ANIMAL MODELING

Editor's note: The following submission by Raymond O'Connor resonated with many of us at the GAP program. It suggests there are ways to improve our modeling efforts, such as incorporating data on population fluctuations over time, and that consideration of such improvements may warrant redefining the GAP vision. After a few of our reviewers read the article, it began to inspire some spirited discussion about GAP's future products and purpose. To try to capture some of this discussion, the article by O'Connor is followed by an article by Svancara and others, who elaborate on some potential future considerations for the GAP program. Dr. O'Connor has graciously agreed to give Svancara and others the last word, even though it was not anticipated when he made his submission. He noted that he did not always agree with how some of the specifics of his article had been interpreted. However, he was satisfied with letting both articles stand as written, because they work well together to raise some important issues for the future of the GAP program. We are very appreciative of this constructive attitude and want to thank him and all the contributors involved in this volume.

GAP Conservation and Science Goals: Rethinking the Underlying Biology

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Any successful program develops a momentum of its own, a consensus among its community of participants about what should be done and what the next steps should be. The problem with success—and one that is evident within the GAP community—is that this agreement often concerns tactics, the short-term actions needed to implement long-term goals originally enunciated and tacitly assumed to have remained unchanged. Glance through the programs for recent GAP meetings or look through recent issues of the *GAP Bulletin* and what you find is emphasis on details of assessing the accuracy of GAP models, incremental improvements on classification procedures, discussion of expert systems for inference of species presence, and, of course, reports of landmarks of progress in the GAP projects in individual states or regions. Yet the more successful the GAP community has been, the more pressing is the need to ask whether all these very worthy activities are still directed at the most useful strategy? We can grant the merits of the original goal of GAP; we can grant the merits of the current efforts to improve GAP incrementally; but we can, and should, nonetheless ask whether the accumulating GAP results indicate any need to redefine the larger GAP vision. Some lessons from the Industrial Revolution may be apt here. Early steam engines pressed for more power output had a habit of blowing up. They could always be made more powerful and safer by overengineering in the light of the available practical experience. But the most rapid advances came when engine performance was analyzed in the light of thermodynamic principles. No longer were engineers restricted to "cut and try" approaches: instead engines could be designed successfully for use in novel environments within which they had never before been deployed. So where, and how, might the GAP community be most innovative in deploying its collective skills and expertise?

GAP's basis is in mapping the distribution of *potential* habitat. If GAP scientists unequivocally demonstrate that Kirtland's warbler *(Dendroica kirtlandii)* is a denizen of young jack pine (*Pinus banksiana*) stands in the eastern United States, what exactly does a map of jack pine distribution across Michigan, for example, imply in conservation terms? The origin of GAP was in the notion that it meant a lot. If no stands of jack pine were in some form of protected status, then GAP asserts that one can validly infer that the conservation of Kirtland's warbler will be enhanced by acquiring protection for some blocks of this habitat. Whether the threshold for effective protection should be 10% or 50% or 90% is thereafter considered to be largely a research and conservation management question, to be solved by incremental research. Here I maintain that one can evaluate such threshold questions in unconventional ways that may be better than the incremental advance possible with conventional thinking. In particular I want to suggest that the GAP concept of species distributions is one of container habitats rather than one of habitat correlates. A container can hold the species but need not always do so, and the relevant strategic questions are therefore, first, how specific the specification of the container is to the species in mind, and second, under what conditions the species will actually be present in the container. In contrast, the habitat correlate concept of species distribution envisages an equilibrium world in which a species is always present in its habitat, and the problem is merely one of obtaining a yet better statistical model with which to describe that habitat. This can, in turn, be best done for a species in equilibrium and yields poor results otherwise. More important yet, though, is that this latter notion holds poorly in the growing appreciation of the role of limits and carrying capacities as constraints on species distribution (Huston 2002, O'Connor 2002).

