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ADEQUACY OF WILDLIFE HABITAT RELATION MODELS FOR ESTIMATING SPATIAL DISTRIBUTIONS OF TERRESTRIAL VERTEBRATES

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Abstract: In Gap Analysis potential distributions of terrestrial vertebrate species are based on the synthesis of wildlife habitat relation data and then modelled using a vegetation cover map derived from Landsat Thematic Mapper (TM) imagery. Using long-term species lists from eight National Parks in Utah, we evaluated the adequacy of the Gap Analysis-generated wildlife habitat relations (WHR) data in predicting species distributions at landscape scales. Omission and commission error rates were estimated for major taxonomic groups and for each National Park. Depending on the taxonomic group, omission error ranged from 0% to 25% while commission error ranged from 4% to 33%. Error rates were highest in amphibians and reptiles and lowest for birds and mammals. In general, error rate declined as the size of the park increased. The Utah WHR models performed well when used to predict presence or absence of

terrestrial vertebrates in eight national parks in Utah and should provide valuable information for making conservation decisions in Utah. They also provide a measure of support of the use of WHR models within the Gap Analysis framework. Although likely that accuracy of WHR models will vary from state to state, and even considerably within a state, the WHR modelling process seems robust enough to provide a reasonably high level of accuracy for use in conservation planning at ecoregion levels

Introduction

Biologists have long used knowledge of animal life history attributes to model animal ecology. A common approach is to model animal habitat by linking known habitat use patterns with maps of existing vegetation, thereby identifying the spatial extent of important habitat features for use in conservation and management (see Verner et al. 1986). These kinds of models transcend a variety of different scales and purposes, ranging from species-specific Habitat Suitability Index models (Schamberger et al. 1982) to multiple-species wildlife-habitat matrices (e.g., Verner & Boss 1980) to spatially explicit descriptions of animal distributions for conservation planning (Scott et al. 1987). Kinds and uses of different modelling approaches are outlined in texts by Verner et al. (1986) and Morrison et al. (1992), and should be examined for additional information on habitat modelling.

As conservation efforts begin placing greater emphasis on landscape scales, there is need to make better use of site- and species-specific habitat relation models in predicting broad-scale spatial distributions of animal species. Much of this need revolves around the often conflicting uses of resources on public and private lands, and desires to ensure the continued maintenance of biological diversity. Calls for the maintenance of biological diversity are an explicit recognition that biological loss occurs at a variety of different levels, ranging from genes to species to biomes. Efforts to maintain this diversity must be applied to all these levels, not just endangered species (Noss 1991; Scott et al. 1991). One approach for assessing the current status of biological diversity at all levels, not just endangered species, is called Gap Analysis. It provides a systematic approach for evaluating the protection afforded biological diversity in given areas. It uses geographic information systems (GIS) to identify "gaps" in biological diversity protection that may be filled by the establishment of new preserves or changes in land use practices (Scott et al. 1993, Edwards et al. 1993, Edward & Scott 1994).

Gap Analysis consists of three primary layers in a GIS: (1) the distribution of actual vegetation cover- and land-use types as delineated from satellite imagery; (2) land ownership and management status; and (3) distributions of terrestrial vertebrates as predicted from the distribution of vegetation and known observations. Within the GIS, overlays of animal distribution and land ownership can be used to estimate the relative extent of protection afforded vertebrate animals. A crucial assumption of Gap Analysis is that mapped vegetation accurately describes the spatial distribution of terrestrial vertebrates. Historically, approaches to mapping species distributions included (1) dot distribution maps; (2) grid-based maps; (3) hybrid dot distribution and range maps; and (4) range maps (Scott et al. 1993). These methods rely only on the location of specimens, and typically include no information on the ecological conditions,

such as vegetation, that favor presence of the species. Using vegetation as a surrogate to model presence of animals has limitations (see Verner et al. 1986:Part III, VanHorne & Wiens 1991, Morrison et al. 1992: chapt. 6), but does provide enhancement over the traditional approaches to mapping described above. Because the process does not rely only on known locality records, unsampled areas can be included in predictive models. Coupling known locations with those predicted from vegetation can lead to refined maps of species distribution which can then be used for bioregional conservation planning. Given sufficient samples, the distributions can be mapped as a series of probability or density isoclines (e.g., kriging, see Kemp et al. 1989, Schotzko & O'Keefe 1989).

