point number and distribution of records for each species across the region. Datasets determined to be sufficient in point number and distribution for each species were used for modeling (Table 1).

Prior to developing the predictive Species Distribution Models (SDMs), we reduced sampling bias created by oversampling owing to repeated contributions from single observers, ease of access, or sampling that targeted particular habitat types. We applied two processes to address these biases: 1) a spatial filter to remove occurrences within 600 m of other occurrences, and 2) a targeted background layer (Phillips et al. 2009). The primary purpose of the targeted background was to represent a similar spatial bias in random locations as for the occurrence records used to develop species-specific models. The targeted background layer consisted of data points within the extent of the occurrence data compiled across all priority species to complement the species' point data distributions within the geographic scope of the northeastern United States (i.e., the project region) and to represent and attempt to control for sampling biases that are likely present for the target species (Phillips et al. 2009). The background dataset was clipped to the published digital range maps (http://explorer.natureserve.org/) for each species prior to modeling the species habitat suitability to restrict the modeled habitat to the current species range. The final location data used for each SDM included recorded occurrences and random locations extracted from this background dataset.

Variable selection, model development, and draft PARCA evaluation

We reduced our initial set of 39 explanatory environmental variables to potentially include in each SDM to 19 variables (Table 2). The initial set of 39 variables was broadly inclusive with respect to environmental variables influencing the distribution of reptiles and amphibians. The reduction to 19 resulted from culling variables that were highly correlated ($r > 0.70$) and also based on reviews by three professionals with expertise about northeastern amphibian and reptile species. Data for the 19 selected environmental variables were matched geographically and temporally and resampled to 300 m pixels. We used the Geospatial Modeling Environment (Beyer 2012) to extract environmental covariate data at each presence and background data point from each retained environmental covariate data layer.

We used the Maximum Entropy (MaxEnt; Phillips et al. 2006) presence-only SDM algorithm, which evaluates environmental differences between occupied and random locations, to develop 300 m pixel resolution logistic model predictions of habitat suitability across the geographic range of the focal priority reptile and amphibian species. We initially developed models for 75 priority species and evaluated models by visual inspection of prediction surfaces and comparison of model fit metrics, species ranges, point spread, and thresholds. We repeated these steps until the resultant SDMs were determined acceptable, or removed those species that did not meet our criteria for acceptable model fit based on Area-Under-the-Curve (AUC; Elith et al. 2006). We used the "species-with-data" approach with 10-fold cross-validation to determine AUC estimates and produce a geographic distribution averaged across individual model runs for each priority amphibian and reptile priority species (e.g., Sutton et al. 2014). We identified acceptable SDMs with AUC > 0.70 (64 species), and those with AUC < 0.70 (11 species) were removed from the model set because they did not converge on acceptable solutions (Table 1). Sources of poor SDM fit leading to the species' elimination from the modeled set included insufficient number of occurrences, severe point clustering or point distribution that poorly represented the species' range, and restricted range extent. We converted individual SDMs to binary form by evaluating each MaxEnt SDM logistic output with several threshold metrics (Minimum Training Presence, Fixed Cumulative 1, Fixed Cumulative 5, Fixed Cumulative 10, Maximum Training Sensitivity Plus Specificity; Phillips et al. 2006) and selected the Fixed Cumulative 5 threshold to represent habitat models in the binary form of "suitable" or "unsuitable" habitat (Figure 2).

Compiling the PARCA algorithm

We used spatial analysis software (ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute) to spatially apply the PARCA Criteria and Implementation Guidance (Sutherland and deMaynadier 2012), in which we used landscape integrity (Criterion 1), species rarity (Criterion 2, 3), species regional responsibility (Criterion 4), and species richness (Criterion 5) to guide PARCA determination (Figure 3). We developed spatial representations of Criterion 2, 3, and 4, and added the sum of these criterion layers to maps representing Criterion 5 (with separate values for reptile and amphibian species richness) (Figure 3). Areas represented by Criterion 1 were extracted during development of the individual criterion components. The result was evaluated to identify clusters with large PARCA Criterion values. Processes for developing spatial data layers for each Criterion are detailed below.

We used the Index of Ecological Integrity (IEI) raster Hydrologic Unit Code (HUC) 6 (HUC6 IEI, University of Massachusetts Designing Sustainable Landscapes;

https://umassdsl.org/Data/) to address Criterion 1. We identified areas in the project region with HUC6 IEI >50% (representing landscape integrity >50%, scaled within 6-digit HUCs) and extracted these areas from the spatial representations of each PARCA criterion before compiling them in the PARCA algorithm (Figure 4). Although Criterion 1 indicates a minimum area (1,800 acres; 728 hectares) for PARCA consideration, we did not impose this size restriction, opting instead to provide reviewers (state and District of Columbia biologists) the opportunity to remove draft PARCAs of any size during their review of the modeled PARCAs.

We reviewed the global/national protection status [International Union for Conservation of Nature's (IUCN) RedList, Natureserve, U.S. Threatened and Endangered listings], state conservation status (State Endangered or Threatened), and Northeast Partners in Amphibian and Reptile Conservation (NEPARC) regional responsibility matrix (NEPARC 2010) for each modeled species, and we assigned each species to one of three tiers addressed in Criterion 2-4 (Figure 3). For Criterion 2, we assigned species to Tier 1 with status of IUCN Critical (CR), Endangered (EN) or Vulnerable (VU), U.S. Endangered Species Act (ESA) Endangered (E) or Threatened (T), and Natureserve Global (G1-G3) and Interspecific Taxon (T1-T3) Rank (Table 1). We multiplied the Tier 1 species' binary threshold surfaces (i.e., modeled presence or absence) by rasters coded with a value or weight = 1.0 in all pixels across their range. Our PARCA algorithm addressed Tier 2 species in Criterion 3 by multiplying the binary threshold surface pixel values by 0.75 within the states where their status is state threatened or endangered; otherwise, the cell value used in the species' Criterion 3 weight raster was 0.50. The PARCA Guidance acknowledges regional responsibility for each species in Criterion 4. Species listed as one of regional responsibility in the NEPARC matrix (NEPARC 2010) or having ≥50% of their range in the NEPARC region were considered Tier 3 species. We multiplied the binary threshold

SDMs for Tier 3 species with a weight raster with cell values equal to 0.50 within states with regional responsibility for the species. Thus, each species received a tier-assigned weight of 1.0, 0.75, or 0.50 in each 300 m pixel (with the weight value determined by the within-state status), which was then multiplied by the SDM to create the species' weighted SDM to be combined in the PARCA algorithm (Figure 3). The tier weighted SDMs were then summed across species and extracted for pixels corresponding to the HUC6 IEI >50% (Figure 4). Finally, we extracted the SDM sum (across priority species) raster for each within-state, within-Environmental Protection Agency (EPA) Level III ecoregion (https://www.epa.gov/eco-research/ecoregions) (Figure 5) and scaled the sum to the maximum values within these state-ecoregion areas for a final pixel value ranging 0.0-1.0.

We represented Criterion 5 with state-provided richness data that were supplemented with richness estimated from range maps (http://explorer.natureserve.org/) for areas with gaps in state-provided data. We created range map-based richness data with digital range maps retrieved from the Natureserve and International Union for Conservation of Nature (IUCN, https://www.iucnredlist.org/) databases for reptile (63) and amphibian (87) species believed to occur in the project area. First, we converted each species' range map shapefile to a 100 m pixel binary raster and summed these to create separate amphibian and reptile species richness rasters for the region. Next, we removed pixels corresponding to areas of NODATA in the state-provided richness data, and we replaced them with the richness sums created from range map data to result in a complete species richness raster for amphibians (Figure 6) and another for reptiles (Figure 7) for all areas of the region. We extracted areas with HUC6 IEI >50% (Criteria 1) from this combined state-range map richness raster, resampled the extracted area rasters to 300 m pixels, and subset the resampled raster by within-state, within EPA-level III ecoregions.

We scaled the species counts to maximum within state-within EPA Level III ecoregion to account for latitudinal effects on richness and to match the range (0.0-1.0) of the SDM sum rasters. The scaled richness rasters were then added to the SDM sum rasters (Criteria 2-4) in our PARCA algorithm to create a final PARCA criterion sum raster (Figure 3).

Converging Criteria into draft PARCAs

The PARCA criterion sum is a continuous value raster, with greater pixel values indicating greater sums (and thus larger relative levels of combined rarity and richness) across the Criteria. We partitioned the summed raster by natural breaks into 20 classes, converted the reclassified raster to integer values, and then created a polygon shapefile from the integer raster. We applied the Getis-Ord Gi* Optimization clustering algorithm to the polygon representation of the PARCA criterion sums, finding the optimized distribution of polygons that were clustered in value differently than expected by random occurrence. Our final modeled draft PARCAs represent the high value clusters ("hotspots") with a 90% confidence level.

We repeated the PARCA modeling and converging process to evaluate changes in modeled draft PARCA distributions with alternative data sets and models: 1) state-provided richness data; 2) richness calculated from range maps; 3) absence of richness data (i.e., priority species SDM-only); 4) inclusion of species richness for only priority species; 5) scaling by EPA Level-III ecoregion within state boundaries; and, 6) scaling by EPA Level-III ecoregion across the 12 state and District of Columbia study region. We combined outcomes of the alternative models to identify the draft PARCAs that were invariant among models. The draft modeled PARCAs reviewed by experts (process described below) were those created by summing the priority species SDMs and amphibian and reptile species richness (based on state-provided data supplemented with range map-sourced richness in NODATA areas) scaled within-state and within-EPA Level III ecoregions (Figure 5).

Review of modeled draft PARCAs

We distributed maps of modeled draft PARCAs in each state in printed and pdf format for review by selected state and District of Columbia biologists and other experts knowledgeable about reptile and amphibian distributions and their habitats in each state. We requested that the reviewers provide feedback directly on the provided maps, indicating draft PARCAs for us to retain, remove, or modify per their instructions. In cases where the reviewer modified or removed a draft PARCA, we requested that they provide an explanation for their edits. We also invited the reviewers to delineate areas that they believed to be important for herpetofauna conservation but that were not included in the modeled polygons. If the reviewer requested, we also provided the shapefile so that the reviewers could overlay it with their own spatial data layers to inform their editing or to edit the shapefile directly. Upon receipt of the edited maps and shapefiles, we solicited additional feedback from the reviewers, which we received through phone and email correspondence. We revised the shapefiles of modeled draft PARCA polygons based on this feedback. We tallied general types of feedback received from each state (e.g., type of edits to modeled polygons, comments about herpetofauna conservation approach in their state, etc.) and coded the draft proposed PARCA polygons with attributes indicating the edit source (e.g., state added) or their conservation target in evaluating the draft PARCA (e.g., single vs. multiple species focus). Final draft proposed PARCAs incorporated the state-provided edits to the draft PARCA maps, as well as our post-state review filtering to remove isolated polygons <6 ha that were not identified during the review as important to retain.

Comparison of PARCAs among model types, with conservation lands, and for species representation

We converted the shapefiles of modeled draft PARCAs to binary rasters and summed them across the models created with various combinations of source data used in models (see alternative model sets, above) to identify the number of times each pixel within a draft PARCA occurred in these models. Thus, a pixel sum of six indicated that the pixel was identified as a draft PARCA in six different models, whereas a pixel value of zero indicated that the pixel was not identified as a draft PARCA in any of the models. We also overlaid the draft PARCA shapefile with the U.S. Protected Areas Database (PADUS; https://gapanalysis.usgs.gov/padus/) level 1-3 polygons (Figure 8) and Important Bird Area (IBA; http://www.audubon.org/important-bird-areas/) polygons (Figure 9) to describe the current conservation status of areas in draft PARCAs.

We evaluated the representativeness of draft PARCAs of the greatest suitability habitat weighted by species rareness. We represented PARCA "value" as the percent of high quality or best habitat (i.e., SDM value > 0.50) for each species in each PARCA, weighted by PARCA area. Thus, a small PARCA that contains a large proportion of best modeled habitat for a species received a greater weight in the summed PARCA value than a large PARCA with best habitat for a widely distributed species. We assessed PARCA representation of the best habitat for priority species by setting a maximum area target of 100% of the best habitat in PARCAs for species with the smallest total best habitat area (using 25 km^2 as the lower limit), thus including all the species' best habitat area for conservation. We set a target of 10% of the best habitat in PARCAs for species with the greatest total best habitat area (using 640,000 km^2 as the upper limit), thus including less of the species' total habitat area in individual PARCAs if there was abundant available habitat area (Maiorano et al. 2006). This established the range of target habitat total areas for conservation for each species, based on the amount of available best habitat in the study region for each species. We interpolated between this minimum and maximum area with linear regression on square root-transformed area of best habitat total area to calculate the target amount of conservation area for each species based on the area of available best habitat for each species, and then we compared area captured in PARCAs (i.e., the total area of this best habitat found in the draft PARCAs) with each species' target to evaluate the species' best habitat representation in the draft PARCAs (Maiorano et al. 2006).

RESULTS

PARCA development and evaluation

We reviewed the modeled hotspots representing clusters of potentially suitable priority species habitat with expert state and District of Columbia biologists and qualified scientists. All states and the District of Columbia provided feedback on the modeled draft PARCAs, ranging from no additions to the modeled output (4 states) to adding or removing entire modeled polygons (9 states) or revising the boundaries of modeled areas and coalescing small polygons into larger polygons (all states and DC) (Table 3). Although some states requested that the final draft proposed PARCA polygons be publicly viewable in maps available only at large extent, other states requested a range of options from fully viewable and accessible shapefiles to information viewable only upon request made directly to the state biologist (one state).

Comments made during the feedback sessions (via conference calls and e-mail) when we reviewed the expert-provided edits to the draft PARCA maps indicated that although all the state experts applied aspects of the guidance criteria in their herpetofauna conservation, their approaches and the extent to which they adopted the guidance varied (Table 3). Nine states focused on single species conservation, whereas six states also commented that they target areas known for species richness. Comments indicated that land purchase cost (i.e., less expensive) and development condition (i.e., undeveloped) are considered in prioritizing conservation targets in some states, and unique habitat features are conservation targets in eight states. Two states indicated that they target conservation areas for herpetofauna based on approaches other than that presented in the Guidance (Sutherland and deMaynadier 2012) and that they were unlikely to apply the PARCA criteria to guide herpetofauna conservation in their state.

We delineated 642 draft proposed PARCAs based on feedback from state reviews; proposed PARCAs covered approximately 10,978,682 ha, or 19%, of the project region (Figure 10). Approximately 73% of the draft proposed PARCA area boundaries were generalized to less detail than the original modeled boundaries, with 63% of this revision made by state reviewers (Figure 11). We revised the remainder of draft PARCAs following state-reviewer instructions; 23% of the original modeled draft proposed PARCA area was accepted by reviewers without modification (Figure 11). State reviewers added 4% of the total draft proposed PARCA area; these were areas not predicted by any models (Figure 11). The PARCA Guidance-suggested minimum PARCA size (600 ha) exceeded the area of 124 draft proposed modeled PARCAs, whereas 71% of total draft proposed PARCAs were > 1000 ha (Figure 12). Number of draft proposed PARCAs per state ranged from 6 in Vermont [mean area ± Standard deviation (SD) = 112, 651 ha ± 122,310] to 140 (15,943 ± 55,498 ha) in Virginia, with smallest draft PARCAs in the District of Columbia (243± 389 ha; 13 PARCAs) and largest draft PARCAs in Vermont (Table 4). We delineated PARCAs in all northeastern EPA Level-III Ecoregions, with greatest total area in PARCAs in the North Central Appalachian ecoregion in Pennsylvania (1,069,825 ha) and Northeastern Highlands ecoregion in New York (1,040,616 ha) (Table 5). Ecoregions with the smallest total PARCA area included Delaware's Southeastern Plains (56 ha) and New York's Northern Piedmont (598 ha) (Table 5).

Approximately 62% of the draft proposed PARCAs and 28% of the study region were included in at least one model (Figure 13); 44% of the study region area captured in at least one model was also contained in a draft proposed PARCA. Approximately one third of the draft proposed PARCA area was included in three or more models. The model predicting the greatest area (10,788,950 ha) of potentially suitable habitat combined the priority species' distribution models and reptile and amphibian species richness estimated with range data, and approximately 42% of the modeled area was captured in the draft PARCAs (Figure 13). The model predicting the least area (4,719,143 ha) of potentially suitable habitat used only the species distribution model information (i.e., no species richness information), and approximately 60% of the modeled area was included in the draft PARCAs (Figure 13). Thus, inclusion of species richness estimated with range data increased the modeled estimate of potentially suitable habitat, however, much of this additional area was outside the areas identified as important habitat for reptile herpetofauna conservation in draft PARCAs after review by biologists. Draft PARCAs included the greatest amount of modeled area (78%) predicted with the model that combined ecoregion-scaled priority species distribution models and state amphibian and reptile species richness supplemented with range map data (Figure 13). However, only 36% of the draft PARCA area identified in biologist reviews included this modeled output. The greatest amount of predicted area common among multiple models was in New York, Virginia, Pennsylvania, and Maine (Figure 13). Nine states added at least one draft PARCA that was not modeled, and three states (Virginia, New Jersey, New Hampshire) did not suggest any revisions to the modeled draft PARCAs (Figure 11).

We converted range map shapefiles into rasters for 87 amphibian and 63 reptile species found in the project region. The Southeastern Plains EPA Level-III ecoregion contained the greatest number of amphibian species (39), whereas, the Middle Atlantic Coastal Plain contained ranges of the greatest number of reptile species (43) (Table 6). The maximum priority amphibian species count (17) occurred in the Ridge and Valley EPA Level-III ecoregion, whereas, greatest average priority amphibian richness (11.6) occurred in the Western Allegheny Plateau (Table 7; Figures 14, 15). The Middle Atlantic Coastal Plain and Northern Piedmont EPA Level-III ecoregions contained the greatest number of priority reptile species (22 in both), whereas the greatest average priority reptile richness occurred in the Southeastern Plains (15.8) (Table 7; Figures 14, 15). Within draft proposed PARCAs, the area-weighted priority amphibian species richness was greatest (14 species) in Pennsylvania's Central Appalachians ecoregion, and the area-weighted priority reptile species richness was greatest (20 species) in Maryland's Middle Atlantic Coastal Plain ecoregion. The greatest area-weighted priority herpetofauna species richness overall (27 species) was in Virginia's Middle Atlantic Coastal Plain ecoregion.

Comparison of PARCAs among model types, with conservation lands, and for species representation

Approximately 23% of draft proposed PARCA area occurred on land with status 1-3 in the Protected Areas Database United States (PADUS) (Figure 16), and 36% of draft proposed PARCA area occurred on land designated as an Important Bird Area (IBA) (Figure 17). The greatest percent of draft proposed PARCA area in current PADUS 1-3 status in states overall was in Delaware (42%) and New Jersey (55%) and within EPA Level-III ecoregions in Delaware's Northern Piedmont (72%) and New Jersey's Northeastern Highlands (78%) (Table 8). Approximately 64% of draft proposed PARCAs contained > 500 ha of PADUS 1-3 lands, with median PARCA area of 627 ha in PADUS 1-3 status. There was no land in PADUS 1-3 status in 132 draft proposed PARCAs. The greatest percent area of draft proposed PARCAs in IBAs was found in New Jersey (79%) and Maryland (61%) (Table 9), and the single largest area of draft proposed PARCA in PADUS 1-3 lands occurred in the Adirondack Mountains Park, New York (Figure 10). Combined, lands in IBA or PADUS 1-3 conservation status captured 44% of draft proposed PARCAs in the NA-LCC region (Figure 18).

