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PROJECTED CLIMATE CHANGE EFFECTS ON NUTHATCH DISTRIBUTION AND DIVERSITY ACROSS ASIA

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***ABSTRACT.* –** We used ecological niche modeling approaches to explore climate change implications for one family of birds, the Sittidae, in Asia. Quantitative niche models based on present-day distributions for each of 13 species were projected onto future climate change scenarios. Species' potential distributional areas tended to be predicted to retract along their southern fringes, and at lower elevations along mountain ranges. As observed in other studies, montane systems were relatively more robust to the horizontal effects of climate change on species' distributions compared to flatland systems, so range contractions were focused in Southeast Asia and peninsular India.

***KEY WORDS.* –** nuthatch, distribution, diversity, climate change, niche modeling.

INTRODUCTION

Current rapid changes in global climate reveal a strong tendency toward warmer temperatures and greater variability of climate events (IPCC, 2007). The biological implications of these changes, however, remain somewhat obscure: although numerous recent publications document effects already manifested (Visser et al., 1998; Parmesan et al., 1999; Parmesan & Yohe, 2003; Lovejoy & Hannah, 2005), anticipating changes already initiated but as yet not manifested is a major challenge (Peterson et al., 2005). Several modeling efforts have explored such predictive challenges (e.g., Thomas et al., 2004), but consensus as to likely effects and their dimensions has not been easy (Pearson & Dawson, 2003; Araújo et al., 2005b; Araújo & Rahbek, 2006).

Ecological niche modeling (ENM) provides a predictive framework for anticipating spatial implications of global climate change for biodiversity (Pearson & Dawson, 2003; Soberón & Peterson, 2005). Extensive methodological testing has produced not just consistent and robust projections across future climate projections (Bakkenes et al., 2002; Berry et al., 2002; Erasmus et al., 2002; Peterson et al., 2002; Pearson & Dawson, 2003; Huntley et al., 2004; Peterson et al., 2004; Thuiller et al., 2005a; Araújo et al., 2006; but see Pearson et al. 2006), but also a growing understanding of the sensitivity, assumptions, and limitations of the approach (Pearson & Dawson, 2003; Hampe, 2004; Araújo et al., 2005b; Peterson et al., 2005).

Here, we use ENM approaches to explore climate change implications for one family of birds, the Sittidae. This study builds on a previous ecological and geographic analysis (Menon et al. 2008) of the family. Nuthatch species serve as an interesting group for such studies as their distributions range from narrow endemism to broad distributions across continents. Specifically, we focus on members of the family distributed in Asia, the region that holds by far the richest nuthatch assemblage (Harrap & Quinn, 1995). We develop quantitative ecological niche models based on present-day distributions of each species, and then project those models onto future, changed climates. The result is a picture of likely spatial (geographic) effects of changing climates on

Table 1. Summary of occurrence data available to us for model development, projected current distributional areas (derived from trimmed raw ENM results), and projected proportional range loss under two scenarios of climate change for each nuthatch species occurring in Asia.

Species	Number of occurrence points	Current area (km^2)	Percent loss under HA2	Percent loss under HB2
Sitta cashmirensis	17	510,594	35.2	35.3
Sitta castanea	69	4,204,746	45.2	39.3
Sitta europaea	40	18,018,741	64.8	64.7
Sitta formosa	63	739,304	5.5	5.1
Sitta frontalis	60	3,944,852	47.7	38.9
Sitta himalayensis	27	552,488	22.2	18.1
Sitta leucopsis	23	967,920	11.5	11.7
Sitta magna	45	705,941	24.0	18.0
Sitta nagaensis	27	901,572	17.4	15.9
Sitta tephronota	34	2,822,247	15.1	18.3
Sitta villosa	10	1,116,444	80.4	79.8
Sitta yunnanensis	7	284,822	47.7	43.6
Tichodroma muraria	56	10,846,541	20.0	20.0

each species' distributional potential. We synthesize these results into a picture of regional change in nuthatch species composition and diversity.