Here we examine the Gap Analysis assumption that mapped vegetation, when linked with wildlife-habitat relation (WHR) models, accurately describes the spatial distribution of terrestrial vertebrates. To assess the potential shortcomings of using vegetation as a surrogate for animal distributions, we compared separately derived species lists from eight national parks in Utah to the predictions generated from Utah Gap Analysis. Data from the parks were not used during development of the WHR models for Utah Gap Analysis. Omission and commission error rates were calculated for four major taxonomic groups, amphibians, birds, mammals and reptiles. Error rates were further explored to determine whether the pattern of error was associated with different animal life history attributes. Error was also compared to park size to determine if it varied as a function of park area.

Methods

Data on life history attributes and distributional information for every terrestrial vertebrate in Utah were obtained from a variety of sources, including published and unpublished literature, museum and Federal and State agency records on distributions, and from individuals having expert knowledge on a particular species (Foster 1988, Foster & Shrupp 1991). Information was collected on a total of 524 species, including 313 birds, 130 mammals, 66 reptiles, and 15 amphibians. Not surprisingly, the exact number of species by taxonomic group varied among different agencies having management responsibilities in Utah. Given that Gap Analysis is a state-based information system, we selected the species list accepted by the State of Utah Division of Wildlife Resources (UT DWR, 1596 W. North Temple, Salt Lake City, UT 84116-3154). This does not imply that life history and distributional information was not collected on species not included in the UT DWR list. To the contrary, information was collected on all species, including non-breeding migrant birds, unverified or occasional species, and those few species extirpated from Utah but still found in the Intermountain West (e.g., gray wolf *Canis lupus*). However, for purposes of Gap Analysis, and the analyses presented here, only that list recognized by the UT DWR was used.

To the extent possible, the information collected on species-specific habitat relations was as detailed as possible. Given uncertainties about the number and types of cover-types to be derived from the vegetation mapping, we elected to associate species with recognized cover-types during data base creation. These cover-types included forest types recognized by the Society of American Foresters (SAF) (Eyre 1980), potential natural vegetation classes (Kuchler 1964), and land use classes defined by the UT DWR. Additional data collected included species

gross distribution by latitude-longitude block (birds, Walters 1983; amphibians and reptiles, Schwin & Minden 1979) or county (mammals, from Durrant 1952), an ecoregion designation (after Bailey 1995) containing information on slope and elevation, National Wetlands Inventory class (Cowardin et al. 1979) where appropriate, a structural stage for each cover-type used by the species, and season of use. Animal-habitat associations were noted for all habitat types, even if the type was clearly outside of Utah and the surrounding Intermountain West. Once the WHR models were completed, wildlife-habitat associations were cross-walked into the mapped cover-types. See Homer et al. (in press), Ramsey et al. (1993), Ramsey et al. (1992), and Edwards et al. (1995) for details on vegetation cover-type mapping and validation.

Animal distributions were predicted by intersecting gross distribution, elevation, and cover-type associations from the species-specific WHR models. One problem with use of species habitat associations is the over-prediction of the total area potentially occupied by the animal. For example, numerous amphibians had references indicating association with a broadly defined cover type (e.g., blackbrush *Coleogyne ramosissima*), even though it is clear such species were principally associated with water bodies found within blackbrush. Similar problems exist with bats and other cave-dwelling species whose specific habitat essentially a point location within a broadly defined cover-type.

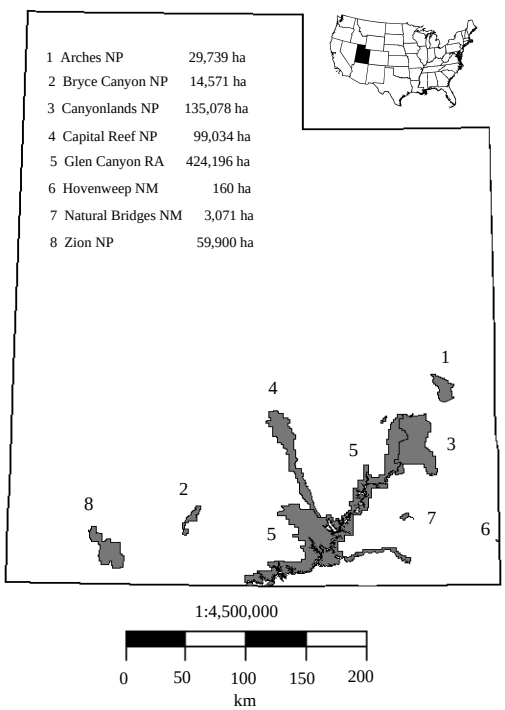

Figure 1. Spatial location and szie (ha) of 8 park study sites in Utah.