Generally, the draft proposed PARCAs captured the best habitat for priority species in the broader study region (Table 10); for example, draft proposed PARCAs captured 6-24% of the best habitat for roughly 2/3 of priority herpetofauna, and a similar percentage of the larger study region contained the best habitat for these species (Figure 19). These patterns also reflected the extent to which draft proposed PARCAs captured the best habitat for priority reptile species and priority amphibian species separately, although the proportions differed slightly: the priority reptile species best SDM area in draft proposed PARCAs was similar to the amount in the study area overall (Figure 20), whereas, the percentage of best habitat for priority amphibian species in draft proposed PARCAs was slightly greater in the PARCAs than that in the study overall for roughly 15% of priority amphibian species (Figure 21). In other words, 15% of priority amphibian species have their best habitat in draft proposed PARCAs. Similar patterns hold for the frequency of reptile and amphibian species' best habitat captured in PADUS 1-3 lands in the study region: roughly 8-26 % of the best habitat for two-thirds of priority species is captured by PADUS 1-3 lands, with more of the best habitat for reptiles captured in the PADUS 1-3 lands than in the larger study area (Figures 22, 23).

Draft proposed PARCAs contained habitat with an SDM value >0.50 suitability across a range of 0 to 34 priority species (reptile and amphibians, combined; mean = 12.6 species, mode

= 9 species) (Figure 24). The most suitable habitat for *Chrysemys picta* occurred in the greatest number (425) of PARCAs, whereas, the most suitable habitat for *Deirochelys reticularia*, *Plethodon punctatus*, and *P. virginia* was found in only one PARCA for each species. The most suitable habitat for five species (*Desmognathus organi, Opheodrys aestivus, Plethodon shenandoah, Plethodon hubrichti, Plethodon welleri*), did not fall within any PARCAs, and three PARCAs contained no best habitat for any priority species.

Three species (*Desmognathus fuscus*, *Diadophis punctatus, Chrysemys picta*) exceeded their conservation targets for capturing their most suitable habitat in draft proposed PARCAs, whereas the most suitable habitat captured for the remaining 61 species was less than their conservation targets (i.e., they are under-represented) in draft proposed PARCAs given the species' modeled distributions (Figure 25). PARCAs capture approximately 25% of the conservation targets for 39% of species; the remaining 39 species are underrepresented in draft proposed PARCAs, with an average difference of 51% between their conservation target and the percent of suitable habitat captured by draft PARCAs. This difference in capture of best habitat in draft proposed PARCAs versus conservation targets generally is similar across the species' tiers, with only one Tier 1, three Tier 2, and five Tier 3 species at or exceeding their target (Figure 26).

DISCUSSION

As globalization and anthropogenic disturbances increasingly affect biodiversity patterns, land management strategies that prioritize conservation of high quality or best habitats for multiple species and taxa may be most effective to mitigate the potential effects of land use and climatic change on biodiversity (Schwenk and Donovan 2012). Globally, amphibians and reptiles represent two of the most threatened vertebrate taxa (Barrett and Guyer 2008, Cushman 2006, Luedtke et al. 2023). Developing and applying unique solutions for their long-term conservation may contribute to their long-term conservation. Effective conservation strategies address both biological requirements of target species as well as societal and financial limitations and goals (Naidoo et al. 2021). A collaborative approach to conservation provides a framework for efficiently and effectively scaling up local and state knowledge to implement regional and national program goals (Meretsky et al. 2012).

The Priority Amphibian and Reptile Conservation Area guidance integrates concepts of species rarity, richness, and landscape integrity to identify potentially high value areas for conservation of herpetofauna (Sutherland and deMaynadier 2012). The guidance is designed to facilitate identifying a network of herpetofauna conservation areas independent of administrative boundaries, although it is intended to be implemented at the state scale and thus is subject to approaches that may vary by state. Our analysis targeted priority amphibian and reptile species in the 12 northeastern states and District of Columbia, without accounting for whether regional and state-level conservation priorities for reptiles and amphibians would be aligned. Although we considered species' known occurrences, conservation status, and current landscape protection, we incorporated feedback from state and regional scientists, managers, and wildlife biologists to confirm and refine the boundaries of modeled priority conservation areas. We identified elements of the PARCA guidance that the practitioners did not factor into their expert assessments. This informed collaborative approach to conservation planning may lead to acceptance of proposed actions because it considers both quantitative results and expert knowledge (Knight et al. 2008) and provides an opportunity to revise the guidance to increase local relevancy. Although we engaged with select biologists from the outset of this project to incorporate their knowledge in the PARCA modeling process, using the models to identify priority conservation areas was not fully embraced by all practitioners in the northeastern states. A more interactive and phased approach that integrates state and regional feedback throughout the model development and application process may result in PARCAs that more effectively address regional conservation goals. Future research could focus on finding opportunities to engage practitioners in an iterative process that may result in reviseddraft proposed PARCAs that include emerging local knowledge about the landscapes, species, and jurisdictional priorities.

The draft proposed PARCAs presented here provide insight into areas that may have habitat value for amphibians and reptiles, however, effective conservation planning happens in the context of multiple conservation priorities at both the state and national level. We found that approximately one-quarter of the draft PARCAs overlapped with lands designated as protected areas with PADUS status 1 – 3, and over one-third overlapped with Important Bird Areas, indicating that these lands may already protect high suitability habitat for reptiles and amphibians. Further, where the PARCA boundaries surround lands already in conservation, there may be additional opportunities to expand these existing conservation networks and thus benefit herpetofauna (Goetz et al. 2009). However, the best habitat captured for most amphibian and reptile species was under-represented in draft PARCAs. Species with limited distributions that are underrepresented in current conservation lands may be particularly sensitive to loss in suitable habitat, especially when these habitats are not connected or accessible. Lands in conservation management may be managed for a variety of priorities that do not include protecting habitat for herpetofauna with limited distributions. The draft PARCA maps can provide information about habitats suitable for priority reptile and amphibian species to include in future land management, acquisition, and conservation planning.

Differences in how the PARCA guidance is applied, coupled with differences in landscape composition, can lead to draft PARCA areas of dramatically different sizes within and among regions. Spatial application of the PARCA guidance in the southeastern United States has resulted in fewer, large PARCAs compared to the numerous small and widely distributed draft PARCAs in the Northeast. These differences may reflect how researchers interpreted the guidance, how practitioners prioritized selecting PARCAs, or it may also reflect differences in human population densities and land use between the regions. Dense populations and less land area in the Northeast that is not developed may leave less of the landscape available for conservation. Recent research has revisited the debate between conserving fewer large areas versus many small areas and offers support for the idea that biodiversity conservation can benefit from small fragments of protected habitat (Rösch et al. 2015; Tulloch et al. 2016; deMaynadier et al. 2023). Not only can small fragments provide inherent habitat protection, they also may provide connectivity among larger protected areas (Olds et al. 2012, Ayram et al. 2016).

Models developed with different variables (e.g., species richness, data source, scaling) resulted in variation in the predicted draft proposed PARCAs, however, there are similarities in the predictions resulting from these different models that can inform conservation actions. The data sources and decisions used to create the different models can be considered by managers when identifying important habitats for reptile and amphibian conservation. We developed the models using the best available occurrence and environmental data, and then consulted knowledgeable biologists to help evaluate and refine the draft PARCA maps. For example, models that used range data increased the estimate of potentially suitable habitat, however, much of this additional area was outside the areas identified by expert biologists as important habitat. Using a variety of data to develop the models and creating multiple models that incorporate these data differently provides opportunities for conservation alternatives with different objectives. Combining multiple models and the knowledge of practitioners who implement species conservation through land management may be the most robust use of the maps of draft PARCAs: biologists can prioritize their actions based on how the data sources used in the models reflect their amphibian and reptile conservation goals.

The PARCA guidance provides a systematic framework for identifying areas that may have high suitability for amphibian and reptile conservation, however, there are caveats to their use. Species occurrence data, range maps, resolution of environmental data, and knowledge about species habitat relationships and distribution of suitable habitat all affect model predictions, which may change with new data. Perception of the reliability of the modeled PARCAs will vary with knowledge about the landscape and target species, and land management priorities may change based on factors other than those that advance conservation. We combined reptiles and amphibians in our analysis, to follow the PARCA guidance, yet conservation goals may differ between these taxonomic groups. No single approach is complete, and combining the tools evaluated here with expert knowledge and updated species occurrence and environmental data as they are available may provide the most robust approach for amphibian and reptile conservation planning. Engaging biologists, land managers, and conservation practitioners together to develop, revise, and evaluate these models can contribute to conserving ecologically complex and diverse landscapes that enable these species to persist.

ACKNOWLEDGEMENTS

The authors are grateful to P. Nanjappa for her assistance securing funds to support this work. A. Moody assisted with gathering initial datasets used to develop the species distribution models. We are grateful for the engagement of state biologists who provided occurrence data and reviewed the modeled PARCAs. The report was improved by reviews provided by S. Snyder and H. Goldspiel. Figure 1 was provided by S. Snyder. Financial support for this project was provided by the U.S. Fish and Wildlife Service, North Atlantic Landscape Conservation Cooperative program and with funds through a Cooperative Agreement to the University of Maine with the U.S. Geological Survey Maine Cooperative Fish and Wildlife Research Unit (USGS-MECFWRU). Questions about state agency contacts may be directed to P. deMaynadier (phillip.demaynadier@maine.gov). Questions about availability of the species distribution models and draft modeled PARCA files may be directed to W. Sutton (wsutton@tnstate.edu). Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Table 1. Species for which Species Distribution Models were developed. Guidance Criterion (Sutherland and deMaynadier 2012) applied in the draft Priority Amphibian and Reptile Conservation Area (PARCA) algorithm and an explanation for the poor model fit for the species models excluded from the draft PARCAs are indicated. Area Under the Curve (AUC), Pennsylvania (PA), New York (NY). Species conservation status tier is captured in guidance criteria as Tier 1 (criterion 2), Tier 2 (criterion 3), and Tier 3 (criterion 4) (Figure 3).

Species	Common Name	Modeled	Guidance criterion applied in algorithm	Source of poor model fit
Anurans				
Acris crepitans	Northern Cricket Frog	yes	3	
Anaxyrus fowleri	Fowler's Toad	no	4	Adequate number of points; inadequate spatial distribution
Gastrophryne carolinensis	Eastern Narrowmouth Toad	yes	3	
Hyla andersonii	Pine-Barrens Treefrog	no	3	Very poor model fit; inaccurate geographic habitat projection
Hyla chrysoscelis	Gray Treefrog	no	3	Adequate number of points; inadequate spatial distribution
Hyla gratiosa	Barking Treefrog	yes	3	

Lithobates pipiensi	Northern Leopard Frog	yes	4
Lithobates sphenocephalus	Southern Leopard Frog	yes	3
Lithobates virgatipes	Carpenter Frog	yes	4
Pseudacris brachyphona	Mountain Chorus Frog	yes	3
Pseudacris kalmi	New Jersey Chorus Frog	yes	3
Scaphiopus holbrookii	Eastern Spadefoot	yes	3
<u>Salamanders</u>			
Ambystoma laterale	Jefferson's Blue-spotted species complex	yes	3
Ambystoma mabeei	Mabee's Salamander	yes	3
Ambystoma opacum	Marbled Salamander	yes	3
Ambystoma tigrinum	Tiger Salamander	yes	3
Aneides aeneus	Green Salamander	yes	2

Cryptobranchus alleganiensis	Eastern Hellbender	yes	2
Desmognathus fuscus	Northern Dusky Salamander	yes	4
Desmognathus monticola	Seal Salamander	yes	4
Desmognathus ochrophaeus	Allegheny Mountain Dusky Salamander	yes	4
Desmognathus organi	Northern Pygmy Salamander	yes	2
Eurycea bislineata	Two-lined Salamander	yes	4
Eurycea longicauda	Long-tailed Salamander	yes	2
Gyrinophilus porphyriticus	Northern Spring Salamander	yes	3
Necturus maculosus	Common Mudpuppy	yes	4
Plethodon glutinosus	Slimy Salamanders (White-spotted, Slimy, Cumberland)	yes	3
Plethodon hoffmani	Ridge and Valley Salamander	yes	4
Plethodon hubrichti	Peaks of Otter Salamander	yes	2

Plethodon punctatus	Cow Knob Salamander	yes	2	
Plethodon shenandoah	Shenandoah Salamander	yes	2	
Plethodon sherando	Big Levels Salamander	no	2	Only one geographic location
Plethodon virginia	Shenandoah Mountain Salamander	yes	2	
Plethodon wehrlei	Wehrle's Salamander	yes	4	
Plethodon welleri	Weller's Salamander	yes	2	
Pseudotriton montanus	Mud Salamander	no	3	Extremely poor model fit (AUC < 0.50)
Pseudotriton ruber nitidus	Red Salamander	yes	3	
Lizards				
Ophisaurus ventralis	Eastern Glass Lizard	no	3	Only two locations in occurrence databases
Plestiodon anthracinus	Coal Skink	yes	2	
Plestiodon fasciatus	Common Five-lined Skink	yes	3	
Plestiodon laticeps	Broad-headed Skink	no	4	Extremely poor model fit (AUC < 0.60)

Sceloporus undulatus	Eastern Fence Lizard	yes	3	
Snakes				
Agkistrodon controtrix	Northern Copperhead	yes	3	
Carphophis amoenus	Eastern Wormsnake	yes	3	
Cemophora coccinea	Scarlet Snake	yes	3	
Clonophis kirtlandii	Kirtland's Snake	no	3	Only 10 locations and poor model projection
Coluber constrictor	Northern Black Racer	yes	2	
Crotalus horridus	Timber Rattlesnake	yes	3	
Diadophis punctatus	Northern Ring-necked Snake	yes	4	
Farancia erytrogramma	Rainbow Snake	no	3	Very poor model fit (AUC < 0.65)
Heterodon platirhinos	Eastern Hognose Snake	yes	3	
Nerodia erythrogaster	Red-bellied Watersnake	yes	3	
Opheodrys aestivus	Rough Greensnake	yes	3	

Opheodrys vernalis	Smooth Greensnake	yes	4	
Pantherophis alleganiensis	Black Rat Snake	yes	3	
Pantherophis guttatus	Red Cornsnake	yes	3	
Pituophis melanoleucus	Northern Pine Snake	yes	3	
Regina septemvittata	Queensnake	yes	3	
Sistrurus catenatus	Eastern Massassauga	no	2	Very limited access to locations in PA (< 10); no locations in NY
Storeria dekayi	Northern Brownsnake	yes	4	
Thamnophis brachystoma	Short-headed Gartersnake	no	4	Very limited access to locations in PA (< 10)
Thamnophis sauritis	Ribbon Snake	yes	4	
Virginia valeriae	Earthsnake	yes	3	
Turtles				
Apalone spinifera	Spiny Softshell Turtle	yes	3	

Chrysemys picta	Painted Turtle	yes	4
Clemmys guttata	Spotted Turtle	yes	2
Deirochelys reticularia	Chicken Turtle	yes	3
Emydoidea blandingii	Blanding's Turtle	yes	2
Glyptemys insculpta	Wood Turtle	yes	2
Glyptemys muhlenbergii	Bog Turtle	yes	2
Graptemys geographica	Common Map Turtle	yes	3
Kinosternon subrubrum	Eastern Mud Turtle	yes	3
Malaclemys terrapin	Diamondback Terrapin	yes	3
Pseudemys rubriventris	Northern Red-bellied Turtle	yes	2
Terrapene carolina	Eastern Box Turtle	yes	2

Table 2. Environmental variables used in Species Distribution Models compiled for draft Priority Amphibian and Reptile Conservation Areas (PARCAs) in the study area.

Variable	Description	Data Source[a]
aspect	Aspect in degrees	UMass DSL project
canopy	Percent tree canopy	NLCD
elevation	Elevation above mean sea level	NED/NHD
flow	Directional flow	UMass DSL project
gdd	Growing degree days (sum of # days mean daily temp >10 °C	UMass DSL project
geology	Rock type	USGS Mineral Resources
gradient	Percent slope derived from USGS DEM, NHD flowlines and flow accumulation	UMass DSL project
lulc	Land use, land cover type	TNC
precip	Mean annual precipitation	UMass DSL project
slope	Slope derived from NED	UMass DSL project
soilca	Calcium content of soil and water	UMass DSL project
soildepth	Depth to restrictive layer below ground surface	UMass DSL project

temp	Mean annual temperature	UMass DSL project
traffic	Traffic rate (average # vehicles/day)	UMass DSL project
wetness	Combination of flow accumulation and precipitation	UMass DSL project
lake	Lake	NWI
river	River	NWI
pond	Pond	NWI
stream	Stream	NWI
wetland	Wetland	NWI/TNC

[a] University of Massachusetts (UMass) Designing Sustainable Landscapes (DSL) project https://umassdsl.org/Data/

National Land Cover Data (NLCD) https://www.usgs.gov/centers/eros/science/national-land-cover-database

National Elevation Data (NED) https://www.usgs.gov/publications/national-elevation-dataset

National Hydrology Data (NHD) https://www.usgs.gov/national-hydrography/national-hydrography-dataset

U.S. Geological Survey (USGS) Mineral Resources https://mrdata.usgs.gov/

The Nature Conservancy (TNC) https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/habitatmap/Pages/default.aspx

National Wetlands Inventory (NWI) https://www.fws.gov/program/national-wetlands-inventory/wetlands-mapper

Table 3. Feedback provided by experts in each state and the District of Columbia in conference calls and e-mails during review of maps containing the draft modeled Priority Amphibian and Reptile Conservation Areas (PARCAs).

Feedback	**Number of states**[a]
Polygon editing	
No change to modeled polygons	3
Selected modeled polygons removed	8
Polygons added (not modeled)	9
Polygons coalesced into contiguous areas	13
Review by only agency biologists	9
Review by non-agency biologists	4
Provided incomplete, dated, or inaccurate data	4
Conservation Approach or Focus	
Single species[b]	9
Select species[b] (>1)	9
Species richness	6
Target low-cost land	3
Target land vulnerable to development	3

Target land with particular habitat features	8
Target undeveloped land	7
Other Comments	
Use draft PARCAs for survey planning	3
Use non-PARCA approach to herpetofauna conservation	2

[a] includes District of Columbia
[b] may include priority species

Table 4. Descriptive statistics of draft Priority Amphibian and Reptile Conservation Areas (PARCAs) within the states and the District of Columbia in the study region. SD is Standard Deviation.

State	count	total PARCA area (ha)	% state area in PARCAs	min	max	mean	SD
Connecticut	45	344,081	27	15	87,239	7,646	15,477
Delaware	24	43,081	8	9	11,612	1,795	2,578
District of Columbia	13	3,164	20	7	1,266	243	389
Maine	39	1,161,037	14	436	262,224	29,770	57,878
Maryland	101	563,559	22	20	70,437	5,580	11,781
Massachusetts	31	182,166	9	671	18,084	5,876	4,807
New Hampshire	33	219,494	9	250	63,350	6,651	13,219
New Jersey	66	237,689	12	56	16,699	3,601	4,120
New York	86	2,673,638	21	11	515,902	31,089	75,927
Pennsylvania	58	2,583,149	22	384	502,259	44,537	90,869
Rhode Island	11	54,544	20	250	22,946	4,959	6,748
Vermont	6	675,909	27	12,676	333,712	112,651	122,310
Virginia	140	2,232,090	22	18	498,163	15,943	55,498

Table 5. Priority Amphibian and Reptile Conservation Areas (PARCAs) and lands in the Protected Areas Database United States (PADUS v1.4; conservation status 1-3) within Environmental Protection Agency (EPA) Level-III Ecoregions in the study region states and District of Columbia.