A GAP assumption is that one can determine a species niche accurately, that one can correctly identify the habitat or environment characteristic of a particular species. GAP sees jack pine forest as a container within which Kirtland's warblers may occur and assumes that a tight one-to-one correspondence exists between the two: jack pine means Kirtland's warblers (assumption I) and Kirtland's warblers mean jack pine (assumption II). Reality quickly cuts in for the first assumption, and it is readily acknowledged that not all jack pine will necessarily hold Kirtland's warbler. There are two possible reasons for this. The first is that it may not really be jack pine that is the habitat but rather (say) jack pine in which tree density is above some critical density, and if we but knew that fact we could redefine the habitat to be appropriately high-density jack pine stands. This merely moves the logic on one step. But even if we had perfect knowledge of all such issues, the perfectly defined habitat may yet remain only locally occupied. Some sites may be unoccupied because a severe winter (or dispersal or migration stresses) killed the birds that would have occupied them, in which case waiting for the population to build up again and fill these stochastic gaps will resolve a temporary violation of the GAP assumption. But other sites may be unoccupied simply because the population is *limited* in the long term by factors other than habitat—perhaps the local use of pesticides, lack of winter habitat, and so on. In that case, there are not enough birds around to occupy all the available jack pine habitat (or whatever variant of it needs to be specified to describe optimal habitat), and the GAP assessment is in long-term error. For stock doves *(Columba oenas)* in Britain in the 1950s, for example, this was the case: thousands of square miles of arable farmland lay open to use, but organochlorine use there limited the population to less than replacement demographic rates (O'Connor and Mead 1984).

Now consider assumption II above, that Kirtland's warblers mean jack pine. For many species individuals make use of secondary habitat when densities are locally at high levels, and they contract back into the core habitat when the population shrinks (Fretwell and Lucas 1970, Lidicker 1962). For such species the niche is, so to speak, somewhat elastic. At low densities individuals are exclusively in a core, optimum habitat (habitat A; ignoring any influence of site fidelity from previous episodes of high density; O'Connor 1985). At high densities, on the other hand, some individuals are forced into a secondary habitat (habitat B) where breeding is also possible but with less success than in habitat A. (This sequence may extend to a third, fourth, etc., habitat in a hierarchy of breeding suitability.) When researchers determine what to treat as the habitat of this species, their conclusion will depend on the prevailing population level. It will be "habitat A or habitat B" if the information comes from a time of generally high densities, for both habitat types are in use in such conditions. But it will be "habitat A alone" if the information comes from a time of generally low densities. The latter is then merely an analogue of the stenotope example discussed above, but the former will lead us to consider, and possibly protect, areas of type B. But although such protection is designed to be most valuable should the species decline, habitat of type B is the very type of habitat that is *not* used when population levels are low! Thinking in terms of the principles of habitat occupancy in this way immediately transforms (or, at least, should transform) thinking among the GAP community about the nature of predictive modeling accuracy and about what the concepts of omission and commission error mean.

In the warbler-jack pine example, omission error (failing to predict the occurrence of a species that actually occurs on the site), could result (1) if the jack pine habitat is too narrow a specification of the habitat tolerance of the warbler (e.g., if it routinely uses other stand types than just jack pine) or (2) if it is subject to Fretwell-Lucas dynamics, and the test of accuracy was done at a time of high population while the model of its habitat use was developed at times of low population. I acknowledge that this could be seen as a special case of (1), but the conservation implications are so different they should be kept separate! (The error patterns arising from the other combinations of differential population levels between model development and time of testing are elaborated by Krohn [1996]). Commission error (predicting the presence of a species that does not occur on the site), on the other hand, could result (3) if the habitat container needed to be specified in greater detail than hitherto appreciated (e.g., to allow for a critical density of trees, as above), or (4) if a nonhabitat factor, e.g., the pesticide discussed for stock doves in Britain, was limiting. But commission error will also appear to occur (5) if the census was inadequate to detect birds actually present.

