USE OF LATITUDE-ADJUSTED ELEVATION IN BROAD-SCALE SPECIES DISTRIBUTION MODELS

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ABSTRACT

Using readily available spatial data and GIS, we developed a method to adjust elevation by latitude using an estimate of the elevation of alpine treeline across a latitudinal gradient. Latitude-adjusted elevation accounted for the influence of latitude on relationship between elevation and annual monthly maximum temperature, which demonstrates the ability of this method to apply elevation as a model predictor variable across latitudinal ranges. Elevation is particularly useful for predicting coarse-grained distribution patterns of many species because elevation integrates influences of climate, physiognomy, and vegetative cover into a single measurement. However, problems arise with use of elevation as a predictor across wide latitudinal gradients because climate and biotic distributions tend to respond to increases in elevation and latitude similarly. Latitude-adjusted elevation can be used to extrapolate species-distribution models beyond the latitudinal extent of data availability. Using this method we extrapolated a model predicting wolverine (*Gulo gulo*) habitat across a large region.

Key Words: alpine treeline, elevation, GIS, *Gulo gulo*, latitude, life zones, regional modeling, timberline, wolverine

INTRODUCTION

It has long been recognized that elevational and latitudinal gradients strongly influence distribution of biota at local, regional, and global scales. Merriam (1895) developed the concept of "life zones" and observed that changes in species associations with increasing elevations was the equivalent of moving to areas of increasing latitude. Since then, the interrelationship between elevation, latitude, habitats, and species distributions has become integral to the field of biogeography. The influence of latitude and elevation on species distributions is so fundamental that the life zone concepts developed by Merriam (1898) and later redefined by Holdridge (1947) are still used to map species occurrences. In some cases the relationship between species distributions and elevation-latitude relationships is extreme. For example, Lambert et al. (2005) found that the lower-elevation limit of Bicknell's sparrow distribution decreased by 81.63 m for every 1° increase in latitude. This relationship is nearly identical to the elevation-latitude relationship for treeline (-83 m/1° latitude) reported by Cogbill and White (1991) for the northern Appalachian Mountains. Therefore, models that attempt to predict distribution of elevation-dependent species over a range of latitudes must account for elevation-latitude interactions to determine suitable habitat. However, obtaining species occurrence data across the full extent of desired model application is not always practical or possible. Therefore, combined influences of elevation and latitude cannot be directly modeled. In these cases, latitude-adjusted elevation as a model input parameter should improve model performance over simple elevation.

Within appropriate areas, alpine treeline provides a convenient baseline for

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adjusting elevation due to latitude. Several estimates of elevation-latitude and alpine treeline relationships have been reported in the literature (Hermes 1955, Li and Chou 1984, Peet 1988, Cogbill and White 1991). However, treeline is predominantly controlled globally by growing season temperature (Jobbagy and Jackson 2000) and locally by topography (Cogbill and White 1991). Therefore, elevation of treeline can vary according to regional and local climate as well as fine-scale patterns of topography. Not surprisingly, previously reported estimates between elevation-latitude relationships and alpine treeline vary with location. Additionally, the relationship tends to be curvilinear over broad ranges of latitude with a shallower slope at lower latitudes (Peet 1988). The utility of using previously published estimates of elevation-latitude relationships to derive latitude-adjusted elevation parameters for model input relies on ability to find an estimate that matches the location and extent of the area being modeled. To address this problem, we developed a GIS-based method using readily available landcover data to estimate the elevation-latitude relationship of treeline and develop a latitude-adjusted elevation layer for input into spatially explicit models. In our case, the intended use was to predict wolverine habitat (*Gulo gulo*), a wide-ranging species typically found in boreal, taiga, and tundra ecotones, but with historic distribution including a peninsular extension south into the Rocky Mountains of the contiguous U.S. Wolverines are difficult and expensive to capture and locate, which places severe limitations on the extent of data available for developing habitat models. In addition, wolverines have been extirpated from much of their historic range in the Rocky Mountains within the U.S. Therefore, species occurrence data suitable for modeling habitat preferences in our study were only available from a 2° band of latitude (43 - 45° N) making it impossible to test the influence of latitude on habitat preference using regression analysis methods. Latitude-adjusted elevation solved this problem by allowing us to estimate the relationship between wolverine habitat preference and elevation across latitudinal gradients beyond the spatial extent of our location data.