State	EPA Level-III Ecoregion	PARCA area (ha)	% of ecoregion in PARCAs	% of state's PARCA area in ecoregion	% of ecoregion in PADUS 1-3	% of PARCAs in ecoregion in PADUS 1-3
Connecticut	Northeastern Coastal Zone	284,695	26	83	9	15
	Northeastern Highlands	59,005	30	17	13	25
Delaware	Middle Atlantic Coastal Plain	40,035	8	94	15	40
	Northern Piedmont	2,530	10	6	20	72
	Southeastern Plains	56	2	0	10	3
District of Columbia	Northern Piedmont	1,203	29	40	1	2
	Southeastern Plains	1,834	14	60	2	6
Maine	Acadian Plains and Hills	692,910	15	60	10	7
	Northeastern Coastal Zone	69,707	23	6	6	12
	Northeastern Highlands	396,672	11	18	19	11
Maryland	Blue Ridge	34,496	59	6	24	40

	Central Appalachians	52,318	38	9	18	34
	Middle Atlantic Coastal Plain	214,012	23	38	16	28
	Northern Piedmont	108,375	15	19	7	22
	Ridge and Valley	80,029	32	14	21	54
	Southeastern Plains	73,001	14	13	8	24
Massachusetts	Atlantic Coastal Pine Barrens	20,878	11	12	31	56
	Northeastern Coastal Zone	111,372	9	62	15	26
	Northeastern Highlands	48,973	8	27	29	31
New Hampshire	Northeastern Coastal Zone	21,879	5	10	11	26
	Northeastern Highlands	197,811	10	90	26	18
New Jersey	Atlantic Coastal Pine Barrens	132,514	13	55	25	48
	Middle Atlantic Coastal Plain	20,680	14	9	34	57
	Northeastern Highlands	41,108	19	17	67	78
	Northern Piedmont	18,156	4	8	9	31
	Ridge and Valley	27,259	16	11	30	64
New York	Atlantic Coastal Pine Barrens	41,956	19	2	14	25
	Eastern Great Lakes Lowlands	577,651	17	22	3	7
	Erie Drift Plain	52,039	18	2	3	3

	North Central Appalachians	137,630	45	5	17	25
	Northeastern Coastal Zone	95,281	11	4	3	4
	Northeastern Highlands	1,040,616	29	39	42	49
	Northern Allegheny Plateau	687,983	19	26	6	9
	Northern Piedmont	598	1	0	6	21
	Ridge and Valley	34,182	15	1	8	21
Pennsylvania	Blue Ridge	22,773	26	1	41	46
	Central Appalachians	126,333	11	5	17	24
	Eastern Great Lakes Lowlands	1,600	5	0	6	39
	Erie Drift Plain	48,397	6	2	5	4
	Middle Atlantic Coastal Plain	4,262	12	0	4	8
	North Central Appalachians	1,069,825	45	41	43	47
	Northeastern Highlands	21,362	28	1	1	1
	Northern Allegheny Plateau	111,083	11	4	3	4
	Northern Piedmont	191,130	16	7	3	9
	Ridge and Valley	812,621	25	31	13	30
	Western Allegheny Plateau	179,180	10	7	3	6
Rhode Island	Atlantic Coastal Pine Barrens	0	0	0	31	0

	Northeastern Coastal Zone	53,994	19	100	20	29
Vermont	Eastern Great Lakes Lowlands	292,276	85	43	5	5
	Northeastern Coastal Zone	7,174	98	1	1	1
	Northeastern Highlands	374,923	18	56	17	8
Virginia	Blue Ridge	229,788	25	10	29	39
	Central Appalachians	78,316	18	4	9	26
	Middle Atlantic Coastal Plain	169,499	21	8	13	10
	Northern Piedmont	42,252	6	2	4	6
	Piedmont	746,116	22	34	3	4
	Ridge and Valley	640,738	24	29	24	44
	Southeastern Plains	309,394	21	14	4	3

Table 6. Species richness (all) by Environmental Protection Agency (EPA) Level-III Ecoregions in the study area, calculated from species range maps downloaded as shapefiles from Natureserve (http://explorer.natureserve.org/) and converted to raster format.

Ecoregion	Area (ha)	Average # amphibian species	Minimum # amphibian species	Maximum # amphibian species	Average # reptile species	Minimum # reptile species	Maximum # reptile species
Acadian Plains and Hills	4,391,256	9	0	18	4	0	13
Atlantic Coastal Pine Barrens	1,349,220	13	0	30	8	0	29
Blue Ridge	1,061,250	26	17	37	24	14	30
Central Appalachians	1,671,665	25	16	32	18	13	25
Eastern Great Lakes Lowlands	3,789,524	15	0	26	10	0	20
Erie Drift Plain	1,080,972	24	18	29	18	12	22
Middle Atlantic Coastal Plain	2,186,569	17	0	38	16	0	43
North Central Appalachians	2,672,736	25	20	29	15	9	22
Northeastern Coastal Zone	4,153,243	11	0	29	8	0	24
Northeastern Highlands	12,397,820	19	11	29	14	9	21

Northern Allegheny Plateau	4,651,028	23	19	27	13	1	23
Northern Piedmont	3,133,010	21	0	28	20	0	34
Piedmont	3,358,196	25	17	34	28	18	38
Ridge and Valley	6,451,501	27	17	36	20	11	28
Southeastern Plains	1,972,634	23	0	39	16	0	41
Western Allegheny Plateau	1,796,337	28	16	31	18	13	22

Table 7. Priority amphibian and reptile species richness by Environmental Protection Agency (EPA) Level-III Ecoregions in the project area.

Ecoregion	Area (ha)	Average # amphibian species	Minimum # amphibian species	Maximum # amphibian species	Average # reptile species	Minimum # reptile species	Maximum # reptile species
Acadian Plains and Hills	4,415,862	3	0	5	4	0	8
Atlantic Coastal Pine Barrens	1,335,212	5	0	10	11	0	21
Blue Ridge	1,062,023	8	0	13	10	0	20
Central Appalachians	1,680,824	11	0	16	8	0	17
Eastern Great Lakes Lowlands	3,750,728	5	0	11	6	0	16
Erie Drift Plain	1,080,838	9	0	13	9	0	16
Middle Atlantic Coastal Plain	2,285,449	4	0	10	14	0	22
North Central Appalachians	2,672,736	8	1	14	7	2	16
Northeastern Coastal Zone	4,133,825	4	0	12	9	0	18
Northeastern Highlands	12,394,031	5	0	13	6	0	18

Northern Allegheny Plateau	4,651,028	8	0	13	7	0	18
Northern Piedmont	3,115,434	7	0	12	14	0	22
Piedmont	3,371,134	6	0	9	15	0	20
Ridge and Valley	6,464,187	9	0	17	11	0	20
Southeastern Plains	1,962,379	5	0	11	16	0	21
Western Allegheny Plateau	1,796,469	12	0	16	11	0	18

Table 8. Draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs) and lands in the Protected Areas Database United States (PADUS v1.4; conservation status 1-3) or Important Bird Areas (IBAs) within Environmental Protection Area (EPA) Level-III Ecoregions within states in the study region.

State	EPA Level-III Ecoregion	area (ha) in IBA	% of ecoregion in IBAs	PARCA area (ha) in IBAs or PADUS 1-3	% of PARCAs in IBAs or PADUS 1-3
Connecticut	Northeastern Coastal Zone	0	0	42,559	15
	Northeastern Highlands	0	0	15,021	25
Delaware	Middle Atlantic Coastal Plain	113,364	23	18,481	46
	Northern Piedmont	5,044	21	1,833	72
	Southeastern Plains	0	0	2	3
District of Columbia	Northern Piedmont	0	0	21	2
	Southeastern Plains	0	0	113	6
Maine	Acadian Plains and Hills	461,081	10	61,122	9
	Northeastern Coastal Zone	5,159	2	8,967	13
	Northeastern Highlands	3,028,243	84	115,123	29
Maryland	Blue Ridge	29,274	50	30,668	89
	Central Appalachians	35,839	26	39,040	75
	Middle Atlantic Coastal Plain	249,378	27	171,467	80
	Northern Piedmont	104,420	15	29,665	27
	Ridge and Valley	73,032	30	71,230	89
	Southeastern Plains	43,107	8	44,085	60

Massachusetts	Atlantic Coastal Pine Barrens	38,621	20	12,189	58
	Northeastern Coastal Zone	210,902	17	43,510	39
	Northeastern Highlands	106,518	17	18,345	37
New Hampshire	Northeastern Coastal Zone	17,364	4	6,145	28
	Northeastern Highlands	601,555	30	51,476	26
New Jersey	Atlantic Coastal Pine Barrens	484,375	48	111,787	84
	Middle Atlantic Coastal Plain	98,924	67	18,085	87
	Northeastern Highlands	114,959	52	37,233	91
	Northern Piedmont	61,091	15	11,414	63
	Ridge and Valley	90,521	54	25,036	92
New York	Atlantic Coastal Pine Barrens	43,679	19	20,894	50
	Eastern Great Lakes Lowlands	328,743	9	104,016	18
	Erie Drift Plain	13,967	5	5,053	10
	North Central Appalachians	103,910	34	61,432	45
	Northeastern Coastal Zone	30,756	4	6,303	7
	Northeastern Highlands	2,307,106	65	775,968	75
	Northern Allegheny Plateau	210,900	6	142,067	21
	Northern Piedmont	3,068	6	124	21
	Ridge and Valley	15,530	7	10,540	31
Pennsylvania	Blue Ridge	61,538	70	21,848	96

	Central Appalachians	362,245	33	68,106	54
	Eastern Great Lakes Lowlands	2,263	6	882	55
	Erie Drift Plain	118,334	15	7,586	16
	Middle Atlantic Coastal Plain	1,849	5	344	8
	North Central Appalachians	1,488,746	63	801,830	75
	Northeastern Highlands	9,009	12	3,371	16
	Northern Allegheny Plateau	47,477	5	14,511	13
	Northern Piedmont	133,359	11	40,920	21
	Ridge and Valley	680,554	21	451,339	56
	Western Allegheny Plateau	165,515	9	66,909	37
Rhode Island	Atlantic Coastal Pine Barrens	0	0	0	0
	Northeastern Coastal Zone	17,871	6	21,409	40
Vermont	Eastern Great Lakes Lowlands	12,539	4	21,538	7
	Northeastern Coastal Zone	4,585	63	4,524	63
	Northeastern Highlands	938,643	44	188,461	50
Virginia	Blue Ridge	337,492	37	160,287	70
	Central Appalachians	64,060	14	32,472	41
	Middle Atlantic Coastal Plain	132,793	17	35,374	21
	Northern Piedmont	148,819	20	21,530	51
	Piedmont	1,442,061	43	427,577	57

Ridge and Valley	183,897	7	295,759	46
Southeastern Plains	296,637	20	76,585	25

Table 9. Lands within draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs) that are in conservation status 1-3 in the Protected Areas Database United States (PADUS v1.4) or designated as Important Bird Areas (IBAs) summarized by state in the study region.

State	area in IBAs (ha)	% of PARCAs in IBAs	PARCA area (ha) in IBA or PADUS 1-3	% of PARCAs in IBAs or PADUS 1-3
Connecticut	0	0	57,580	17
District of Columbia	0	0	134	4
Delaware	118,408	27	20,315	47
Maine	3,494,483	10	185,211	16
Maryland	535,050	61	386,155	69
Massachusetts	356,041	27	74,044	41
New Hampshire	618,919	8	57,621	26
New Jersey	849,869	79	203,556	86
New York	3,057,658	37	1,126,395	42
Pennsylvania	3,070,887	49	1,477,646	57
Rhode Island	17,871	22	21,409	39
Vermont	955,767	28	214,523	32
Virginia	2,605,760	32	1,049,584	47

Table 10. Number and total area (ha) of draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs) containing best habitat (Species Distribution Model Habitat suitability or SDM value > 0.50) for priority reptile and amphibian species in the study region.

Species	Number of PARCAs with species	Total area (ha) of SDM > 0.50 in PARCAs
Acris crepitans	219	1,037,149
Agkistrodon contortrix	323	2,012,300
Ambystoma jeffersonianum/laterale	201	1,082,135
Ambystoma mabeei	17	18,160
Ambystoma opacum	239	1,078,245
Ambystoma tigrinum	18	41,841
Aneides aeneus	23	88,362
Apalone spinifera	41	21,490
Carphophis amoenus	167	1,184,468
Cemophora coccinea	72	515,840
Chrysemys picta	425	1,001,730
Clemmys guttata	137	231,787
Coluber constrictor	361	1,784,594
Cryptobranchus alleganiensis	59	40,668

Crotalus horridus	134	1,474,025
Desmognathus fuscus	286	1,699,641
Desmognathus monticola	80	211,363
Desmognathus ochrophaeus	111	861,122
Deirochelys reticularia	1	11,342
Diadophis punctatus	323	2,809,617
Emydoidea blandingii	24	112,397
Eurycea bislineata	270	2,202,312
Eurycea longicauda	179	658,030
Gastrophryne carolinensis	46	287,668
Glyptemys insculpta	264	1,410,371
Glyptemys muhlenbergii	41	59,989
Graptemys geographica	31	49,065
Gyrinophilus porphyriticus	259	1,608,397
Heterodon platirhinos	289	1,606,563
Hyla gratiosa	19	62,226
Kinosternon subrubrum	107	451,569
Lithobates pipiens	181	828,636

Lithobates sphenocephalus	117	350,251
Lithobates virgatipes	63	151,446
Malaclemys terrapin	55	12,596
Nerodia erythrogaster	10	55,300
Necturus maculosus	127	216,912
Opheodrys vernalis	216	3,229,031
Pantherophis alleghaniensis	163	587,046
Pantherophis guttatus	104	122,155
Pituophis melanoleucus	12	34,081
Plestiodon anthracinus	38	724,945
Plestiodon fasciatus	173	1,213,029
Plethodon glutinosus/kentucki/cylindraceus	169	1,505,555
Plethodon hoffmani	47	449,590
Plethodon punctatus	1	7,497
Plethodon virginia	1	20,965
Plethodon wehrlei	26	168,253
Pseudacris brachyphona	18	286,172
Pseudacris kalmi	59	143,764

Pseudotriton ruber	256	1,706,321
Pseudemys rubriventris	153	44,163
Regina septemvittata	143	336,632
Scaphiopus holbrookii	110	111,589
Sceloporus undulatus	155	1,217,865
Storeria dekayi	326	1,618,503
Terrapene carolina	181	543,772
Thamnophis sauritus	336	1,320,532
Virginia valeriae	73	633,076

Figure 1. Extent of the Northeast Priority Amphibian and Reptile Conservation Area (PARCA) study region (dark gray). States in the project area include Maine (ME), New Hampshire (NH), Vermont (VT), Massachusetts (MA), Connecticut (CT), Rhode Island (RI), New York (NY), New Jersey (NJ), Pennsylvania (PA), Maryland (MD), Delaware (DE), and Virginia (VA). The District of Columbia (DC) (red dot) is included in the project area.