I will assert unequivocally that these principles mean that it is bad science to treat either commission or omission error within GAP methodology as though error were a unitary phenomenon. It is meaningless to report error as 20% or 50% or 80% without considering the different types of error possible. Moreover, it is at least poor science, and maybe should even rate as bad science, to make the unitary measurement for either type of error and then simply to discuss these different origins as possible factors influencing the result. If we know that these ecological processes are at work, surely they should be taken into account in the design of the error measurement. This need not mean gathering huge amounts of new data: simply thinking through the processes involved allowed Schaefer (2002), for example, to set upper and lower bounds on the possible error in GAP assessment for individual species, and these bounds turned out to be far closer to each other than one would naively have expected. In other cases it may indeed be true that to distinguish between some of the possibilities above requires sustained research, and that the documentation of a significant error rate has to be the first step towards establishing the influences of one or more of these factors. Yet I can safely assert that most treatments of GAP error present their results as though they are definitive determinations of error rather than as a delineation of the scope of underlying uncertainty in GAP conclusions. The error assessment process needs, I suggest, to be more conscious of the temporal dynamics of the species and perhaps needs to eschew the use of "found data" (extant data whose collection protocol was not expressly designed for this new use) in quantifying error. For a species that is essentially equilibrial in distribution, one would be justified in setting aside those of my concerns based in biological dynamics. However, between half and two-thirds of all bird species examined both in Britain (Greenwood and Baillie 1991) and in the United States (Boone 1991) have proved to have the density-dependence typically associated with Fretwell-Lucas dynamics, and the methodology used in both the studies cited are such that failure to detect density dependence in any species is more a "not proven" verdict than proof of density independence. Lidicker (1962) and Bowers (1994) provide analogous evidence for small mammals. Most species, therefore, need some thought about their dynamics to figure into the interpretation of error assessment. Even in the absence of empirical data for many taxa, one can conduct the thought experiment of calculating how sensitive one's conclusions would be to a (say) 25% decline in species abundance or to a 10% density-compensation; if one's results are not stable against such perturbation of population, they are perhaps too shaky to be offered as firm findings. Moreover, such findings may indicate that better science will result from repeating a previous survey to determine the extent of population stability in a habitat than from doing something new.

However, such issues also affect GAP's logic with respect to conservation action, for the nature of GAP protection depends on the scale of the spatial extent and dynamics of the species involved. The famous multimillion dollar land swap in Hawaii engineered by Michael Scott and his colleagues (Scott et al. 1987) reflects, I suspect, the effective deployment of GAP thinking in a Hawaiian context limited in space and population excursions. Within the conterminous United States, though, scale is more important. As GAP moves to recommend a 10% protection level, the internal logic on which GAP has historically been based should lead it to accept any 10% of the identified habitat, subject only to concerns for territory size vis-a-vis reserve size. (Though this discussion is in respect to a single species, similar thinking applies to multiple species protection, naturally constrained more by issues of complementarity.) Some species have a mosaic distribution, distributed as small population islands within the block of habitat. Others congregate into one large population within the block. Protecting any 10% of the mosaic distribution may well be as effective as protecting any other 10%, but protecting 10% of the "central occupancy" species is effective or ineffective to the extent that the protected area lies within the core of the species distribution. Yet to know where a proposed reserve lies relative to the distribution of the populations involved requires information that is not intrinsic to GAP projects! Evidence as to the scale on which species dynamics play out is only beginning to accrue, and then primarily for birds (Koenig 1998), but shows a range of dimensions as small as 40 km (rather few species) to several hundred kilometers (many species; O'Connor 1996). Because disjunct populations look like island ones when viewed over large extent, knowledge of scale will surely be helpful in advancing the utility of GAP analysis. But even if we have only crude information about the location of core range, taking the core effect into consideration will yield better conservation decisions than will ignoring the effect (Wilcove and Terborgh 1984).