METHODS

***Input Occurrence Data.* –** We included all Eurasian nuthatches, specifically all species in the genera *Sitta* and *Tichodroma* occurring in the region. Occurrence information was drawn from natural history museums across North America, including the Museum of Comparative Zoology, Field Museum of Natural History, University of Kansas Natural History Museum, and the U.S. National Museum of Natural History; data were also drawn from databases developed by BirdLife International (Collar et al., 2001). Textual descriptions of occurrence localities were translated into geographic coordinates in decimal degrees via the GeoNet Names Server (National Geospatial Intelligence Agency, 2007) and BioGeomancer (Chapman & Wieczorek eds., 2006). The final dataset consisted of 7-69 occurrences per species (Table 1, Figure 1; see Menon et al., 2008 for more detail).

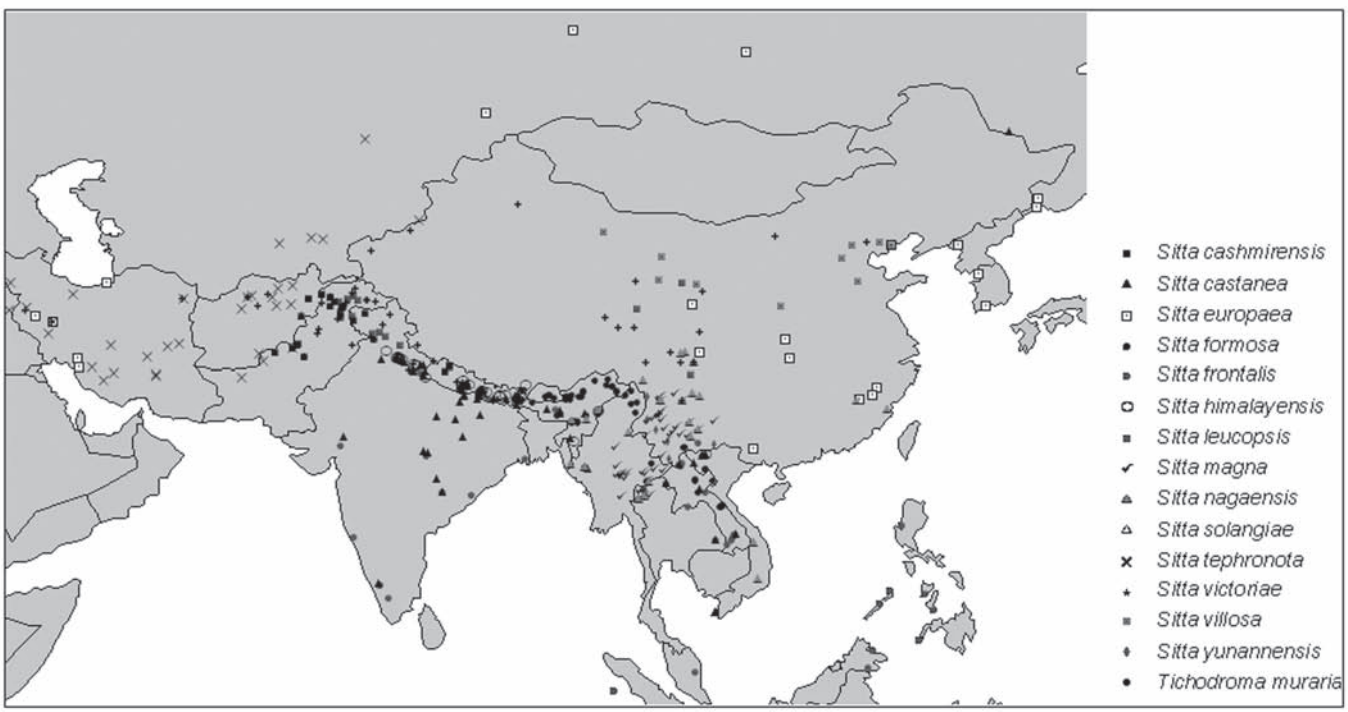

Fig. 1. Occurrence points for 12 *Sitta* species and one *Tichodroma* species used in this study. *Sitta solangiae* and *S. victoriae* each had fewer than 5 occurrence points and were excluded from the analysis.

***Environmental Data Sets.* –** Climate data were drawn from a global summary for 1960-1990 at 0.5° resolution (New et al., 2002). In particular, we used data layers summarizing annual precipitation, mean annual temperature, maximum annual temperature, minimum annual temperature, diurnal temperature range, and vapor pressure. We supplemented these data sets with information from the U.S. Geological Survey's Hydro-1K dataset (http://edc.usgs.gov/products/elevation/gtopo30/hydro/) for topography and landform (slope, aspect, compound topographic index). We resampled all data sets to 0.1° resolution for analysis to avoid overinterpretation of the precision of the point occurrence data.