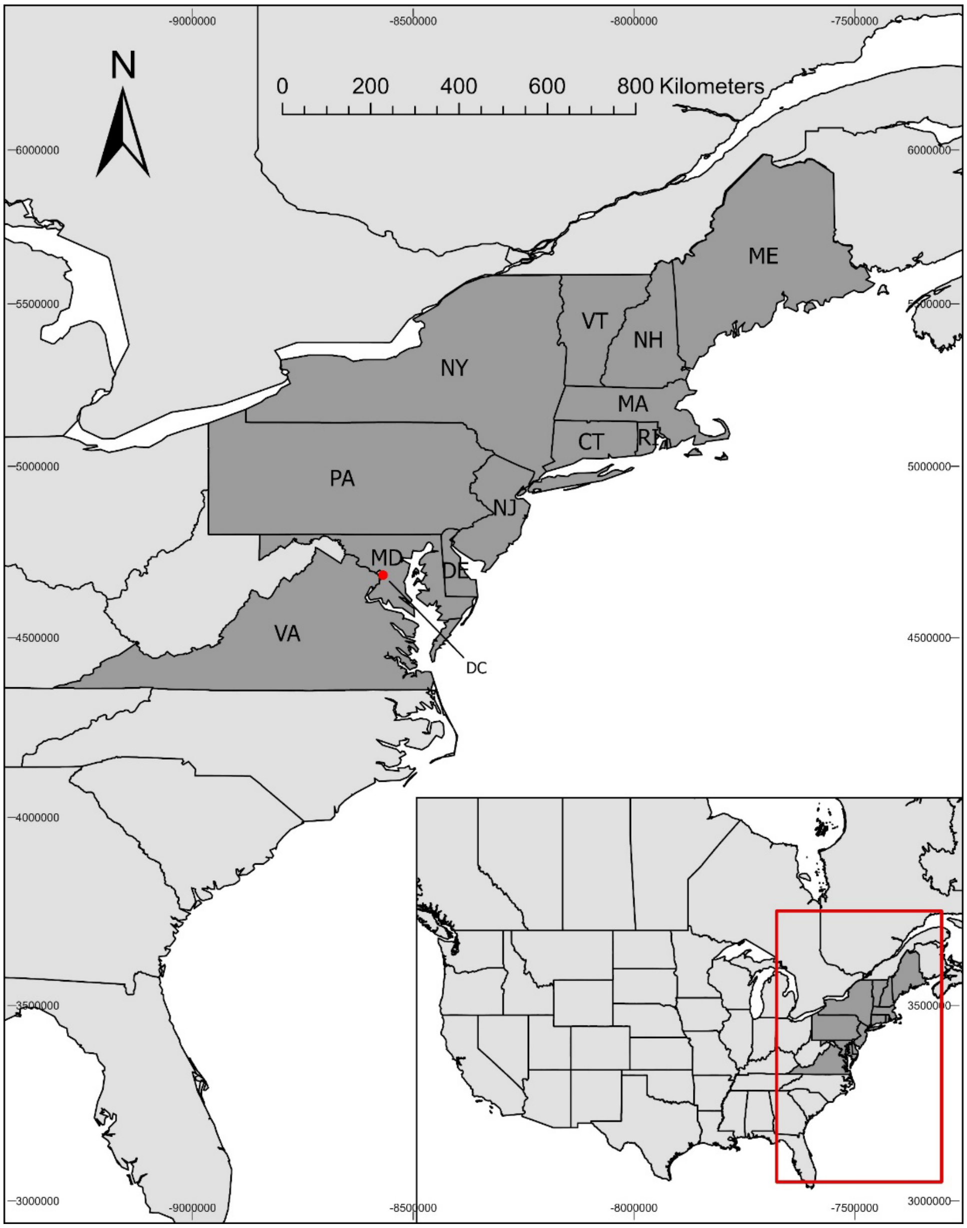
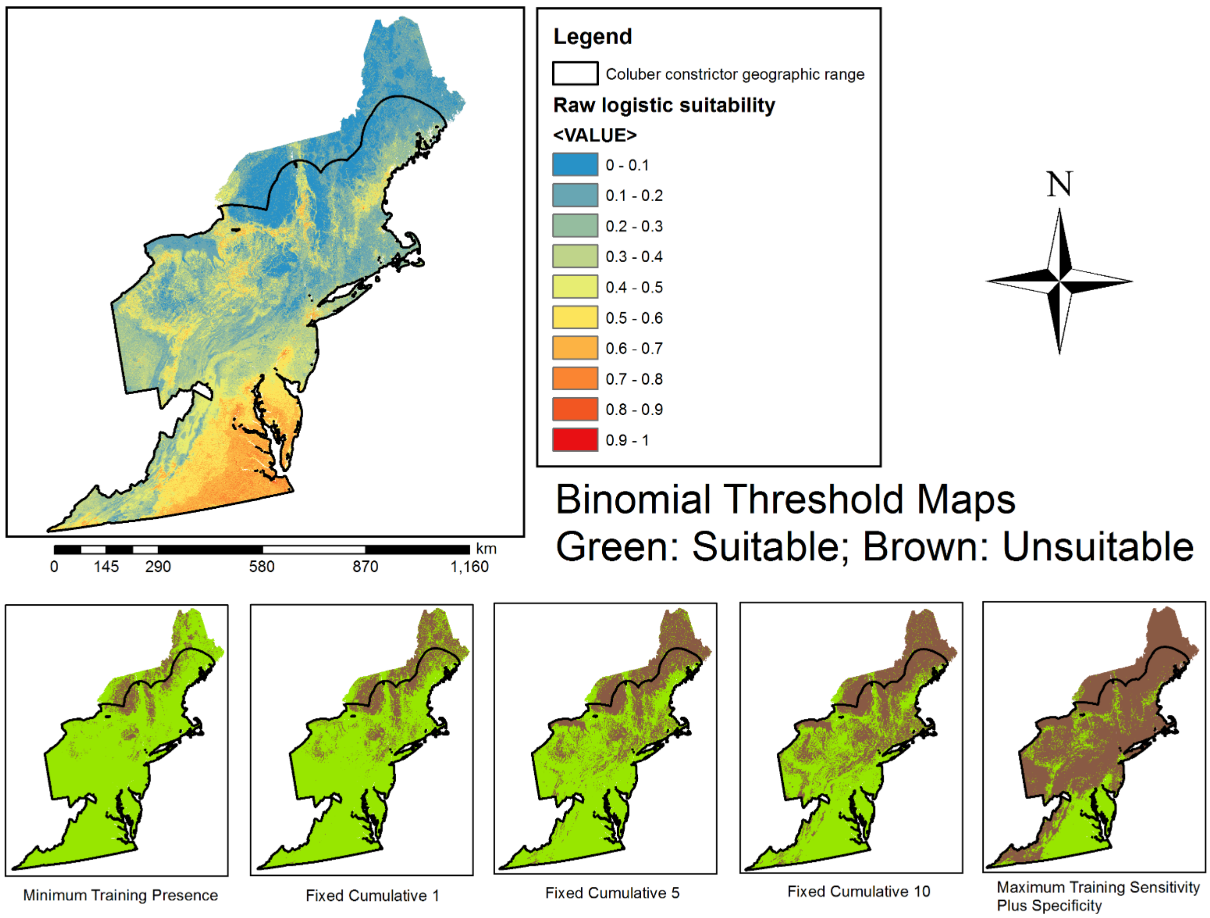
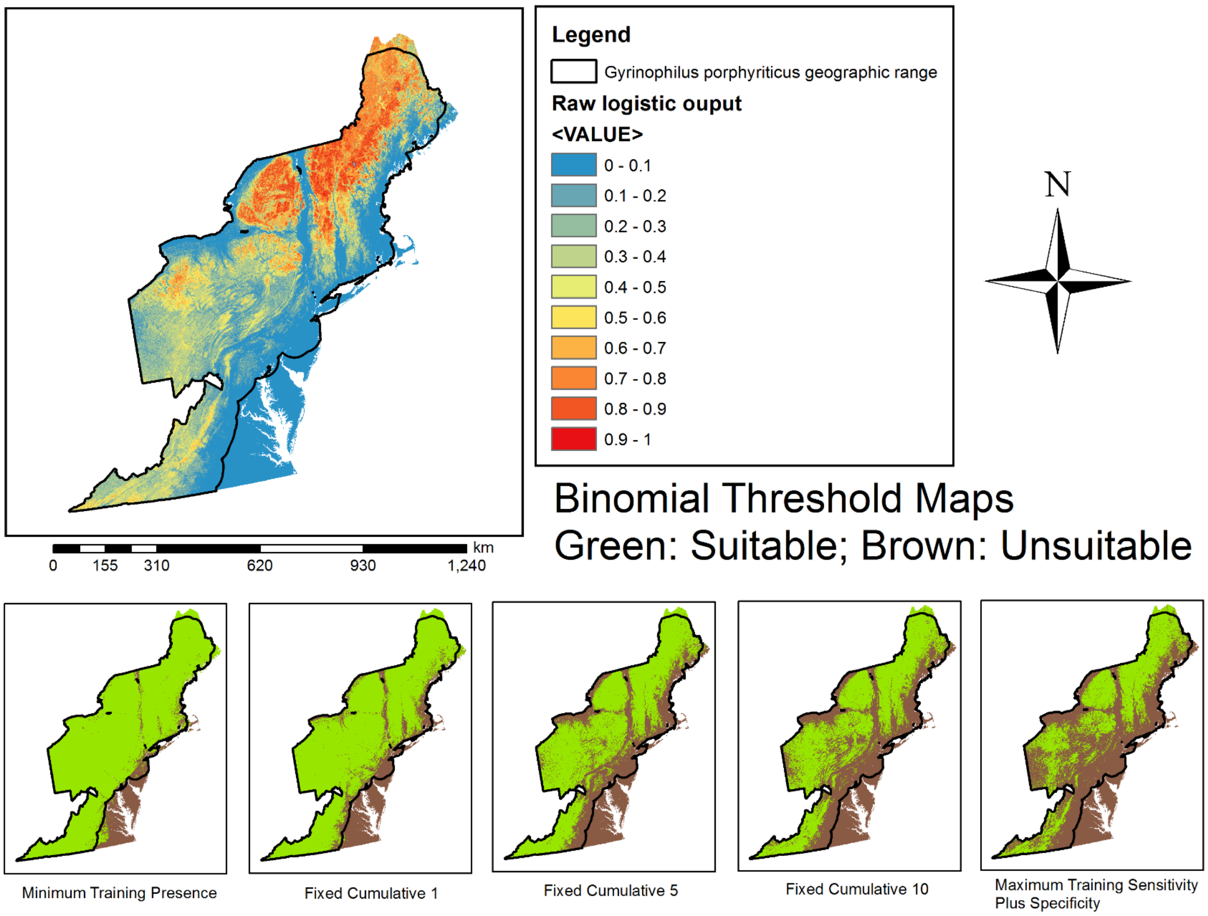


Figure 2. Example Species Distribution Models in logistic and threshold forms for (a) *Coluber constrictor*, (b) *Gyrinophilus porphyriticus*, and (c) *Terrepene carolina.*

a) *Coluber constrictor*



b) *Gyrinophilus porphyriticus*



c) *Terrepene carolina*

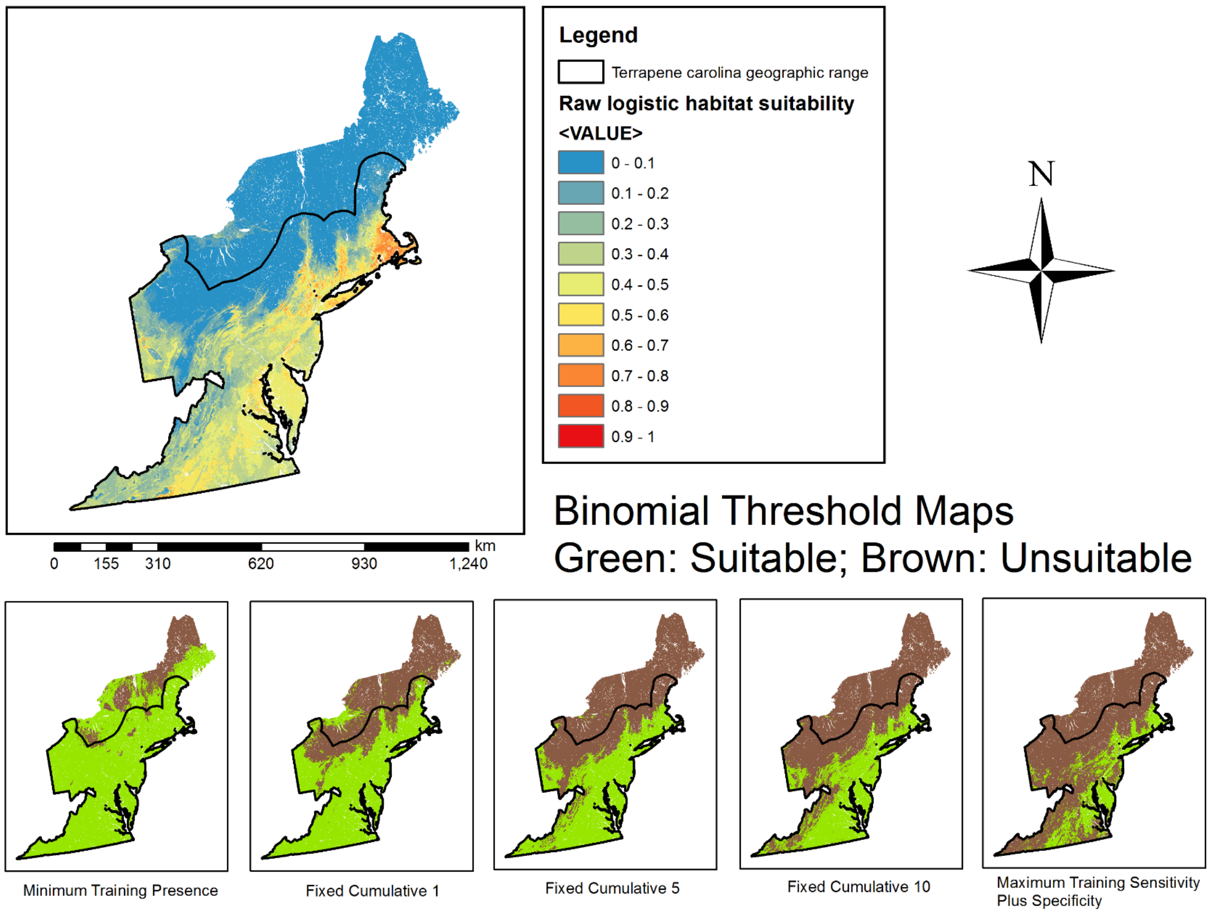


Figure 3. Flowchart for spatial application of the Priority Amphibian and Reptile Conservation Area (PARCA) Guidance criteria (Southerland and deMaynadier 2012). International Union for Conservation of Nature (IUCN) Critical (CR), Endangered (EN); U.S. Endangered Species Act (USESA) Endangered (E) or Threatened (T); Natureserve Global (G1-G3) and Interspecific Taxon (T1-T3) Rank; Northeast Partners in Reptile and Amphibian Conservation (NEPARC); Hydrologic Unit Code (HUC); Index of Ecological Integrity (IEI); Environmental Protection Agency (EPA); Protected Areas Database United States (PADUS); Important Bird Areas (IBA).

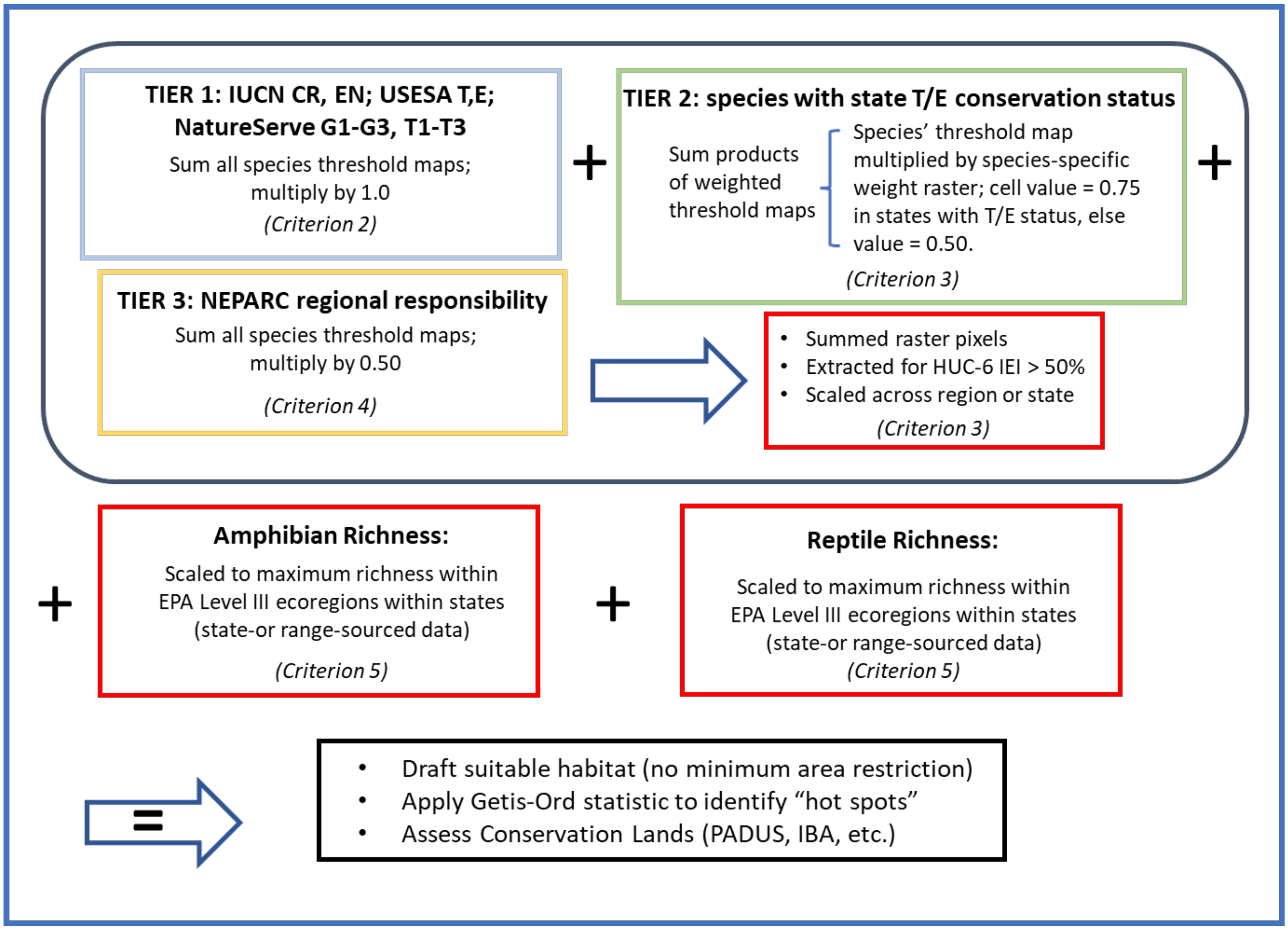


Figure 4. Index of Ecological Integrity (IEI) Hydrologic Unit Code (HUC) HUC6 IEI, University of Massachusetts Designing Sustainable Landscapes (https://umassdsl.org/Data/) scaled within HUC6 IEI >0.50 (brown) in the Priority Amphibian and Reptile Conservation Area (PARCA) project region.

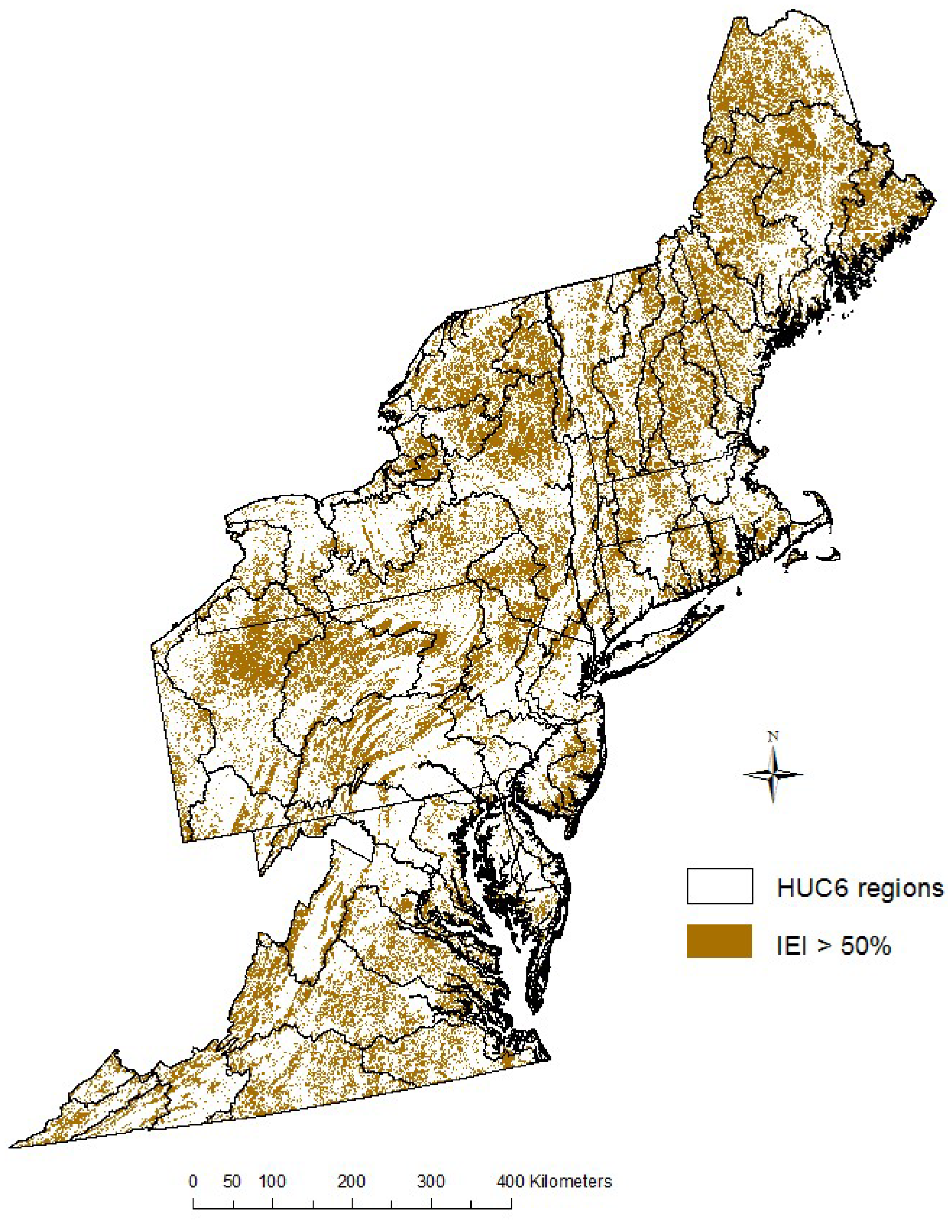


Figure 5. Environmental Protection Agency (EPA) Level-III Ecoregions in the Priority Amphibian and Reptile Conservation Area (PARCA) project region (https://www.epa.gov/eco-research/ecoregions).