METHODS

We developed a raster grid of latitude-adjusted elevation over a five-state region within the United States: Colorado, Idaho, Montana, Utah, and Wyoming (~ 49° N, -118° E to 37° N, -101°E). We conducted GIS analysis using ArcGIS 9.1 (ESRI, Inc., Redlands, CA), the National Landcover Dataset (NLCD) (Homer et al. 2001), and a Digital Elevation Model (DEM) from the National Elevation Dataset (NED) to estimate the elevation of treeline for each 1° band of latitude across the study extent (n = 13, 1° intervals). Both datasets were retained at their original 30-m resolution. We selected 50,000 forested pixels (either conifer or deciduous) at random and assigned each pixel with its corresponding elevation value from the DEM and the midpoint latitude value for the corresponding 1° latitude band (e.g. 44°-45° band = 44.5°). Midpoint latitudes provided an average approximation of the exact latitudes of samples used to estimate treeline within each 1° latitude interval. We estimated treeline elevation for each 1° latitude interval by calculating the maximum elevation that contained 95 percent of the sampled forested cells within the latitude band. That is, 95 percent of all forested cells occurred at or below our estimated treeline elevation for each 1° latitude interval. The smallest sample size for any of n latitude intervals was $n = 875$ with only three intervals containing < 4000 sample points. This resulted in a single estimate for treeline elevation in each of the 13 1° latitude intervals.

We calculated adjusted elevation using the following equation: Latitude-adjusted Elevation = $E - (\hat{Y} - T_{std})$, where E = Actual Elevation, $\hat{Y}$ = Predicted Treeline elevation at the latitude of E, and Tstd = Predicted Treeline elevation at 44.5 N Latitude. We chose 44.5 N Latitude as our standard treeline because it occurred at mid-latitude of our wolverine habitat model validation area. Thus, we adjusted elevation upward for locations north of the standard and adjusted downward for locations south of the standard.

We tested whether latitude-adjusted elevation can account for the influence of latitude in regional models using mean annual temperature within the Greater Yellowstone wolverine study area (45° N, -112° E to 43° N, -110° E) and within the elevation band (2743-3048 m) preferred as habitat by wolverine (Inman, unpublished data). The annual mean maximum temperature (AMMT) derived from the PRISM model within the GYA study area was 7.5° C. PRISM (Parameter-elevation Regressions on Independent Slopes Model) data are spatial datasets gridded from point climate data using a knowledge-based approach developed by Christopher Daly, Director, Spatial Climate Analysis Service, Oregon State University, Corvallis (Daly et al. 2001) (http://www.ocs.oregonstate.edu/prism). Temperature grids are available at 4-km resolution. We extracted all points with a AMMT of 7-8° C ($n = 2044$) and regressed latitude on elevation and then latitude on latitude-adjusted elevation using SAS (Cary, NC) statistical software. If latitude-adjusted elevation accounted for influence of latitude on AMMT, then the slope and correlation coefficient of the latitude on latitude-adjusted regression should approach zero and the predicted latitude-adjusted elevation of 7-8° AMMT would be the same at all latitudes.

RESULTS

We observed a strong relationship between latitude and the estimated elevation where treeline occurs. A polynomial curve produced the best fit.

Treeline elevation (m) = (-10.727 * Latitude^2) + (792.47 * Latitude) - 11280
($n = 13$, $R^2 = 0.97$)

But a simple linear regression also provided a good fit:

Treeline elevation (m) = (-130.08 * Latitude) + 8427.5
($n = 13$, $R^2 = 0.91$)

We eliminated the effect of latitude vs. the elevation of AMMT by using latitude-adjusted elevation in place of elevation. Latitude is a reasonably good predictor of the elevation where AMMT = 7.5 ± 0.5 °C (Fig. 1):

AMMT Elevation (m) = (-155.93 * Latitude) + 9432.8
($n = 2043$, $R^2 = 0.73$)

Latitude was not a good predictor of the latitude-adjusted elevation where AMMT = 7.5° ± 0.5 °C occurred (Fig. 2):

AMMT Latitude-adjusted Elevation (m) = -22.963 * Latitude) + 3595.7
($n = 2043$, $R^2 = 0.05$)

Latitude-adjusted elevation reduced both the slope and correlation coefficient of the relationship. The predicted elevation, where AMMT = 7.5 ± 0.5 °C, was 2728 m ± 857 m, but the range of predicted latitude-adjusted elevation, where AMMT = 7.5 ± 0.5 °C occurs, was much smaller (2608 m ± 149 m).