Many of the same issues critically limit any idea that GAP data can be used as the basis for monitoring populations or communities over time. (If I appear to be flogging a straw man here, as far as most of the GAP community is concerned, it is because I have been present at a workshop in which a leading GAP scientist passionately and persistently argued for GAP to be considered as the basis for population monitoring.) GAP has little to say about monitoring a species that undergoes Fretwell-Lucas dynamics within its fundamental niche. The loss of habitat B above has no immediate conservation significance for a once abundant, but now declining, species that has retreated to habitat A, yet attempting to monitor from GAP data would infer there was such significance (namely, whenever habitat B happened to increase or decrease in ubiquity). It is true that recording losses of habitat A has long-term significance for the species—in the extreme, the habitat might be less abundant than needed to support the remnant population. But a species could decline dramatically in response to new stressors within a GAP-critical habitat that is otherwise unchanged in extent. The loss of stock dove populations from arable habitats in Britain as organochlorine use proliferated is one such example; the declines of osprey (*Pandion haiaetus*) and brown pelican (*Pelecanus occidentalis*) in the United States are others. Even where a tight one-to-one linkage between organism and habitat element has been established for GAP purposes, monitoring from GAP data is not possible: one has no certainty that the association of species occurrence and habitat has remained unchanged. In Britain the stock doves switched to breeding in coastal and island habitats, which they previously avoided for competition from rock doves (*Columba livia)*, thereby destroying the dove-arable correlation that would have underlain a GAP assessment of their status. Basically GAP as a monitoring tool fails to pass what I call "the organochlorines test": if I fly a helicopter across the area monitored, spraying 1960s-era organochlorines over the area, will the program subsequently detect the effects of this treatment on the bird populations present? A monitoring program that registers only the presence of the habitat in the area and assumes, in the absence of evidence, that the species-habitat link continues indefinitely, will fail to detect such habitat-independent losses. This is also Young and Hutto's (2002) explanation for the failure of many management initiatives based on premanagement correlation studies. Even viewed as a series of snapshots of the state of a species, GAP is ineffective as a monitoring tool unless the underlying species-habitat associations are determined afresh for each snapshot.

What might these issues imply for GAP in its pursuit of utility in conservation? The first message is that GAP's mapping of potential is closer to the fundamental notion of carrying capacity than are correlation-based analyses of habitat requirements (O'Connor 2002). The source of the issues above lie paradoxically in this strength. GAP is not a poor person's version of sophisticated habitat models, to be improved by the introduction of better correlation techniques. Instead improvement must come from efforts (1) to understand that the habitat association models behind GAP give different results at different population densities: a founder population may be in optimal habitat, but populations at saturated equilibrium may use far wider niches. For species with slow dynamics any given habitat association result is likely to have long-term validity. For species with fast dynamics the value of any association is likely to be ephemeral. And (2) GAP also needs awareness of the likely implications of a dynamic population fluctuating under a carrying capacity ceiling approximated in GAP by an effectively "habitat container" notion, quite independently of the temporal robustness with which that container was determined. The implications of these two points in relation to the current thrust towards determining the commission and omission rates associated with GAP models were discussed above.

A second message for GAP is the need to think more about the spatial patterning of the habitat containers. The issue of where to position possible protected areas is quite different where blocks of suitable habitat are distributed in mosaic fashion than where the habitat occurs as a single large, contiguous block. This difference essentially originates in the uncertainty as to the level of occupancy of the habitat. GAP in principle proceeds as if occupancy was certain, but in practice a variety of GAP-related studies have felt it necessary to try to correct for the error in this assumption, for example, by proposing the use of likelihood-of-occurrence ranks (Boone and Krohn 1999) or by developing species-specific error estimates (Schaefer 2002). What such methods are trying to do is to improve the specificity of the presumed association of the habitat with the species of interest. A more promising approach might be to incorporate the Dufrêne-Legendre (1997) index, devised to reflect the ecological indicator value of a habitat in respect to a particular species, into the characterization of that association. The Dufrêne-Legendre index for a given habitat and species is

$$I = 100(n/H)(n/S)$$

where n is the number of (the given) habitat units that contained the species, H is the number of (the given) habitat units examined, and S is the total number of units (of all habitats) that contained the species (see McCune et al. 2002 for additional explanation and implementation). Such data require that one samples representatively within the species range and within the habitat distribution, perhaps a promising avenue for future GAP investigation. The two fractions in parentheses correspond to assumptions I and II above, and with perfect specificity of association the index is 100. For partially filled habitat containers or for Fretwell-Lucas dynamics, one or the other of the two fractions is reduced, reflecting the lower specificity of the association. Such indices would normally fill a species-habitat matrix, but for GAP this collapses to one value per species and, when summed across the species entering any GAP map, provides a pathway to indexing the reliability of any conservation conclusion drawn.