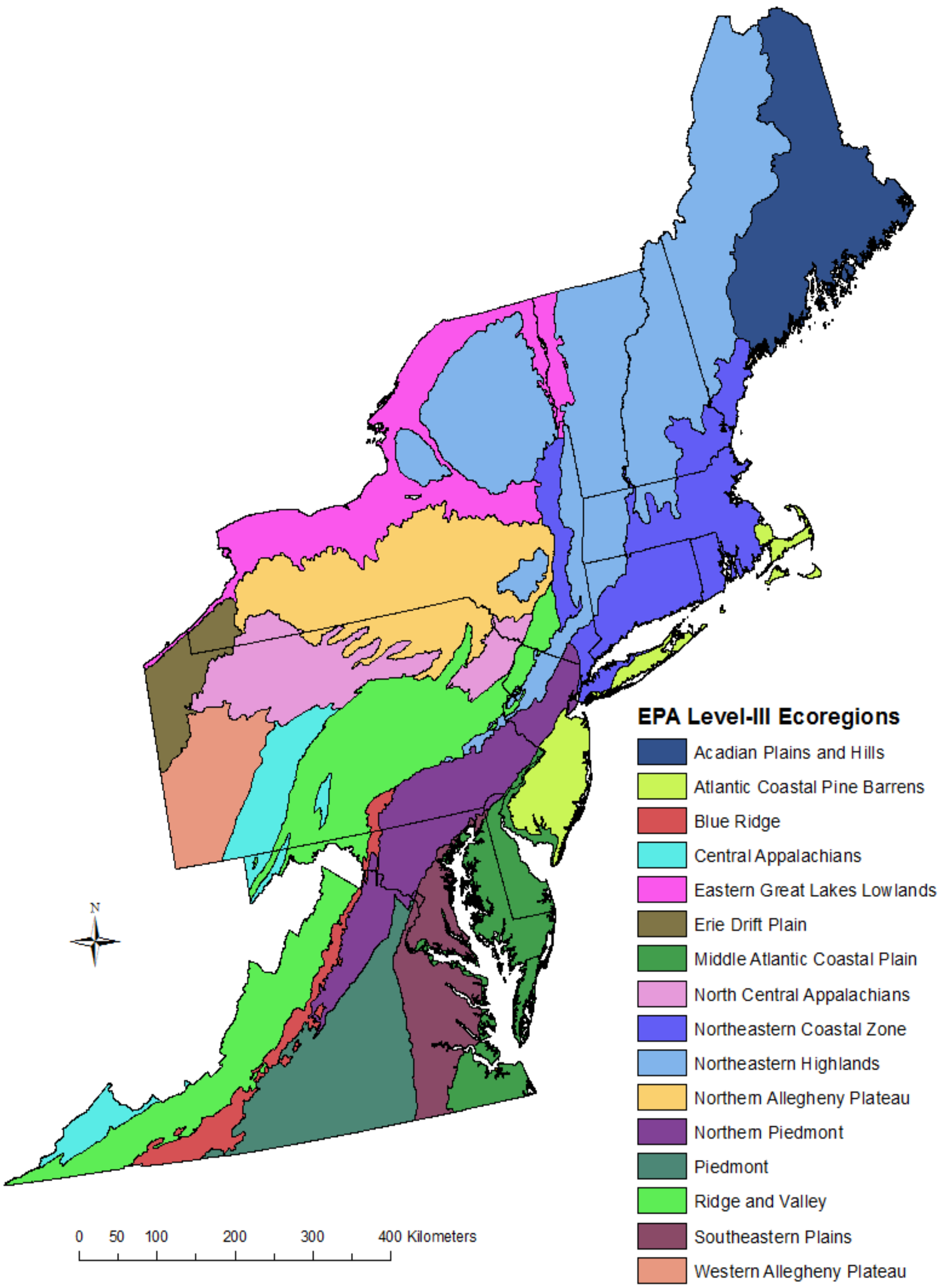


Figure 6. Amphibian species richness in the Priority Amphibian and Reptile Conservation Area (PARCA) project region compiled from range maps retrieved from Natureserve (http://explorer.natureserve.org/).

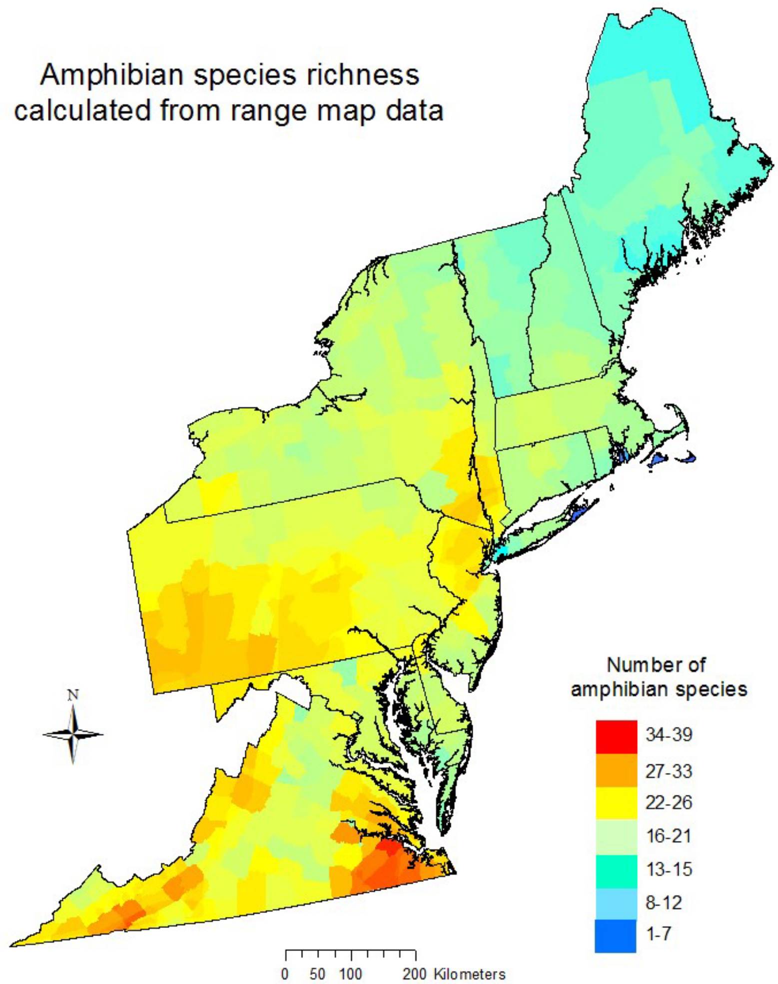


Figure 7. Reptile species richness in the Priority Amphibian and Reptile Conservation Area (PARCA) project region compiled from range maps retrieved from Natureserve (http://explorer.natureserve.org/).

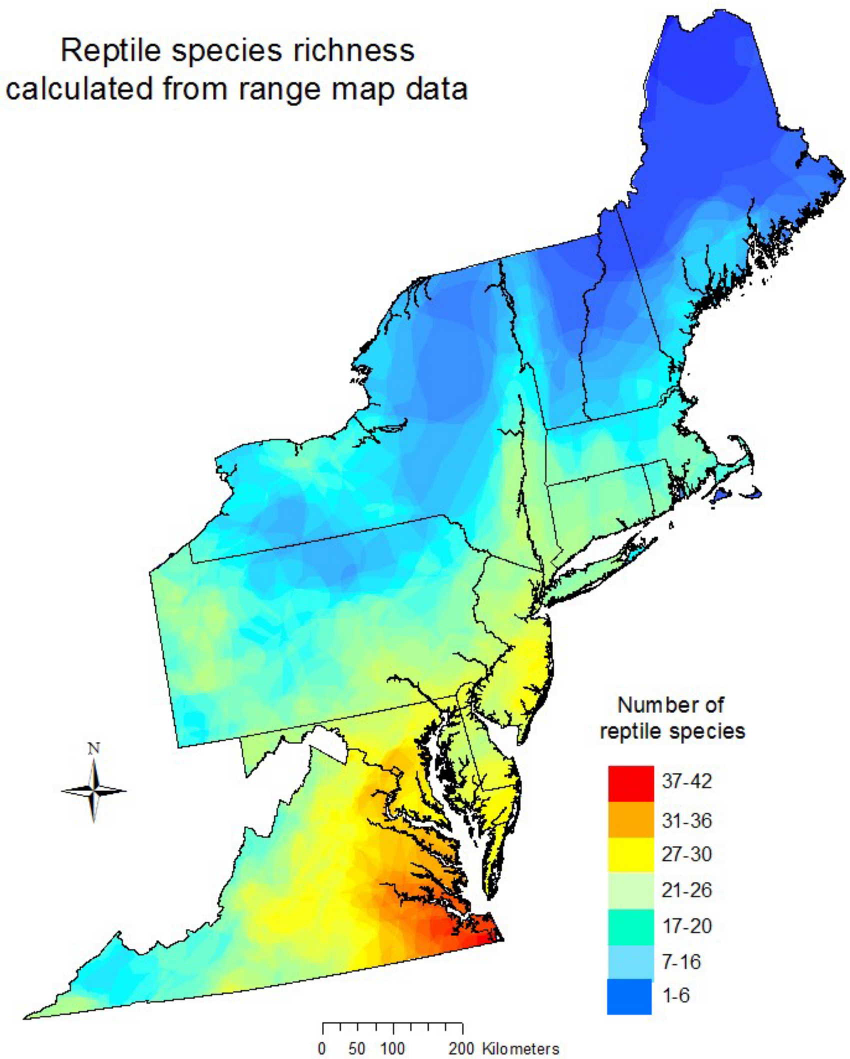


Figure 8. Areas (orange) in the Protected Areas Database United States (PADUS; https://gapanalysis.usgs.gov/padus/) status level 1-3 polygons in the Priority Amphibian and Reptile Conservation Area (PARCA) project region.

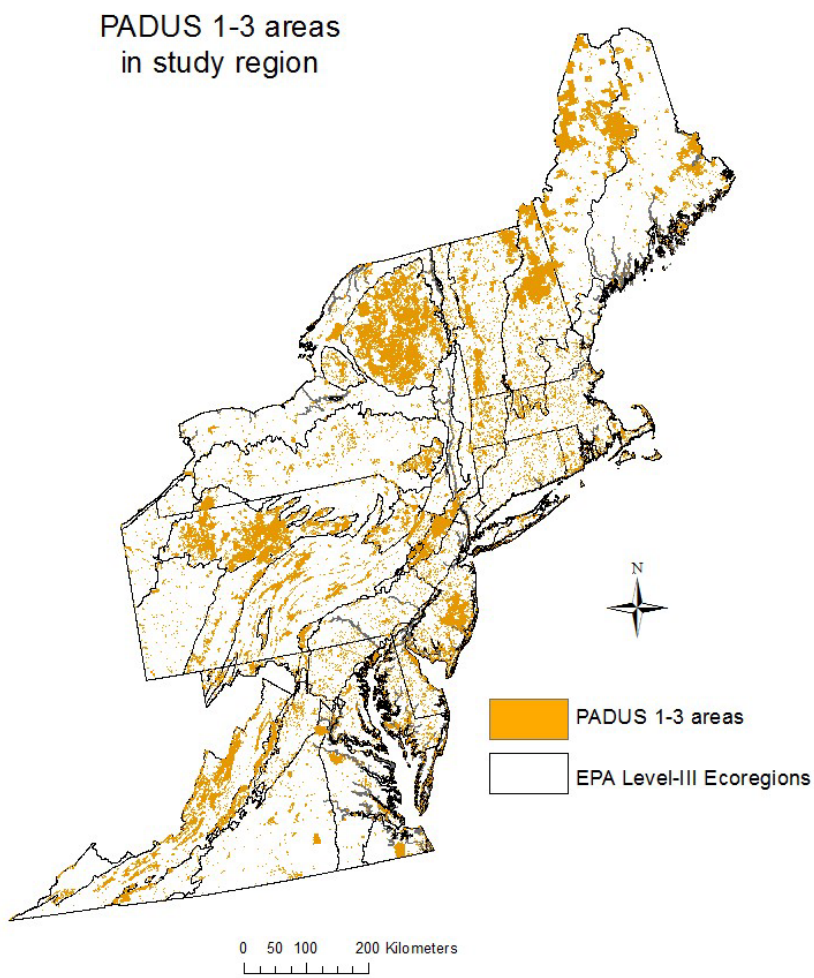


Figure 9. Areas (blue) designated as an Important Bird Area (IBA; http://www.audubon.org/important-bird-areas/) in the Priority Amphibian and Reptile Conservation Area (PARCA) project region.

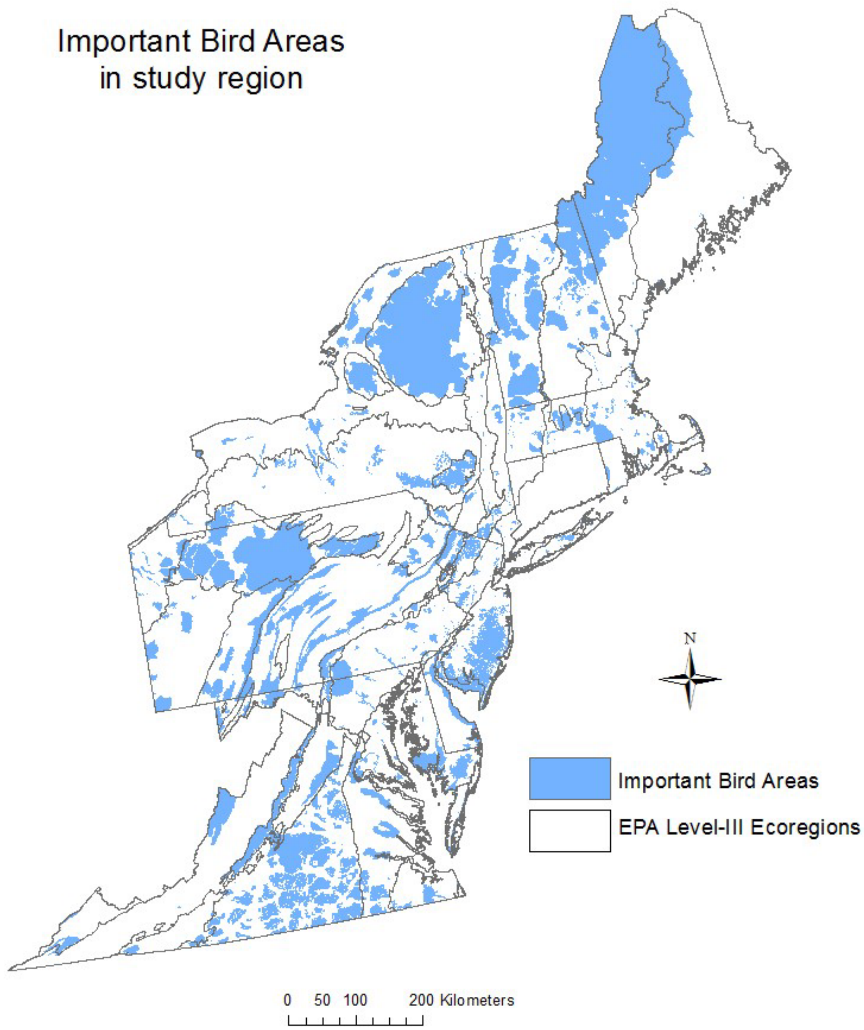


Figure 10. Draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs) (green) in the project region, edited with expert review of modeled draft PARCAs. Draft proposed PARCAs in Massachusetts have been obscured owing to state request.

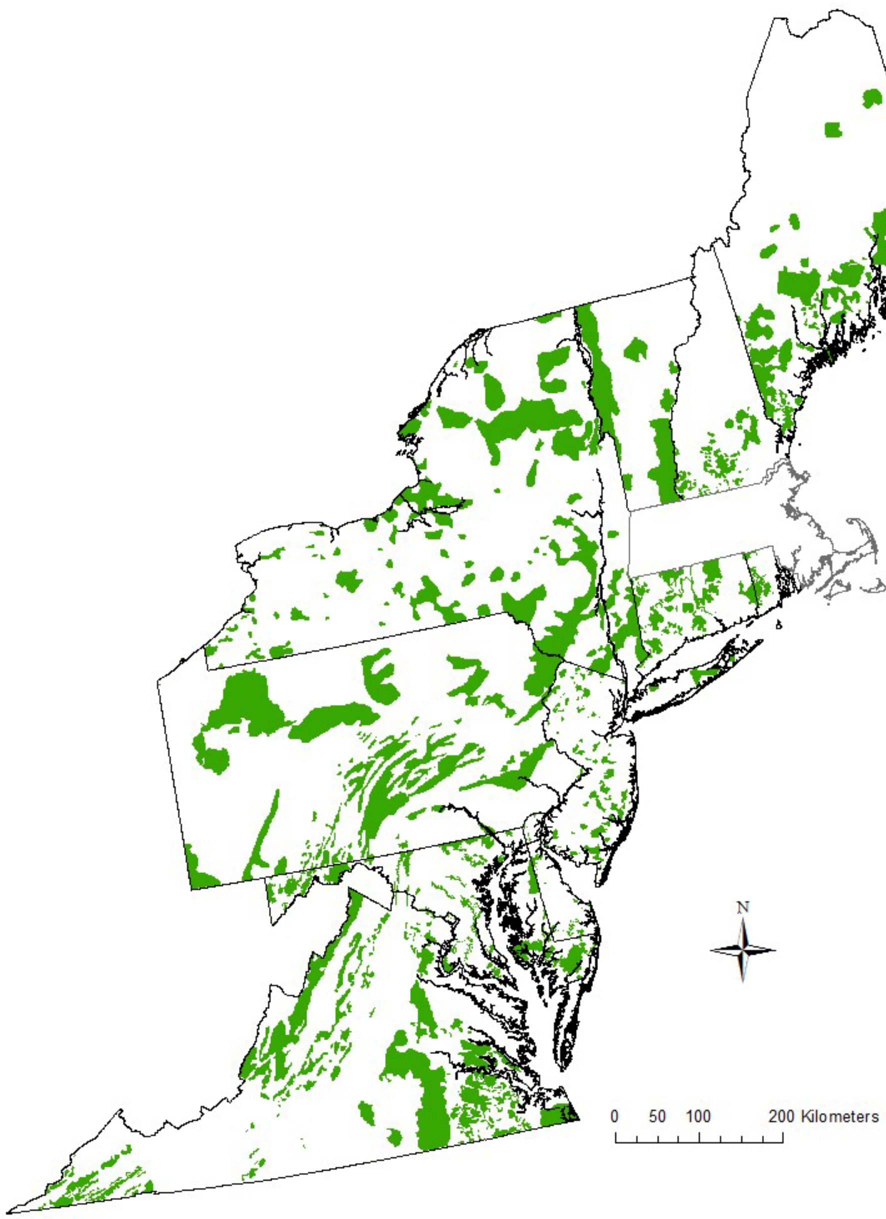


Figure 11. Type of revision to the original modeled Priority Amphibian and Reptile Conservation Area (PARCA) boundaries for the draft proposed PARCAs in the project region, after expert review of the modeled draft PARCAs is incorporated. Draft proposed PARCAs in Massachusetts have been obscured owing to state request. Colors indicate different types of editing provided by state experts during their review of the modeled PARCAs in their state.