DISCUSSION

The life zone concept (Merriam 1895, Holdridge 1947) is important to consider when attempting to model species distributions and habitat across regional scales. This consideration becomes particularly important when modeling across mountainous terrain where the variable of concern may be associated with ≥1 elevational life zones. In such cases, elevation may be a useful predictor but the elevation-latitude relationship must be accounted for if the user intends to apply the model over a wide range of latitudes.

Using alpine treeline as a baseline for adjusting elevation provides an efficient method to predict elevational shifts across a latitude gradient for application in coarse-grained regional models. However, one must realize that treeline provides only a coarse approximation of the elevation-latitude relationships of other ecotones. For example, Cogbill and White (1991) reported that the upper and lower bounds of the spruce-fir (*Picea-Abies*) ecotone in the Appalachian Mountains resulted in a narrower zone at southern latitudes. However, they cautioned that both regional and local variation of the actual ecotone is large and within the magnitude of predicted convergence. Therefore, we recommend that methods described here be used with caution if applied to models intended to predict fine-grained patterns of species distributions or potential habitat. Likewise, our method for deriving latitude-adjusted elevation would likely prove unsatisfactory for modeling distributions of species strongly associated with a narrow range of habitat types unless it incorporates other regional and local predictors of habitat distribution.

Latitude-adjusted elevation did not completely eliminate the relationship between latitude and temperature. Although latitude-adjusted elevation greatly reduced the slope of the relationship (Figs. 1 and 2), the slope was still significantly different from zero ($\alpha = 0.05$). Errors in the GIS input data, such as misclassification of landcover types, generate noise but do not explain the residual negative relationship of the results. However, this residual relationship was not unexpected since annual temperatures are determined by factors other than elevation and latitude, such as regional weather patterns or prevailing aspects.

Our technique provides a useful method for using latitude-adjusted elevation for modeling wildlife habitat and other variables over large extents. This method relies only on readily available digital landcover and elevation data that eliminates a need for extensive collection of field data to measure the elevation-latitude relationship of a parameter. Using these methods, one may

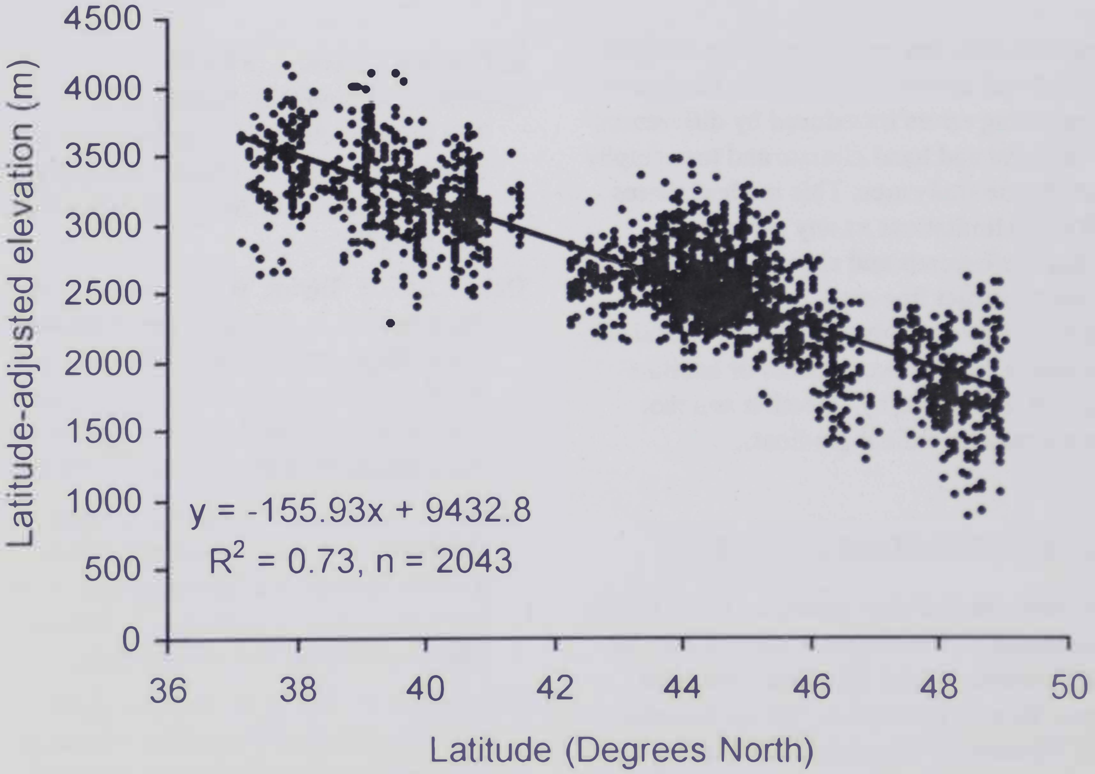

Fig. 1. Latitude vs. Elevation of Equal AMMT (7.5 ± 0.5°C). Linear regression between latitude and elevation of points with equal annual mean maximum temperatures across a five-state region.