To represent future climatic conditions, we used output from the HadCM3 general circulation model (GCM). We assessed both a conservative (HB2) and a less-conservative (HA2) view of future atmospheric condition and consequent climate change. These climate model results are presented in terms of a 30-year average around 2055 (2040-2069), so our results do not take into account the potential effects of increased climate variability (e.g., El Niño events) on species' distributions. Because GCM results are provided at a spatial resolution of 2.5 x 3.75° grid cells, expected changes in temperature and precipitation under each scenario were extracted from the coarse raw data sets--these expected changes were applied to the New et al. (2002) current climate data layers (0.5 x 0.5° grid cells), thus achieving a reasonable spatial resolution.

***Ecological Niche Modeling.* –** Several studies have compared potential distributional estimates resulting from different ecological niche modeling approaches, concluding that algorithms capable of fitting complex and non-linear relationships generally provide better predictions than simpler analogues (Segurado & Araújo, 2004; Elith et al., 2006). In these studies, however, measures of model performance did not often assess the full predictive challenge, often focusing more on challenges of interpolation than on challenges of transferability (Araújo et al., 2005a). As a consequence, and in spite of years of exploration and testing, little guidance can be provided regarding selection of 'best' ENM algorithms for applications related to transferability (Lobo et al., 2007; Peterson et al., 2007).

Here, we used the Genetic Algorithm for Rule-Set Projection (GARP; Stockwell & Peters, 1999), a method that has been used successfully in studies involving transferability—training niche models on one landscape for projection to different landscapes as predictions (Iguchi et al., 2004, Peterson et al., 2007). GARP is an evolutionary-computing method that builds ENMs based on nonrandom associations between known occurrence points for species and sets of GIS coverages describing variation in several ecological parameters of environments. Occurrence data are used by GARP as follows: 50% of occurrence data points are set aside for an independent filtering to assure predictive ability of models (extrinsic testing data), 25% are used for developing models (training data), and 25% are used for tests of model quality internal to GARP (intrinsic testing data). Distributional data are converted to binary raster layers, and by random resampling from training and intrinsic test data and areas of 'pseudoabsence' (areas lacking known presences), two data sets are created, each of 1250 points; these data sets are used for rule generation and model testing, respectively (Stockwell & Peters, 1999).

Within GARP's processing, the first rule is created by applying a method chosen randomly from a set of inferential tools (e.g., logistic regression, bioclimatic rules). The genetic algorithm consists of specially defined operators (e.g. crossover, mutation) that modify the initial rules, and thus the result is models that have "evolved"—after each modification, the quality of the rule is tested (to maximize both significance and predictive accuracy) and a size-limited set of best rules is retained. Because rules are tested based on independent data (the intrinsic test data), performance values reflect expected performance of rules, an independent verification that gives a more reliable estimate of true rule performance.

Following recent best-practices recommendations (Anderson et al., 2003), for each species, we developed 100 replicate random-walk GARP models, and filtered out 90% based on consideration of error statistics, as follows. The 'best subsets' methodology consists of an initial filter removing models that omit (omission error = predicting absence at points of known presence) heavily based on the extrinsic testing data, and a second filter based on an index of commission error (= predicting presence in areas of known absence), in which models predicting very large and very small areas are removed from consideration. Specifically, in GARP, we retained only the 20% of models that showed lowest omission errors, and then retained only the central 50% of the frequency distribution of proportional area predicted present (an index of commission error); the result was 10 'best subsets' models (binary raster data layers) that were summed to produce a best ensemble estimate of geographic projection.