Data from eight National Parks in Utah were not included in the development of the WHR models and were reserved to assess the adequacy of the WHR models in predicting presence of species (Figure 1). A list of Gap-predicted species for each park was created by intersecting cover-type polygons and animal species distributions based on the WHR models within each park boundary. This list was compared to a park-generated matrix of species observed in each park. Data included in the park species lists were obtained from a variety of sources. These data were compiled using information contained within the park resources, such as wildlife observation cards and faunal collections, if present. We included park-specific unpublished reports and checklists and some published documents (e.g., Rado 1975; Atwood et. al. 1980). The park species lists were reviewed by researchers who were familiar with the fauna in each of the national parks prior to our use.

Omission and commission error rates were used as indicators of the strength of the Utah Gap Analysis WHR models. Errors of omission were defined as the percent of species not included on the Gap-predicted list, but present on the corresponding park-generated list. Conversely, an error of commission measured the percent of species

incorrectly included on the Gap-predicted list. Accuracy was defined as the percent of species predicted from the Gap Analysis models and found in the corresponding park-generated list. Omission and commission error rates were further plotted against park size to determine if error varied as a function of park size. Because information on use of each cover-type by each animal species within each park was limited, we were unable to evaluate specific cover-type use by species. Instead, only presence or absence of species was assessed.

Results

A total of 481 of the 566 (84.9%) state-recognized species were predicted to occur in the eight national parks, representing 15 of 15 amphibians (100%), 315 of 353 birds (89.2%), 110 of 131 mammals (83.9%) and 41 of 67 reptiles (61.2%) in the state. Numbers of species found in the eight parks were 10 amphibians (66.7% of the state list), 282 birds (60.0%), 98 mammals (74.8%), and 46 reptiles (68.6%).

Mean commission and omission error for four major taxonomic groups (amphibians, birds, mammals, reptiles) in eight national parks in Utah are shown in Table 1. Within parks, omission error ranged from 0% to 25% for amphibians, 0.7% to 6.4% for birds, 4.1% to 7.8% for mammals, and 7.2% to 18.8% for reptiles. Omission was lowest for birds and greatest for reptiles. Commission was similarly lowest in birds, but was greatest in amphibians rather than reptiles (Table 1). Accuracy ranged from a high of 90.6% for birds to a low of 69.4% for amphibians.

Table 1. Mean and standard deviation (SD) omission and commission error and accuracy of Gap Analysis-predicted WHR models by taxonomic group for eight national parks in Utah.

	Omission (%)		Commission (%)		Accuracy (%)	
Group	Mean	SD	Mean	SD	Mean	SD
Amphibians	16.07	8.45	14.51	6.23	69.42	5.41
Birds	1.86	1.33	7.51	4.04	90.63	5.18
Mammals	4.92	1.04	11.50	1.51	83.58	1.07
Reptiles	9.99	1.94	11.57	4.50	78.44	4.59

Omission and commission error varied considerably among parks and by taxonomic group (Figure 2). Overall, commission was greater than omission across all parks and taxonomic groups, with the exception of amphibians and reptiles in Glen Canyon National Park (Figure 2). Within taxonomic group, error rates tended to decrease from amphibians to reptiles to mammals to birds. Overall accuracy by taxonomic group ranged from 60.0% to 85.7% for amphibians, 81.1% to 95.3% for birds, 78.2% to 84.8% for mammals, and 69.9% to 83.2% for reptiles (Table 2).

In general, omission and commission error decreased as park area increased (Figure 3). Amphibian error was highest; however, much of this scatter can be attributed to few amphibians per park (maximum of 11) and the resulting influence of single observations on the error rates. Park by park examination of error revealed no pattern based on guilds or other life history attributes.