Finally, let the above not be seen as the routine cry for ever greater elaboration of the research effort. I am well aware of the heroic efforts that have been needed, in the face of shoestring budgets, to make GAP such an effective component of applied science within the contemporary conservation map. Applied science is about crafting or engineering a solution to a science problem under the twin limitations of finite (very finite) resources and limited technical information. But the best engineering, as with the steam engines mentioned above, has always been achieved when fully informed by the principles of physics and chemistry. Moreover, contemporary conservation biology emphasizes principles as much as practice. It will not hurt, therefore, nor will it be an exercise in futility, to ask whether each current GAP activity is more craft than science. Nor to ask if each current task is still strategically important for conservation through GAP. Nor to ask if new and unanticipated questions may surface on thinking about how basic population dynamics permeate GAP. If nothing else, the effort will make for stimulating conversations about the goals, methods, and priorities of GAP.

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Comments Inspired by O'Connor

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Introduction

In reading O'Connor's thought-provoking essay, we found ourselves having two very different reactions. The first is that we agree with virtually all of his points about habitat modeling. He wrote an equally thought-provoking chapter for the book "Predicting Species Occurrences: Issues of Accuracy and Scale" (O'Connor 2002) that raised many of the same criticisms about the field of habitat modeling as a whole, and the arguments were just as compelling there as they are here. However, our second response stems from this point: if the issues he raises are systematic problems with the science of habitat modeling, what should the response of a product-oriented, applied project such as the Gap Analysis Program (GAP) be? We will argue in our comment that the answer to this question is twofold: GAP should continue to use the best available data and standard practices in meeting its primary mission but should simultaneously encourage research into the sort of basic issues that O'Connor raises in his essay. Our response reflects O'Connor's success in his stated purpose of stimulating discussion, because we have strayed substantially from a point-by-point response and offer additional thoughts of our own.

To begin, we feel it is necessary to review the original goals and objectives of GAP. Gap analysis is a coarse-filter approach to biodiversity protection (Scott et al. 1993). The process assumes that distributions of land cover and vertebrates correspond to overall biodiversity, and habitat can be used as an indirect indicator of animal species distribution. Scott et al.'s underlying belief was that we could prevent species from becoming endangered by maintaining biodiversity in natural landscapes. In other words, the mission of GAP was, and is, to provide the information necessary to keep common species common.

We recognize that publicly available data sets will be used in a variety of ways beyond their original intent, and we feel it is worthwhile to reiterate some of the limitations of gap analysis data originally identified by Scott et al. (1993). First, maps of vegetation only show habitat patches larger than the minimum mapping unit, and species responding to habitat at finer scales will likely be misrepresented. Second, GAP vegetation maps only portray the distribution of dominant, overstory cover types. Third, map boundaries are sharper than ecological boundaries. Fourth, because predicted vertebrate distribution maps do not reflect habitat quality, population density, or within-habitat distributions, they are best treated as hypotheses to be tested, refined, and retested. GAP models represent a simple (and perhaps often too simple) conceptual relationship between animals and their habitats, but one that can be applied broadly to a great many species, including ones about which little is known; information on problems of population viability, differences between source and sink habitats, interrelationships between species, and disturbance regimes must come from other sources. Therefore, GAP represents only a first step in comprehensive land conservation planning for any region.

The GAP approach is a GIS model overlay. Rather than representing statistical associations between animals and habitats, GAP models are mapped depictions of the description of habitat and known range extent for the species of interest. Therefore, appropriate uses of GAP models vary with development methods, scales, species knowledge base, and research objectives (see http://www.gap.uidaho.edu/Projects/Use.htm). With the historical development of GAP in mind, we need to address perceived deficiencies in these methods if the program is to continue being a useful part of conservation. In that spirit, we move on to current issues.

Habitat Models Model Habitat

We second the point O'Connor calls the "organochlorines test": habitat models do indeed only model habitat. A habitat model will not predict changes in distribution or abundance independent of the habitat. We also generally agree with his assertion that any habitat model, including GAP models, cannot be the sole basis for population monitoring. We may make an exception when the primary threat to a species is known to be habitat loss or alteration, in which case a habitat model may be a good predictor of population change (and may even be better than the typical, noisy population time series data that are used for population monitoring). Habitat change would need to be tracked on a reasonable time scale for this to be effective, but it is possible. GAP data could also be used to monitor changes in spatial configuration of habitat, which for some species could be a good predictor of population change. However, a great deal of information about the species is needed before this criterion can be met. For most vertebrates, we lack the kind of basic ecological information that was common in 19th century biology needed to meet this assumption (Laymon and Barrett 1986, Karl et al. 1999, Heglund 2002).