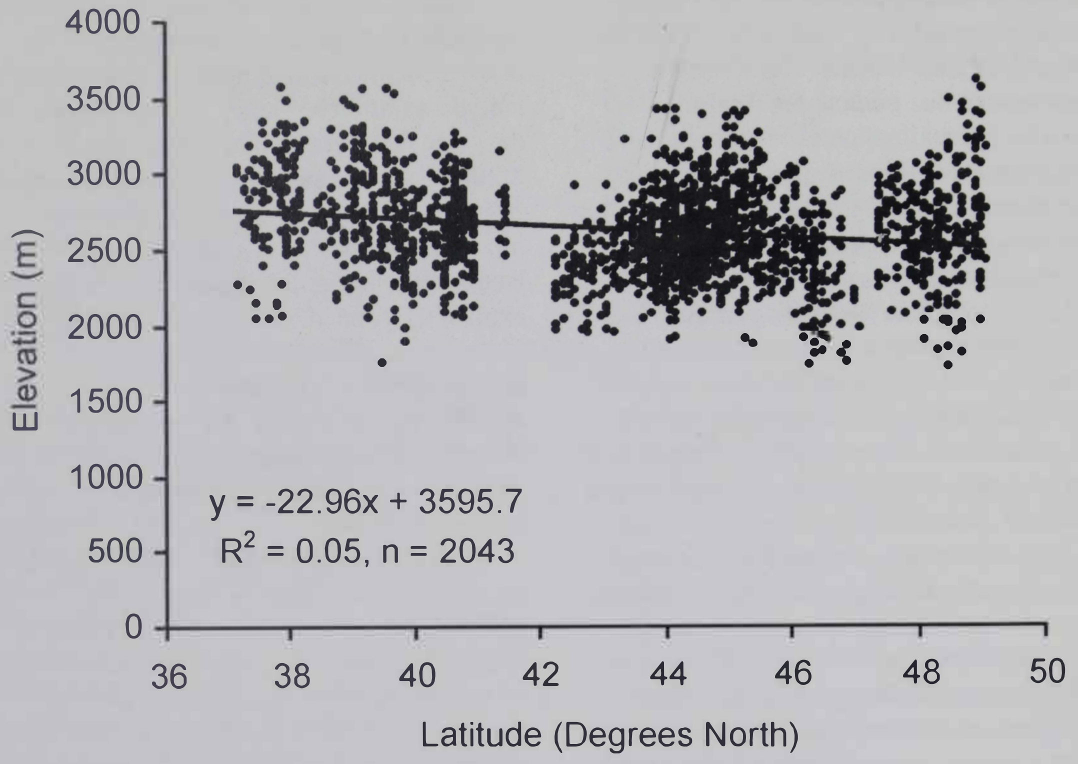

Fig. 2. Latitude vs. Latitude-Adjusted Elevation of Equal AMMT (7.5 ± 0.5 °C). Linear regression between latitude and latitude adjusted elevation of points with equal annual mean maximum temperatures across a five-state region.

improve accuracy by confining the analysis to the focal extent of a particular study and eliminating errors introduced by differences in regional and local climate and topography outside the study area. This method shares the same limitations as any estimator of broad-scale trends and should not be relied upon to predict fine-scale patterns. Given these limitations, this technique is useful for modeling species occurrences or habitats that are influenced by elevation and that span broad latitudinal gradients.

ACKNOWLEDGEMENTS

We thank the Bullitt Foundation, Laura Moore Cunningham Foundation, Richard King Mellon Foundation, M.J. Murdock Charitable Trust, Tapeats Foundation, Turner Foundation, and Wilburforce Foundation for funding. We also thank Jeff Burrell and Tom Olenicki for critical comments on the manuscript.

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Received 25 March 2006
Accepted 8 July 2006