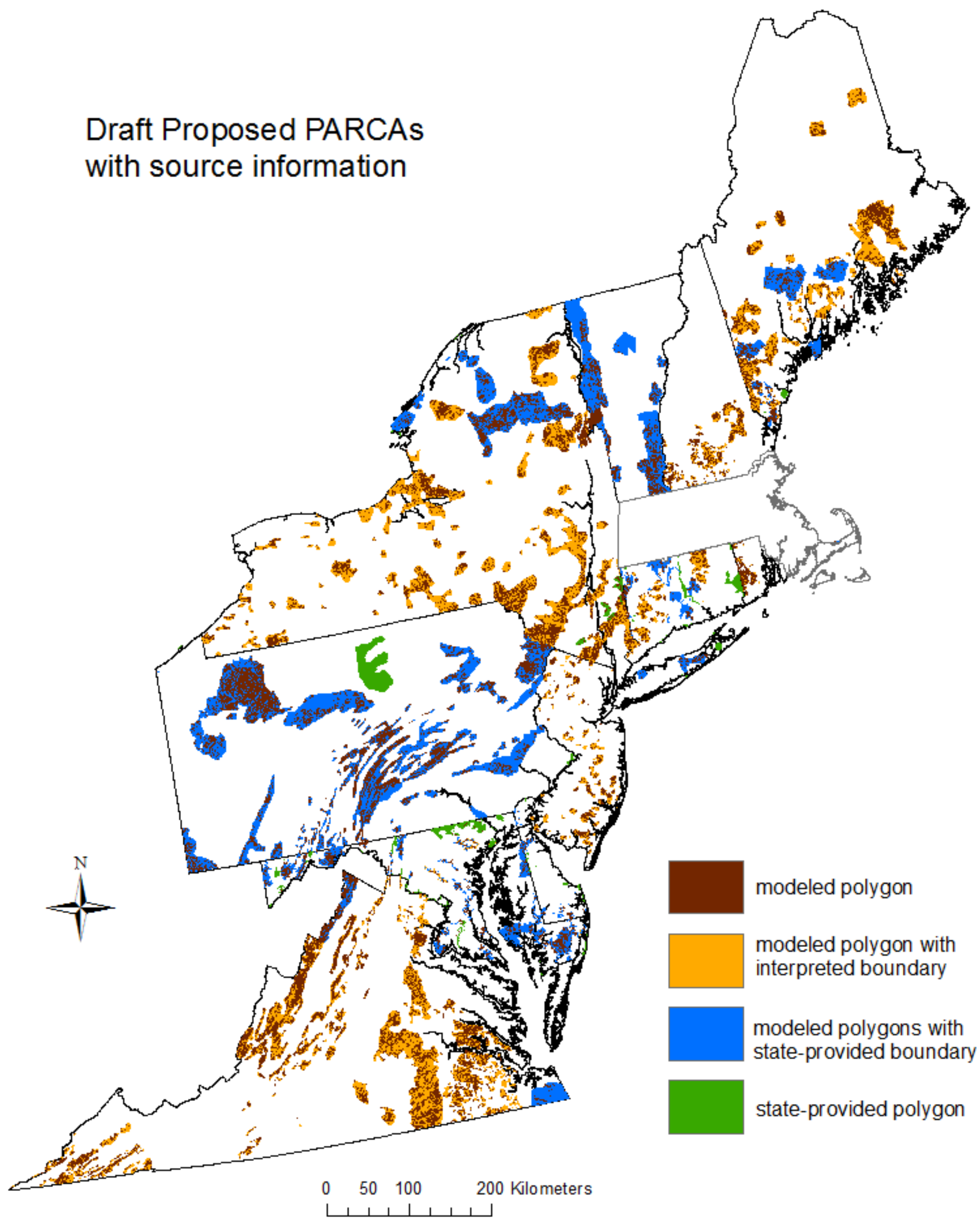


Figure 12. Size distributions of draft proposed Priority Amphibian and Reptile Conservation Area (PARCAs) in the project region.

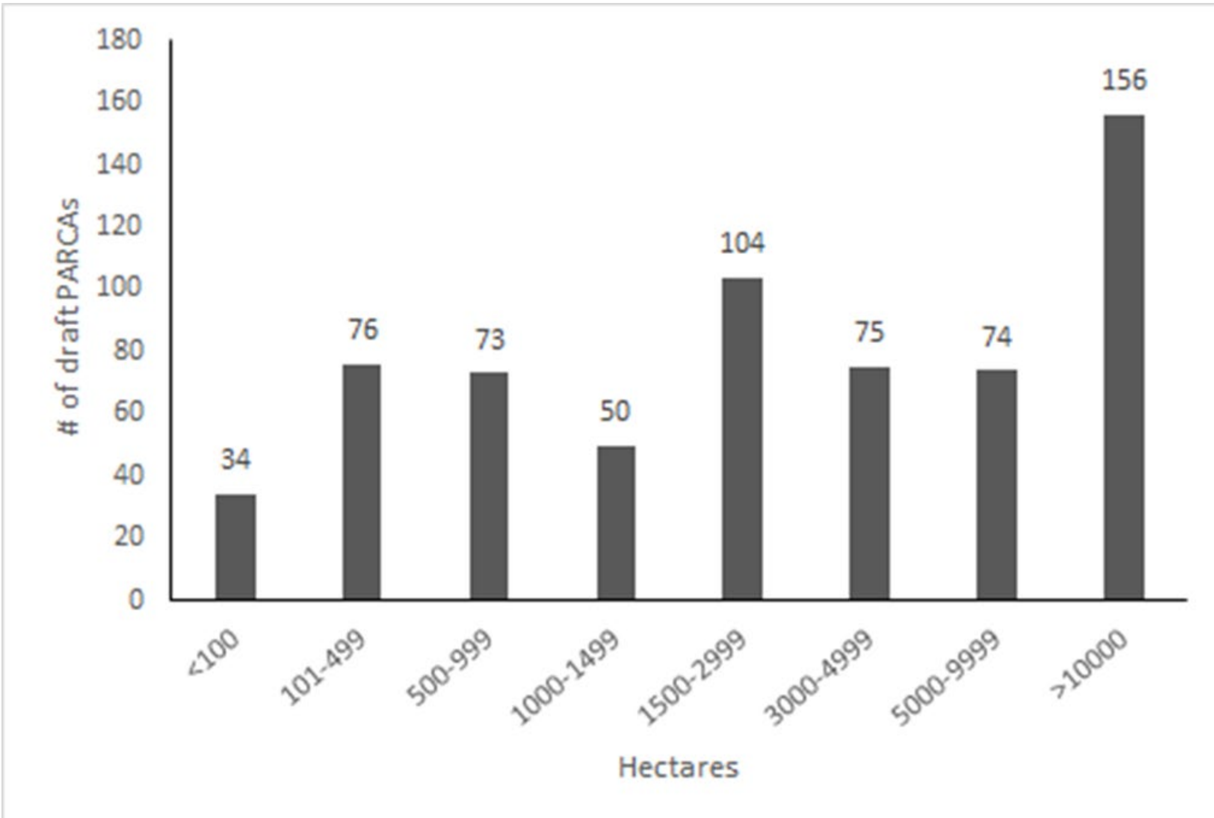


Figure 13. Number of models predicting pixels as hotspots. Models varied with different combinations of data. These combinations were alternative data source, including or omitting species richness, including all species or only priority species, and scaling to Environmental Protection Agency Level III ecoregions within or across states and the District of Columbia. Draft proposed PARCAs in Massachusetts have been obscured owing to state request. SDM = species distribution model.

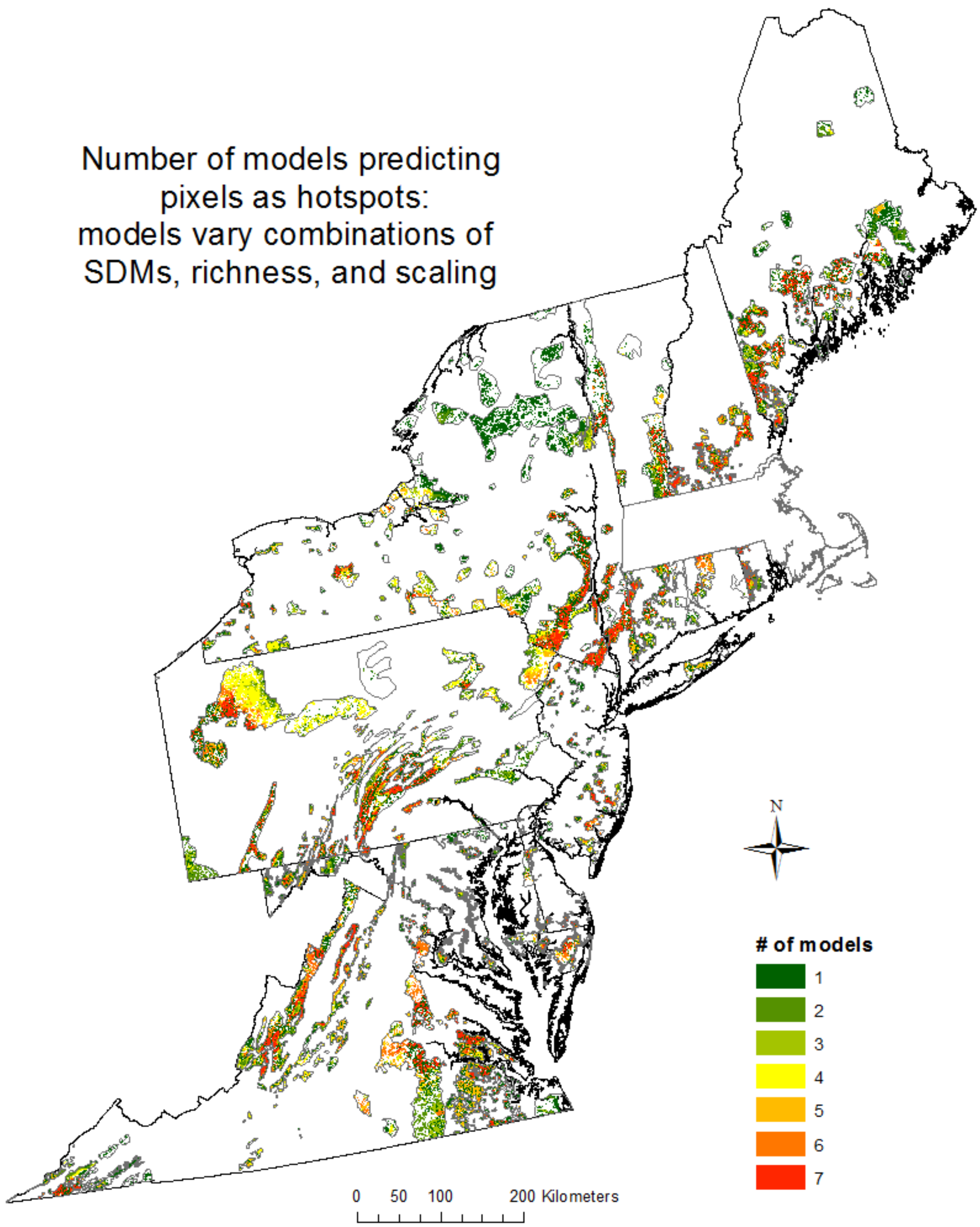


Figure 14. Priority amphibian species richness in the project region, calculated from summation of species distribution models in binary form.

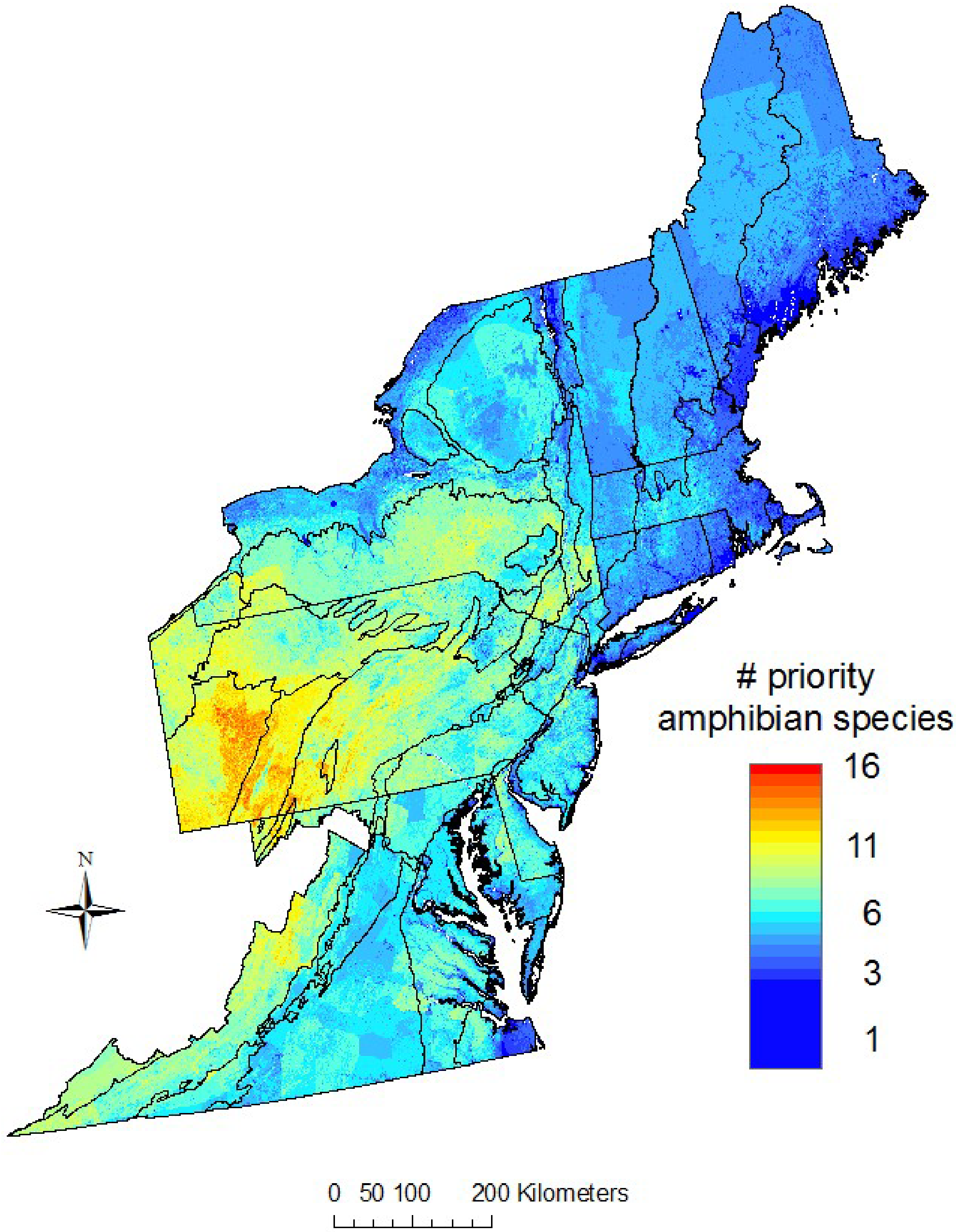


Figure 15. Priority reptile species richness in the project region, calculated from summation of species distribution models in binary form.

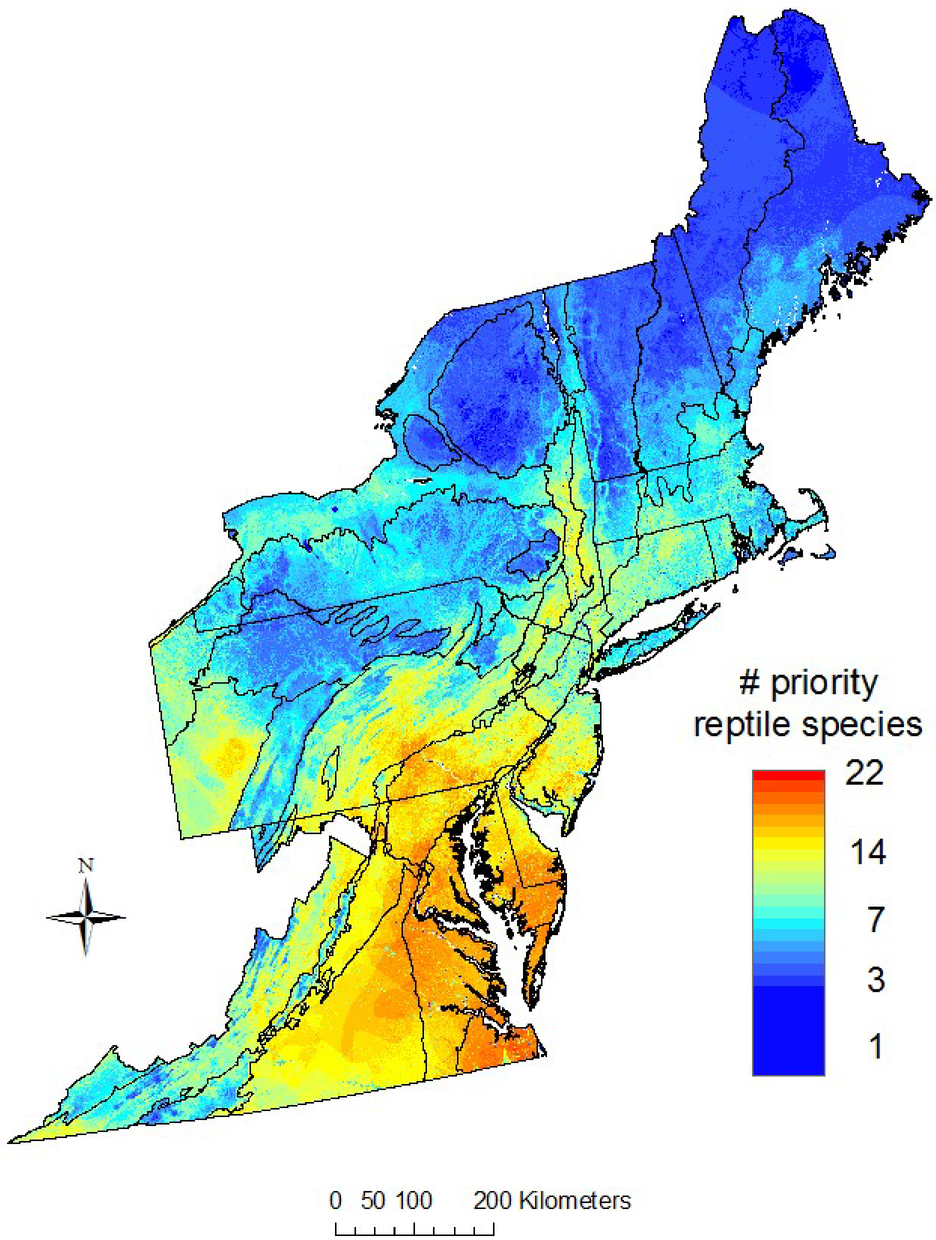


Figure 16. Draft proposed Priority Amphibian and Reptile Conservation Area (PARCAs) in areas designated as status 1-3 in the Protected Areas Database-U.S. (PADUS). Draft proposed PARCAs in Massachusetts have been obscured owing to state request.