We also point out that the counterpoint to the "organochlorines test" is that absence of a species that has been extirpated from its habitat (due to poisoning or other reasons) does not indicate that the habitat is poor, nor will the species recover in the wild without adequate habitat. In short, GAP may be able to contribute the habitat information needed for comprehensive conservation planning, but the other needed information will have to come from other sources.

Habitat Model Accuracy

We generally concur with O'Connor about the need to consider omission and commission error separately in habitat models. The list of possible sources of prediction errors is long, and growing longer. We are currently working on what we believe to be a formerly unappreciated source of error that comes from rounding the predictions from continuous functions to whole numbers (i.e., rounding probabilities to 0 for absence and 1 for presence). This seemingly benign, completely standard practice can under some circumstances result in large numbers of prediction errors, because it lumps together model predictions that are essentially the toss of a coin with those that are near certainty. Although O'Connor's point about omission and commission is well taken, we suggest that a comprehensive approach to error assessment is not yet available.

This point is important, because we do not yet know what constitutes a reasonable expectation of prediction accuracy. The disconnect between the strikingly obvious habitat associations we see everywhere we look, and the poor predictive accuracy of models based on these associations never ceases to amaze us. The difference between the questions, "Given that we are looking at an Acorn Woodpecker, what habitat are we standing in?" and "Given that we're in oak woodland, what are the chances that we will see an acorn woodpecker?" can be much greater than we would expect. When the uncertainty in the answer to the second question is great, we begin to lose confidence in our answer to the first. However, despite their rhetorical similarity, the two questions are actually very different. Consider the following example, adapted from an introductory mathematical statistics textbook (Bain and Engelhardt 1992). Consider a model of the woodpecker habitat association whose confusion matrix (i.e., the relationship between the model predicted outcome and the observed outcome) appears in Table 1. This is a good habitat model by anyone's standards, with only 10 errors out of 200 predictions for the data that were used to build the model. Given that the model explains the occurrence of the woodpecker so well, should it not also predict well? In other words, shouldn't the probability of seeing a woodpecker when we are standing in oak woodland be fairly close to 95%? To answer that question, we need Bayes' Theorem, which states:

$$P(B_j \mid A) = \frac{P(B_j)P(A \mid B_j)}{P(B_j)P(A \mid B_j) + P(B_i)P(A \mid B_i)}$$

The probabilities of observing the animal (B_j), or not observing the animal (B_i, or 1-B_j), at a random location in the landscape, without reference to the habitat, are called the "simple" or "prior" probabilities. For example, if the animal occurs in one of 50 survey points, B_j is 1/50, and B_i is 49/50. The conditional probabilities represent the information provided by the habitat model, which come from Table 1. For example, the probability that the model predicted a presence given an observed presence (or $P(A \mid B_j)$) is found by dividing the correctly predicted presences by the total predicted presences, which is 95/100. Similarly, the probability of a model-predicted presence given that the species was absent (or $P(A \mid B_i)$) is 5/100. Plugging in the values from Table 1, we get:

$$P(B_j \mid A) = \frac{(1/50)(95/100)}{(1/50)(95/100) + (49/50)(5/100)} = 0.27$$

This means that, even in light of the enviably good habitat model shown in Table 1, we would only have a 27% chance of observing an Acorn Woodpecker, given that we were standing in the habitat where the species was predicted to occur. Thus, the predictive accuracy of the model depends both on how good the model is and on the amount of suitable habitat present in the landscape. If woodpeckers occur in 5/50 instead of 1/50 locations, the probability rises to 0.68—better, but far short of the 95% we would hope for. At a frequency of occurrence of 1/2, there is no difference between Table 1 and the Bayes' Theorem calculation, and as the frequency of occurrence increases above 0.5, the Bayes' Theorem calculation is even better than anticipated from Table 1 (for example, if woodpeckers are present at 80% of sampled locations, the probability of seeing one given that you are in oak woodland rises to 0.99).