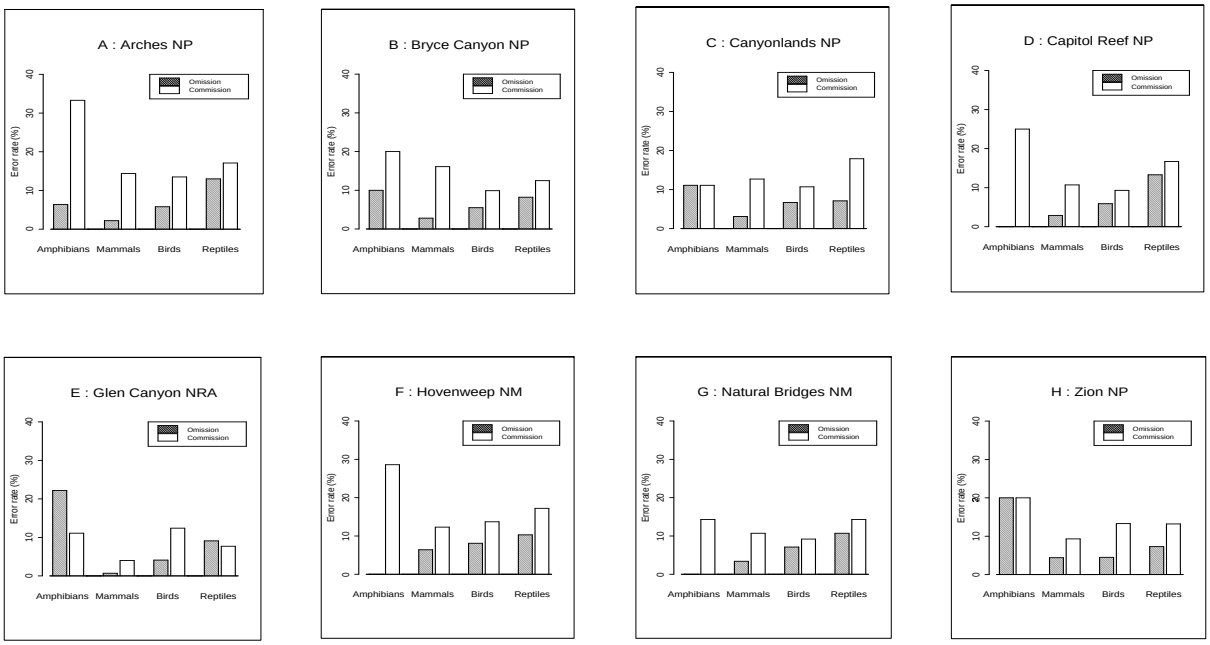

Figure 2. Omission and commission error by national park and taxonomic group (A=amphibians, B=birds, M=mammals, R=reptiles).

Table 2. Number of commission errors (N_C), omission errors (No). matches (Na), and accuracy* for four taxonomic groups in eight national parks in Utah. Results are based a comparison of Gap Analysis-predicted and park-observed species lists.

	Amphibians				Birds				Mammals				Reptiles			
Park	N_c	N_o	N_a	accuracy*	N_c	N_o	N_a	accuracy*	N_c	N_o	N_a	accuracy*	N_c	N_o	N_a	accuracy*
Arches	2	0	4	66.7	25	4	145	83.3	7	3	42	80.8	4	3	16	69.6
Bryce Canyon	1	1	6	75.0	36	6	181	81.3	9	5	77	84.6	3	2	19	79.2
Canyonlands	1	1	7	77.8	28	7	185	84.1	7	5	63	84.0	5	2	21	75.0
Capitol Reef	2	0	6	75.0	25	7	202	86.3	8	5	73	84.9	5	4	21	70.0
Glen Canyon	1	2	6	66.7	11	2	259	95.3	12	4	81	83.5	3	4	32	82.1
Hovenweep	2	0	5	71.4	19	10	126	81.4	7	4	40	78.5	5	3	21	72.5
Natural Bridge	1	0	6	85.7	19	6	152	85.8	6	5	54	83.1	4	3	21	75.0
Zion	2	2	6	60.0	27	13	249	86.2	12	4	74	82.3	5	3	30	78.9

*% accuracy = $[N_a/(N_c+N_o+N_a)]*100$.