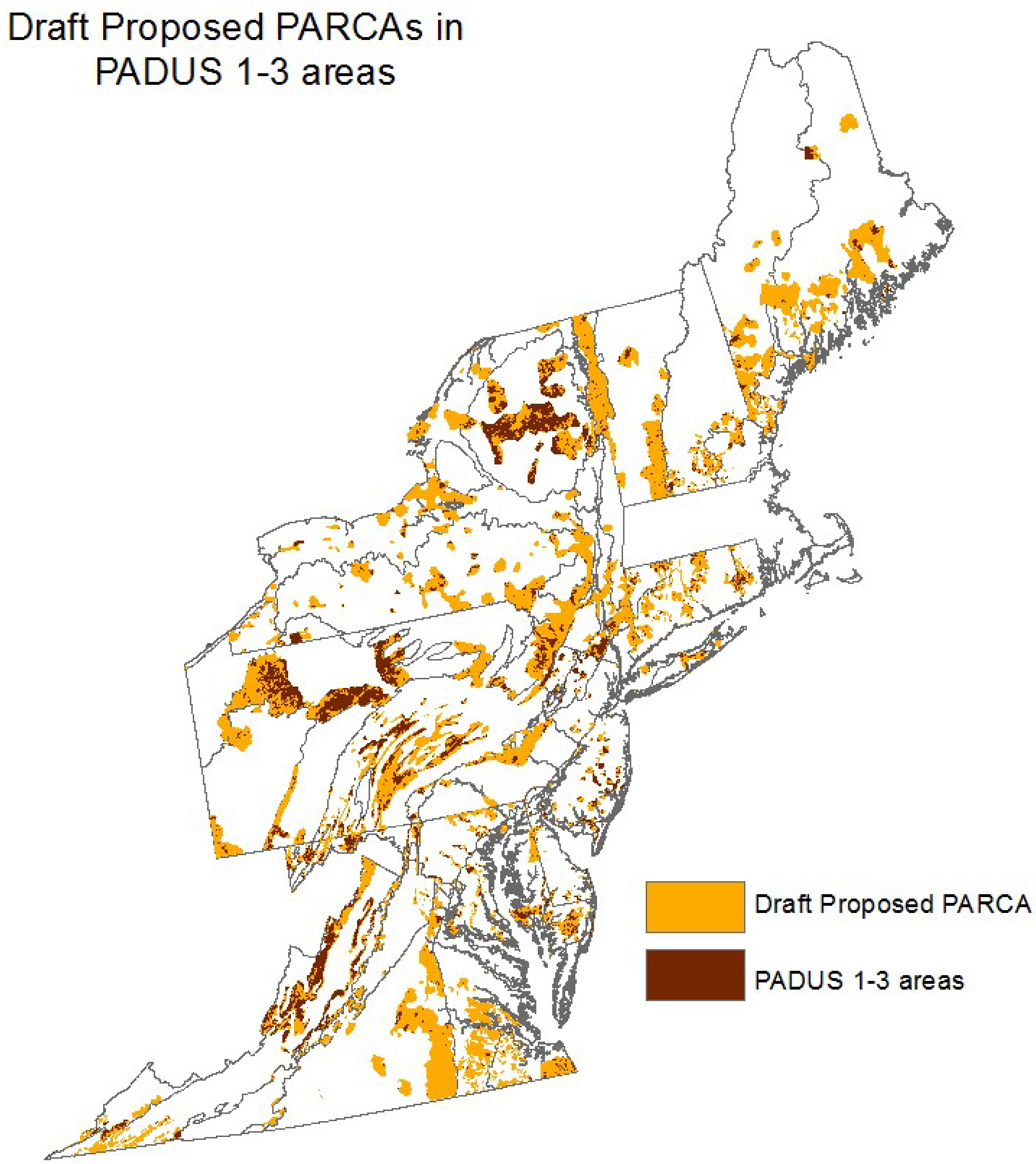


Figure 17. Draft proposed Priority Amphibian and Reptile Conservation Area (PARCAs) in areas designated as Important Bird Areas (IBA). Draft proposed PARCAs in Massachusetts have been obscured owing to state request.

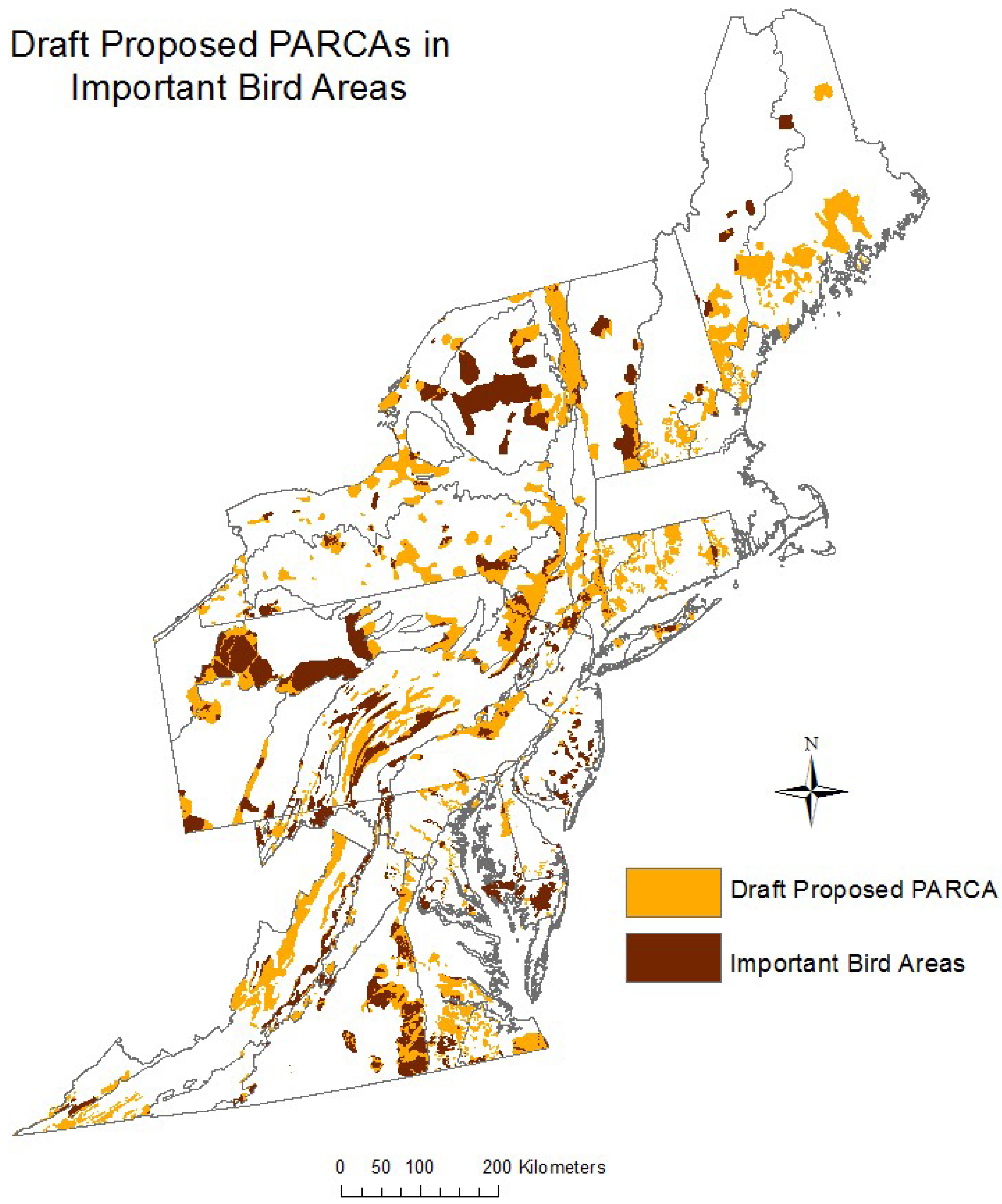


Figure 18. Important Bird Areas (IBAs) or Protected Areas Database (PADUS) rank 1-3 status lands within draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs). Draft proposed PARCAs in Massachusetts have been obscured owing to state request.

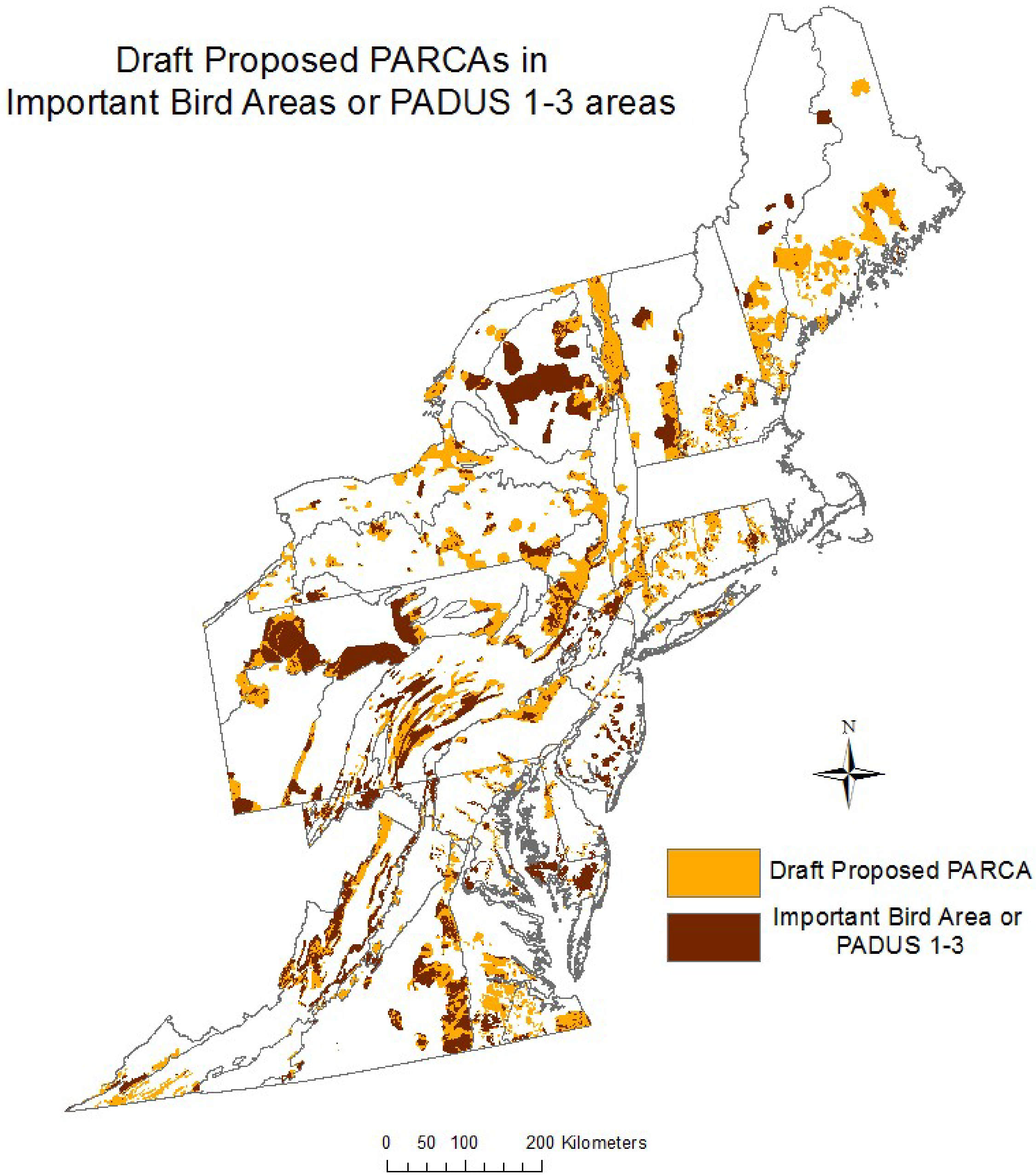


Figure 19. Percent of all priority species distribution model (SDM) areas (value > 0.50) in draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs), compared to the percentage of the study region that contains the species SDM best habitat (value > 0.50) for all priority species. The gray line is the percent of all priority species distribution model area in PARCAs. The dashed line is the percent percentage of the study region that contains the priority species SDM best habitat.

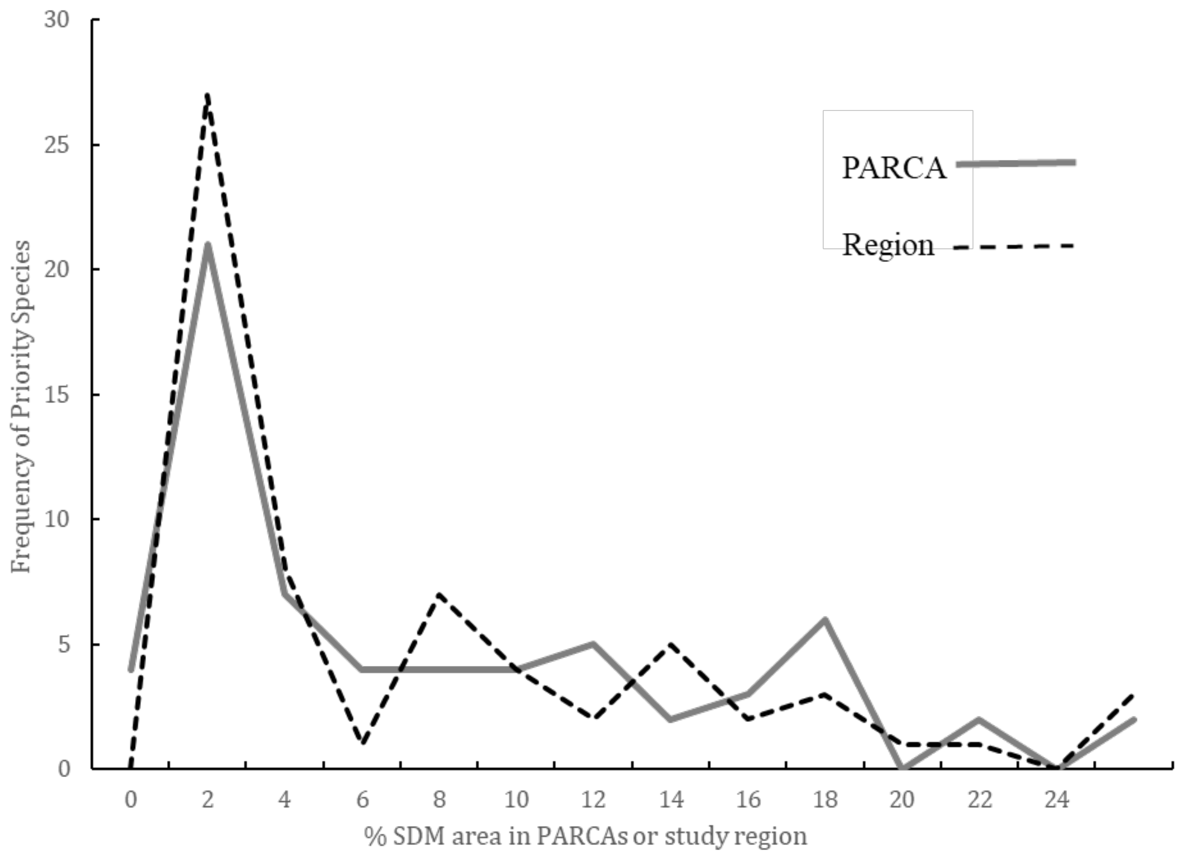


Figure 20. Percent of reptile species distribution model (SDM) area (value > 0.50) for priority reptile species in draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs), compared to the percentage of the study region that contains the reptile species SDM best habitat (value > 0.50). The gray line is the percent of reptile species distribution model area in PARCAs. The dashed line is the percent percentage of the study region that contains reptile species SDM best habitat.

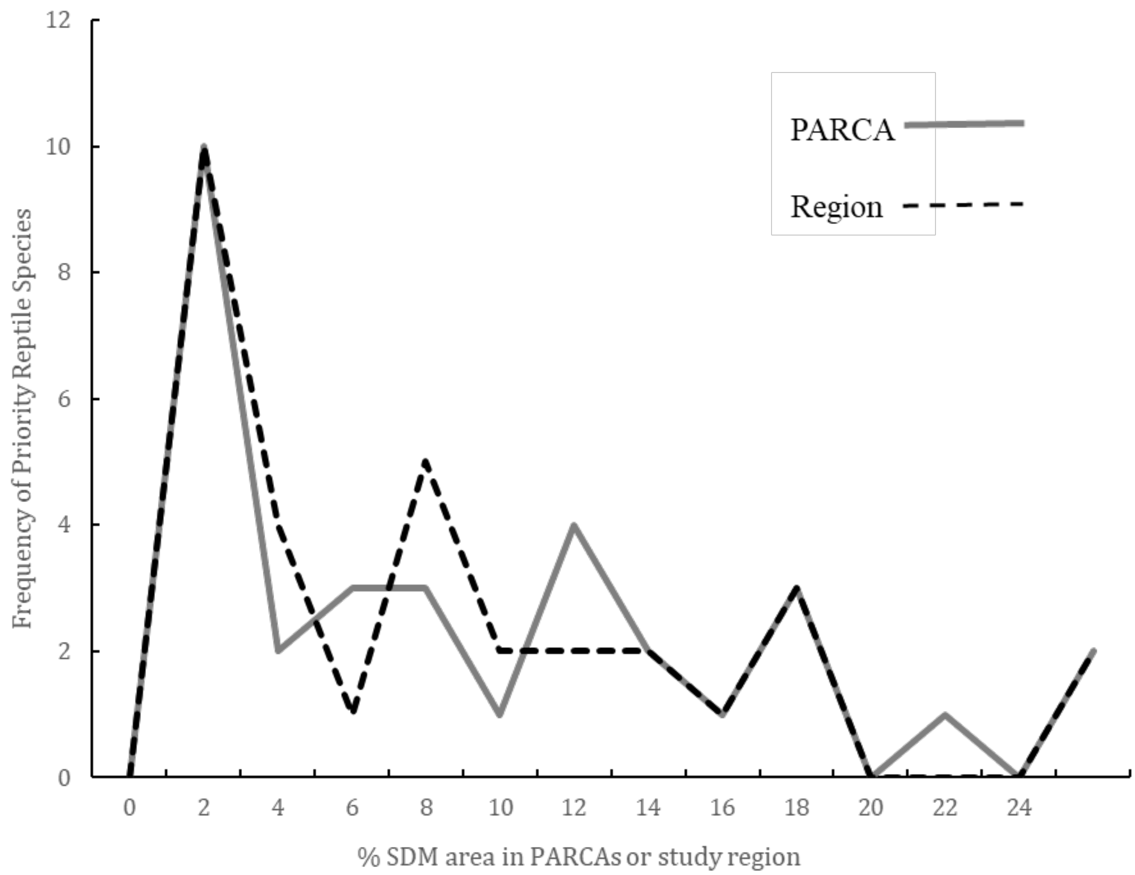


Figure 21. Percent of amphibian species distribution model (SDM) area (value > 0.50) for priority amphibian species in draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs), compared to the percentage of the study region that contains the amphibian species SDM best habitat (value > 0.50). The gray line is the percent of amphibian species distribution model area in PARCAs. The dashed line is the percent percentage of the study region that contains amphibian species SDM best habitat.