Table 1. A confusion matrix to kill for.

		Predicted	
		Present	Absent
Observed	Present	95	5
	Absent	5	95

We present this example because it points out that explanation and prediction are fundamentally different, and that under some circumstances even a model that accurately represents a strong animal-habitat relationship can predict spectacularly poorly. We share O'Connor's discomfort with some of the more conspicuous prediction failures in habitat ecology, but we also assert that we should not be too quick to abandon approaches until we understand the reasons for their failures (and anyone who is surprised by our example should acknowledge that we don't yet fully understand the reasons for our habitat model failures). We may find that habitat models will never predict some species well, but we want to be able to reach this conclusion with confidence and not wonder whether we actually didn't really know the species-habitat relationship after all.

Representation

We would like nothing better than for the 10% "rule" to die a rapid and merciful death. We also agree with O'Connor that the spatial arrangement of habitat is not considered in GAP models, and that greater attention to the lessons of biogeography and landscape ecology could benefit GAP (more on this point in "GAP Research and Development" below). We add that we are extremely dubious that any fixed percentage of protected habitat will be adequate for all species (including 100% for species whose habitat is already mostly lost), and even if a conservative rule-of-thumb is to be chosen, 10% has no particular claim to being the right number; others have suggested levels of 12%, 20% and 50% (Odum and Odum 1972, Specht et al. 1974, Ride 1975, Miller 1984, Noss and Cooperrider 1994). Given the points raised in the Acorn Woodpecker example and the spatial (in)accuracies of vertebrate models, what would a fixed percentage mean for the conservation status of the species? Models such as GAP models that are based on current literature and expert opinion (Hepinstall et al. 2002) tend to overestimate habitat. However, returning to our Acorn Woodpecker example, if we protect 20% of predicted Acorn Woodpecker habitat, but we only have a 27% chance that the species will be present in any given sample, then those protected areas would really only be capturing approximately 5% of theoretically occupied habitat under the model. However convenient, fixed percentages do not represent these intricacies.

So, how much is enough? Although GAP "seeks to identify habitat types and species not adequately represented in the current network of biodiversity management areas" (GAP Handbook, Preface, Version 1, pg. I), it is unrealistic to create a standard definition of "adequate representation" for either land cover types or individual species (Noss et al. 1995). It is not known how much area is needed to protect biodiversity over the long term (Scott et al. 1987). The 10% threshold often reported in GAP reports is arbitrary and, while protecting 10% of a cover type may be a heroic accomplishment (Soulé and Sanjayan 1998), it lacks biological relevance and needs to be tested against the biological criteria of representation, redundancy, and resiliency (Shaffer and Stein 2000). A practical solution suggested by Scott et al. (2002a) is to report both percentages and absolute area in biodiversity management areas and allow the user to determine which vegetation types or vertebrate species are adequately represented, based on additional detailed studies of the ecology and population viability of the species as well as spatial and temporal dimensions of ecological processes. We suggest that probability of occurrence should also be reported.

GAP Research and Development

Now that we have largely agreed with O'Connor's points and added some concerns of our own, we would like to address how we believe GAP should respond to them. We see two very different kinds of research and development needs for GAP. The first kind of project is meant to refine existing methodology. Studies that fall into this category include improved remote sensing and classification techniques, studies of the best spatial resolution for models of particular species, accuracy assessment techniques, and other improvements in the methods used to conduct a traditional gap analysis. This sort of work may appear to be tinkering with details rather than addressing fundamental problems, but we expect incremental—but ultimately substantial—improvements in gap analysis to result from this kind of work. Most current GAP research falls in part or in total into this category, and it is necessary work. The second kind of research can be viewed as "futures" research, the kind of research and development that is intended to address fundamental problems with current methods and ultimately to allow us to move beyond them. Advances in the underlying scientific fields of population biology, landscape ecology, and biogeography should be investigated, interpreted, and brought to bear on conservation problems as soon as possible. We, as a field, may be chagrined that "developments" such as the Fretwell-Lucas dynamics mentioned by O'Connor that have been known for 30 years are not yet easily applied to habitat modeling, but it is so. We see O'Connor's suggested changes to GAP as one of each of these basic kinds of research; Schaefer's method for accuracy assessment is a proposed refinement of existing techniques, and Dufrêne-Legendre's index of habitat selection is a possible new direction based on a putative measure of habitat quality.