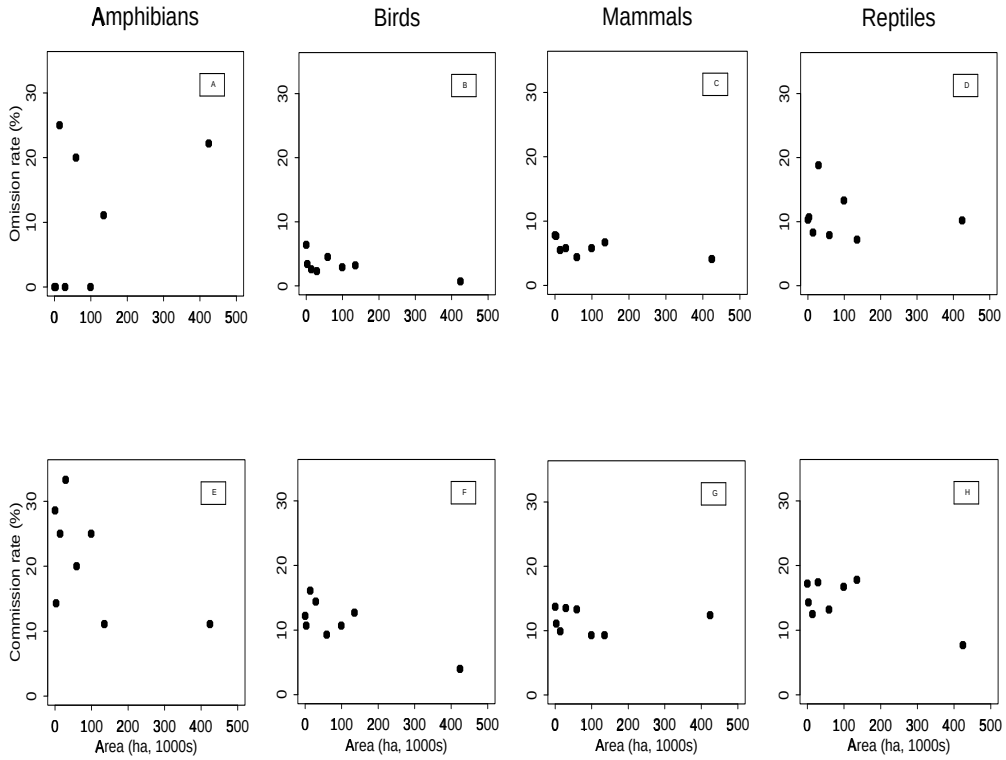

Figure 3. Omission and commission error by taxonomic groups and park size (ha).

Discussion

The Gap Analysis process relies on WHR models to link animals to mapped vegetation, and then to use vegetation as a surrogate for predicting potential spatial distributions of terrestrial vertebrates (Scott et al. 1993). Once distributions are mapped, the information can be used as a course filter for siting of reserves or for other management purposes. Accordingly, an estimate of the uncertainty associated with use of WHR models is critical to use of Gap Analysis information in reserve siting or other management issues (Kareiva 1993).

Our analyses indicate that linkage of WHR models to mapped cover-types and the subsequent prediction of vertebrate spatial distributions is fairly reliable in eight national parks in Utah. Accuracy ranged from a high of 91% for birds to a low of 69% for amphibians. Error rates for amphibians and reptiles were greater than birds and mammals, not an unexpected result given the difficulties associated with inventorying the former two taxonomic groups relative to the latter two groups (see Heyer et al. 1994), as well as an historical emphasis on birds and mammals. Further, data from the parks, while carefully screened by park biologists, was not specifically collected to answer the questions we posed. The lack of design directly linked to our question undoubtedly resulted in undersampling for some rare and localized species, thereby contributing to our overall error rate.

In general, commission error was greater than omission error. This indicates that our models tend to over-predict rather than under-predict the presence of animal species. Given that Gap Analysis is a tool for predicting geographic distributions of terrestrial vertebrates for use in conservation planning, we argue that commission is preferred over omission. As a measure of uncertainty, commission could arise from many factors, including difficulties in detection among species (e.g., Mayfield 1981), bias associated with observers and sampling technique (e.g., Bart & Schoultz 1984), problems with rare species, and incomplete species lists from each of the parks we analyzed. Although many of these problems can be overcome by establishment of rigorous inventory designs, it is virtually impossible to retroactively apply a rigorous design to data collected from numerous sources over extensive time periods. From the perspective of conservation planning, commission error can be considered risk-aversive. It is better to over-predict rather than under-predict. Omission, in contrast, represents species whose WHR models are inadequate in their predictive ability, and high omission leads to the potential exclusion of species from conservation plans.