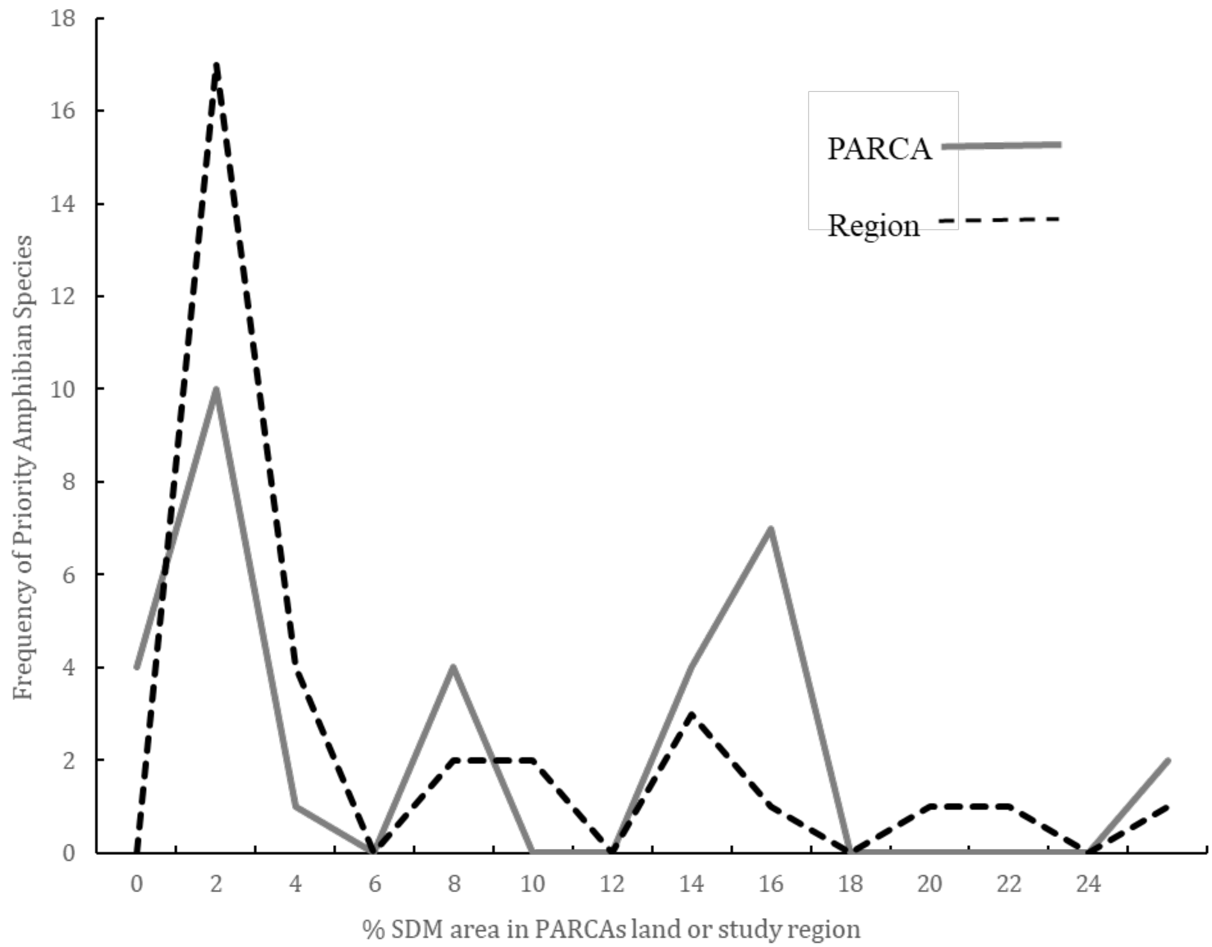


Figure 22. Percentage of priority reptile species distribution model (SDM) area (value > 0.50) in Protected Areas Database United States (PADUS) status 1-3 land, compared to the percentage of the study region that contains the reptile species SDM best habitat (value > 0.50). The gray line is the percent of reptile species distribution model area in PADUS status 1-3 lands. The dashed line is the percent percentage of the study region that contains reptile species SDM best habitat.

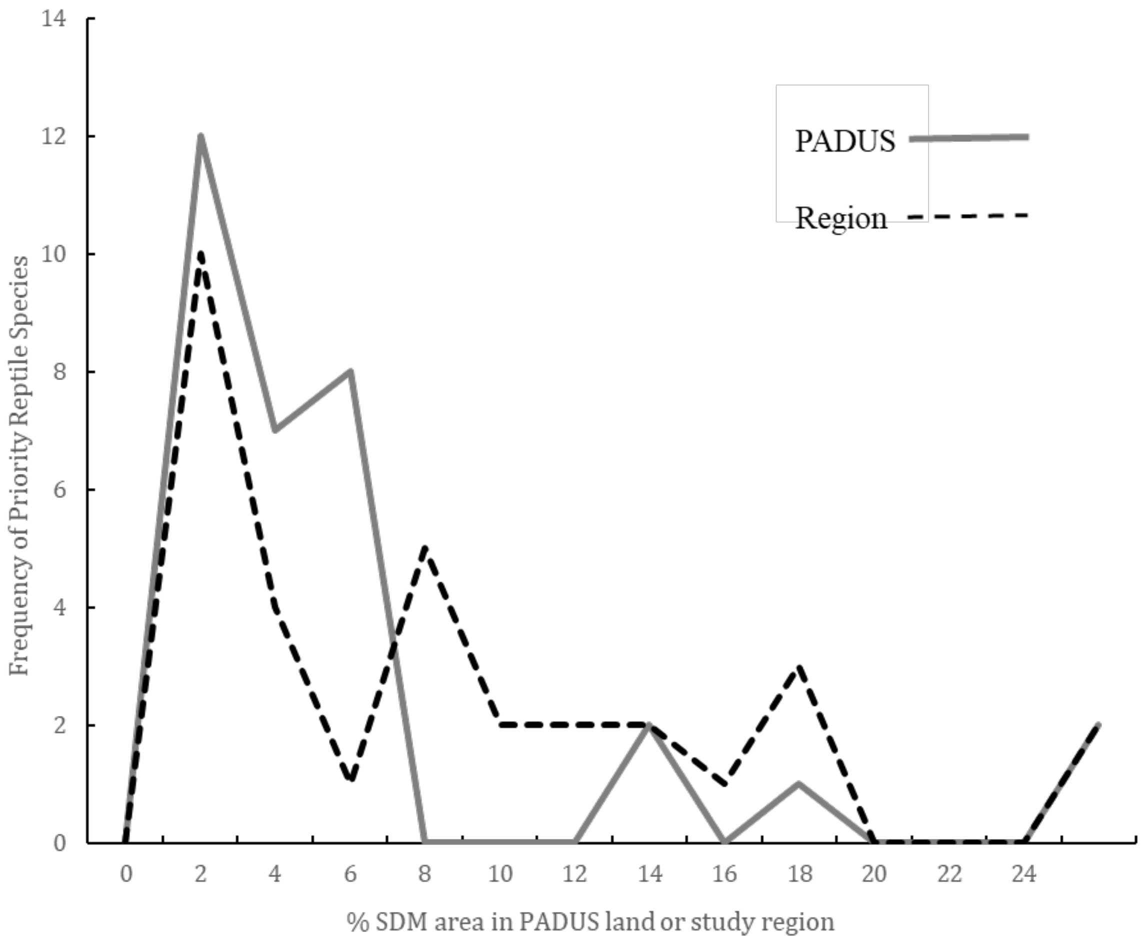


Figure 23. Percentage of priority amphibian species distribution model (SDM) area (value > 0.50) in Protected Areas Database United States (PADUS) status 1-3 land, compared to the percentage of study region that contains the amphibian species SDM best habitat (value > 0.50). The gray line is the percent of amphibian species distribution model area in PADUS status 1-3 lands. The dashed line is the percent percentage of the study region that contains amphibian species SDM best habitat.

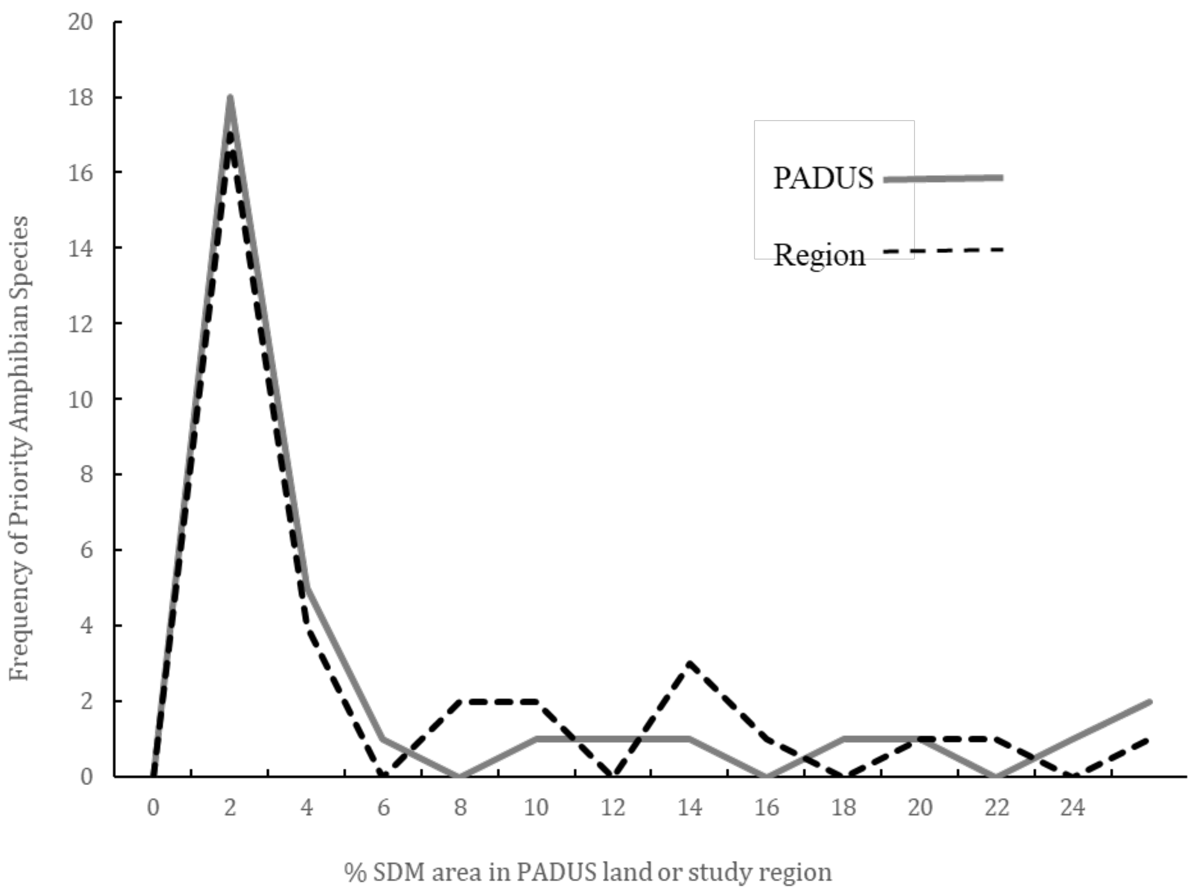


Figure 24. Number of priority species with species distribution model (SDM) value > 0.50 in draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs).

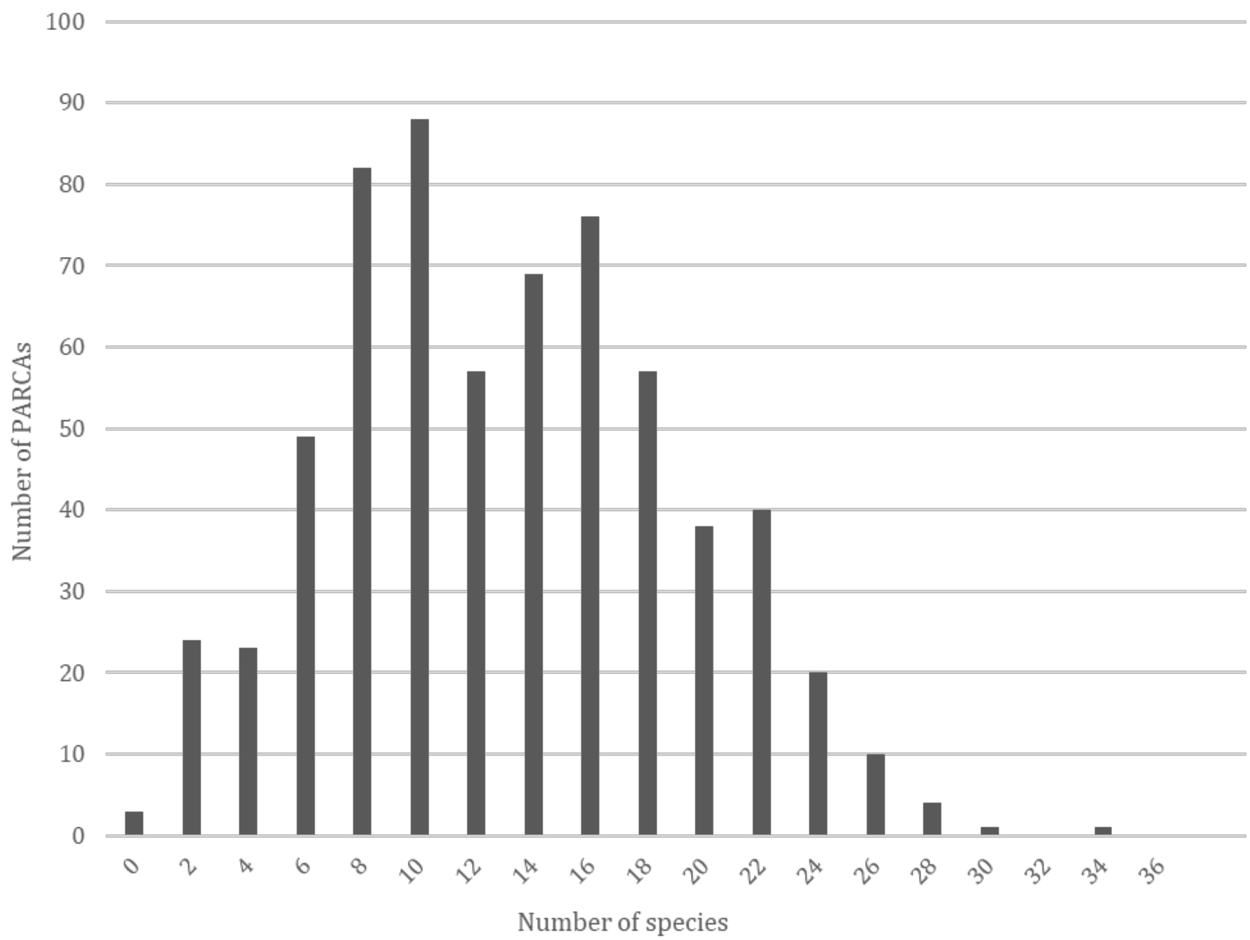


Figure 25. Number of priority species (frequency) with best habitat (species distribution model, SDM > 0.50) in draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs; black bars) compared to area-weighted conservation targets (dotted line) for the species.

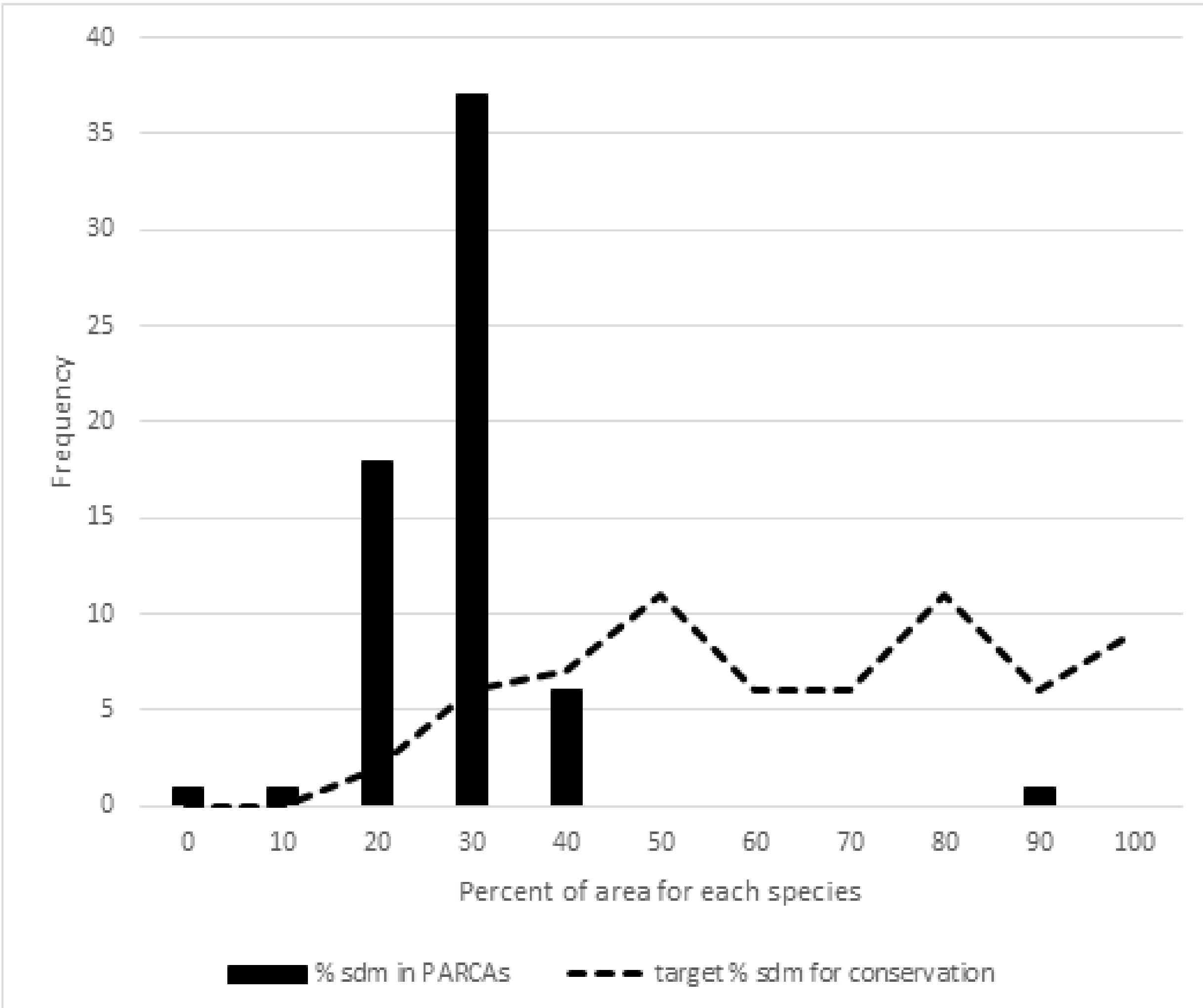


Figure 26. Area-weighted conservation targets for priority species compared with the priority species' species distribution model (SDM; value > 0.50) area in the draft proposed Priority Amphibian and Reptile Conservation Areas (PARCAs). Tier 1 species (blue; PARCA Criterion 2; Sunderland and deMaynadier 2012) have status of International Union for Conservation of Nature (IUCN) Critical (CR), Endangered (EN) or Vulnerable (VU), U.S. Endangered Species Act (ESA) Endangered (E) or Threatened (T), and Natureserve Global (G1-G3) and Interspecific Taxon (T1-T3) Rank. Tier 2 species (orange; PARCA Criterion 3) multiplies the binary threshold surface SDM pixel value by 0.75 within the states and the District of Columbia where the species' status is state threatened or endangered. Species listed as one of regional responsibility in the Northeast Partners in Amphibian and Reptile Conservation (NEPARC) matrix (NEPARC 2010) or having ≥50% of their range in the NEPARC region are considered Tier 3 species (green). We multiplied the binary threshold SDMs for Tier 3 species with a weight raster with cell values equal to 0.50 within states with regional responsibility for the species (Criterion 4).