***Range Loss Scenarios.* –** Projections of potential distributional areas for present and future climate scenarios were summarized as follows. First, we decided on particular predictive thresholds (= suitability scores) above which model predictions would indicate suitable conditions, and below which model predictions would indicate unsuitable conditions—we used the lowest training presence threshold (= lowest suitability score assigned to any of the occurrence points on which the model was based; Pearson et al., 2007). Raw ENM results for each species were inspected relative to known occurrences and relative to published range maps (Harrap & Quinn, 1995) and disjunct areas of overprediction removed. This step is equivalent to an assumption that the range is reasonably well sampled at coarse geographic resolutions, and that disjunct areas represent areas of overprediction for reasons of limited dispersal across geographic barriers (Soberón & Peterson, 2005). We are comfortable with the general assumption of negligible dispersal ability because nuthatches are generally associated with forest or woodland habitats, and because they show

little affinity to disturbed areas. We assume explicitly that sampling has been sufficient to detect and document the major features of each species' range.

Projections of ENM rule sets onto future climate conditions require explicit consideration of the dispersal abilities of the species in question (Pearson & Dawson, 2003). In the case of the nuthatches, we assume negligible dispersal abilities, given that nuthatches are generally restricted to forest. In addition, the forested habitats themselves are unlikely to shift broadly (i.e., on geographic scales) in response to rapid climate change over just a few decades. As such, our hypothesized future distribution for each species was the area determined by the intersection of the present-day and future predictions (Peterson et al., 2001).

RESULTS

Individual nuthatch species are projected to experience diverse effects from changing climates across Asia. *Sitta tephronota* and *S. frontalis* provide good illustrations of general tendencies (Figure 2): their potential distributional areas tend to retract along their southern fringes, and at lower elevations along mountain ranges. Projected climate change effects on species' potential distributions ranged from 5.1-79.8% areal loss under the B2 scenario, and 5.5-80.4% under the A2 scenario (Table 1). These tendencies—in general at least—are well known, and have been both predicted in previous climate change forecasting studies (Peterson et al. 2005) and documented in real-world observations of climate change effects on species (Parmesan, 1996; Parmesan et al., 1999; Parmesan & Yohe, 2003).

These general tendencies of range loss, when summed across many species, can be used to produce a picture of expected changes in biodiversity across the continent (Peterson et al., 2002), which can be considered in a variety of dimensions. Expected local losses of species (Figure 3, upper left panel) are focused in the Himalayan foothills, the flatlands areas of Southeast Asia, and the Indian Subcontinent; viewing these numbers as percentages of the existing community emphasizes the flatlands of Southeast Asia and the Indian Subcontinent (Figure 3, upper right panel). Translating these numbers into estimates of current and future species richness (Figure 3, bottom panels), Southeast Asia and much of peninsular India are seen to lose significant portions of their nuthatch faunas, in many cases (e.g., Cambodia) losing nuthatches essentially completely.

DISCUSSION

This study offers a first likely view of biodiversity implications of changing climates across Asia. It is a limited view, however, as it focuses on a single clade of birds that probably is itself constrained as to its ecological potential by its evolutionary history—as such, these analyses offer only a partial view of what effects climate change will have on biodiversity. Broadening this study to consider more groups with diverse evolutionary histories will make for more robust conclusions.

The ecological niche modeling approach to such forecasting of climate change implications for biodiversity is itself not without limitations. Most importantly, such forecasts depend rather critically on the assumption that species' ecological niches will be conservative in the face of changing conditions (Peterson, 2003a)—this assumption has, nonetheless, now seen considerable support in numerous empirical assessments (Peterson et al., 1999; Martínez-Meyer et al., 2004; Wiens, 2004; Wiens & Graham, 2005; Martínez-Meyer & Peterson, 2006; Kambhampati & Peterson, 2007). Beyond this fundamental assumption, the ecological niche models may or may not be robust and predictive, and many considerations enter into their training, testing, and application, although considerable attention in the literature is now clarifying the pitfalls and challenges in the modeling process (Midgley et al., 2003; Thuiller et al.,