Several factors complicate the use of vegetation to predict species presence and absence (Scott et al. 1993). Birds, for example, respond more to vegetation structure than to floristic composition (e.g., Cody 1985). Because Gap Analysis vegetation mapping in Utah relies principally on floristic composition rather than structure, bird distribution maps may contain error. Gap Analysis assumes that within floristically defined vegetation classes the structural characteristics necessary to the bird do occur.

A second complicating issue is differences in habitat breadth. Some species, like coyotes (*Canis latrans*), are generalists in their habitat. Others are restricted to a single habitat type. If an animal is associated with a single type, and that type can be mapped, Gap Analysis provides an excellent predictor of range. If the type cannot be mapped because it is below the resolution of the cover-map, is difficult to discriminate from remote sensing techniques, or is contained in another class, predicted range can be far from actual. Moreover, our ability to map habitat classes often exceeds the natural history information available for a species. For example, Holland (1986) recognizes 375 plant communities in California. Many of the vegetation units differ only in the ratio of dominant to associated plant species. Although of interest to plant community ecologists, these differences may or may not be of importance to animals.

Although the number of plant communities can be high, natural history data linking animals to specific communities is sparse for most species. This requires that mapped habitats be grouped into categories that correspond to the known information about a species. For example, the best information on a bird species may be that it is associated with coniferous forests. Given that at least 7 mapped classes in Utah contain conifers, the potential distribution for that species is exceedingly general.

With the exception of amphibians, error rates presented here tended to decline as park area increased. There are several possible reasons for this observation. First, larger parks generally have better inventories of their flora and fauna than smaller parks (Stohlgren and Quinn 1992). Hence the species lists we used to test our Gap-predicted models might be more complete in the

larger parks we evaluated, leading to lower error rates. Specifically, more complete species list in larger parks would reduce commission error, a generalization supported by our data (Figure 3). In addition, as area increases the likelihood of "capturing" more rare habitat types increases and effects of habitat mapping error are likely to diminish. From the perspective of Gap Analysis, which is targeted at ecoregional levels, this tendency for error to decline as area increases suggest that species modelling approach used in Gap Analysis is sufficient when applied to large areas. Extrapolation to local scales, however, is problematic and should be viewed with caution.

Although our analyses indicate that the WHR models were sufficient for predicting species presence in eight national parks in Utah, several problems still exist in evaluating the strength of Utah Gap Analysis WHR models. First, no data exist to statistically evaluate specific habitat associations for individual animal species. Our results are restricted to presence or absence within geographic regions only and draw no conclusions about habitat use. Second, our data sets were restricted to the Colorado Plateau region of Utah. No systematically collected and reviewed data exist to test predicted animal distributions in the Wasatch-Uinta or Basin and Range ecoregions. Thus, the predicted distributions of species not found in the other two ecoregions were not evaluated. Last, the combined effect of spatial error in the vegetation map, error in the WHR models, and error from potentially incomplete species lists in the parks is unknown. How error propagates when dealing with numerous information layers in a GIS remains a fruitful area of research for which little is known (see Veregin 1989; Goodchild & Gopal 1989).

A statistically reliable evaluation of specific habitat associations is currently beyond the scope of Utah Gap Analysis, and would require a long-term commitment of resources applied in a statistically rigorous design. Ideally, such efforts should be coordinated with existing federal, state and private agencies to increase the scope of coverage for an area, and reduce costs and error associated with incomplete inventories like those described by Stohlgren and Quinn (1992). Yet, even with the potential sources of error noted here, use of vegetation as a surrogate for modelling animal species distributions remains a powerful tool for the conservation and management of biological diversity. The Utah WHR models performed well when used to predict presence or absence of terrestrial vertebrates in eight national parks in Utah and should provide valuable information for making conservation decisions in Utah. They also provide a measure of support of the use of WHR models within the Gap Analysis framework. Although likely that accuracy of WHR models will vary from state to state, and even considerably within a state, the WHR modelling process seems robust enough to provide a reasonably high level of accuracy for use in conservation planning at ecoregion levels.

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