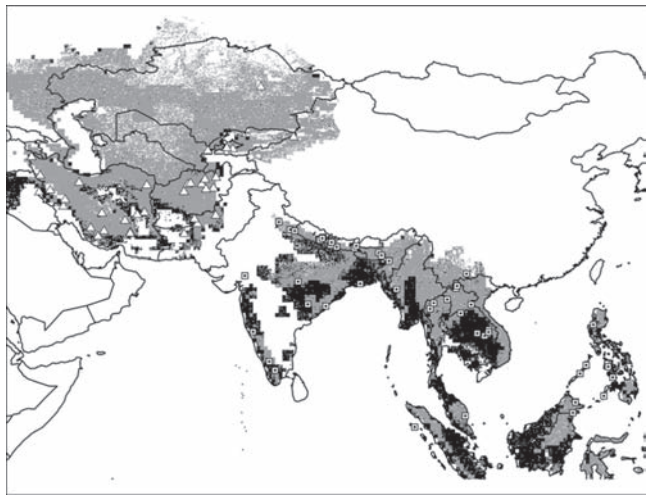

Fig. 2. Model predictions of species distribution area retained (gray) and lost (black) due to climate change for two example species, *Sitta tephronota* (white triangles, western area) and *S. frontalis* (dotted squares, eastern area).

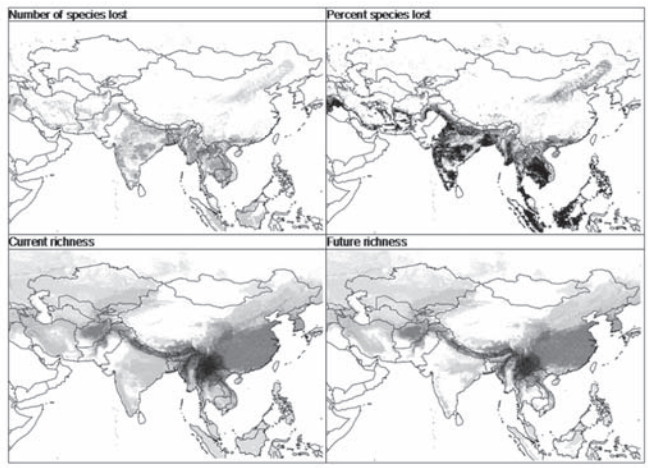

Fig. 3. Model predictions regarding number and percent of nuthatch species lost due to climate change, along with estimated current and future species richness for nuthatches. Shading ramps range from white (minimum) to dark gray (maximum) as follows: number of species lost 0-5, percent of species lost 0-100, and current and future species richness 0-9 species.

2004; McNyset, 2005; Soberón & Peterson, 2005; Thuiller et al., 2005b; Peterson & Nakazawa, 2008; Peterson et al., 2008).

Given these caveats, the results of this set of analyses nonetheless point to some general expectations for biodiversity changes across Asia with changing climates. In particular, in terms of range contraction, the foci of effects documented herein were Southeast Asia and peninsular India, with broad range retractions anticipated across several species. As has been observed in other studies (Peterson, 2003b; Siqueira & Peterson, 2003; Peterson et al., 2004), montane systems appear to be relatively robust to spatial (i.e., horizontal) effects of climate change on species; flatlands systems, in contrast, appear considerably more vulnerable. That is, range retractions appear to concentrate in flatlands areas, where relatively small changes in conditions can translate into appreciable spatial shifts. Jetz et al. (2007) provided future distributional scenarios for many of the same species as are examined herein; however, their methods (ranges summarized as extent of occurrence maps, coarse resolution) at best serve to give a general picture of overall tendencies, but do not suffice as genuine forecasts for individual species.

Of the nuthatch species included in this study, four (*S. solangiae*, *S. yunnanensis*, *S. formosa*, *S. magna)* have wide ranges, but are considered threatened by habitat loss and degradation; two (*S. formosa* and *S. magna*) listed as Vulnerable in the IUCN Red List Category, have small, declining, and severely fragmented ranges; and two (*S. solangiae* and *S. yunnanensis*), listed as Near Threatened in the IUCN Red List Category, are impacted by ongoing habitat loss and degradation (Matthysen, 1998; BirdLife International, 2008). Our results show that climate change effects will exacerbate the effects of habitat loss and degradation especially in the flatlands. However, climate change will have relatively less impact on the montane areas of nuthatch distribution, at least in horizontal dimensions.

Middle elevation forests hold the highest nuthatch species diversity (Menon et al., 2008). Unfortunately, montane areas generally, and middle elevation forests especially, are not immune to pressures from deforestation and fragmentation leading to habitat loss and isolation of populations, and exacerbating any climate change effects (Brooks et al. 1999, Pandit et al. 2007). In light of the vulnerability of flatlands to climate change effects, our study further emphasizes the importance of middle elevation habitats in this region for the conservation of this group.

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