We feel this distinction is important, because GAP should respond differently to the findings of these different kinds of research projects. Having adopted a conceptual approach, we see no reason to delay implementing improvements in its application. Therefore, improvements in existing methods should be tested and deployed as soon as possible, so that the full potential of the method can be realized. In contrast, the findings from futures projects require a greater degree of evaluation and careful consideration. O'Connor's example of the Dufrêne-Legendre index, for example, represents a particular measure of only one of the many ways that patterns of distribution and abundance can overlay habitat quality. We have known for years that density can be a misleading indicator of habitat quality (Van Horne 1983), and the recent explosion of interest in ecological traps (e.g., Schlaepfer et al. 2002, Delibes et al. 2001, Donovan and Thompson 2001, Kristan in press) has shown that even an animal's habitat preference can be misleading. Animals may be strongly attracted to others of their species, either because conspecifics are used as indicators of habitat quality, or because being close together increases mating opportunities independent of the habitat (Muller et al. 1997). Metapopulation dynamics can cause patches of habitat that are clustered together to be more consistently occupied than identical patches of habitat that are far apart; it stands to reason that in some cases lower-quality patches of habitat that are close together may contain animals more frequently than higher-quality patches that are far apart. Each of these different insights from basic ecological research suggests distinct, and sometimes contradictory, implications for habitat modeling. In other words, unless we are able to tell which of the long list of possible problems are actually occurring for a particular species, the list does not provide any information that we can use to improve our models. So, what should we do?

We suggest that these points do not mean that all of habitat-based conservation is valueless, but rather that until these issues are thoroughly understood, attempting to incorporate them into applied projects runs the risk of chasing the latest fads and infatuations. We do not suggest that GAP should stand still and wait for others to bring these advances to us, but rather we suggest that a substantial fraction of GAP-funded research and development should be designed to bring advances in population biology, landscape ecology, and biogeography to the program.

Future Directions for GAP

We agree whole-heartedly with O'Connor's assertion that habitat modeling needs to move forward, and we will close our comment with some suggestions for future directions (including research and development needs) we think will allow GAP to make continued progress.

1. Dynamic models - Information on the distributions and habitat associations of vertebrate species is probably the most incomplete of any of the information used in GAP projects. This informational deficiency, coupled with dynamic landscapes, requires an adaptive management approach. As has been stated since the beginning, models of predicted habitat are testable hypotheses and need to be treated as such. This means field verification at appropriate spatial and temporal scales, refinement of the models, and reevaluation. Examples of this approach are rare in the literature. Such an approach will allow us to incorporate changes in landscape characteristics, address regional differences in habitat associations, and create models that are effective as management tools.

2. Hierarchical approaches - As data at a variety of spatial resolutions become available, GAP should move beyond emphasizing a single spatial and temporal scale in species models. Plants and animals are exposed to multiple scales simultaneously, and the interacting effects of coarse- and fine-grained habitat features need to be better understood.

Similarly, hierarchical approaches to conservation planning are necessary (e.g., The Nature Conservancy). The original concept of gap analysis was proposed as one specific component of an integrated conservation program aimed at addressing the problem of declining biodiversity (Scott et al. 1987, Scott et al. 1988, Scott et al. 1993). Today's products from GAP provide the context to proactively identify and manage species before they are threatened or endangered, but fine-scale assessments are still needed.

3. Move beyond presence/absence - The primary advantages of presence/absence predictions are that they are less likely to fail than are predictions of abundance, they are easy to explain to the lay-public, and they are in the same units as the observations, so that errors are easy to count. In truth, though, the presence or absence of a species at a point in space and time is a chance event and would more accurately be represented by a

probability. Currently, we risk confusing a model that predicts badly (that is, fails to predict the presence or absence of species even when the probabilities of occurrence are close to 0 or 1) with a good model applied to a landscape full of marginal habitat (and in which probabilities are thus close to 0.5, where predictive accuracy is expected to be poor). Promising work is being done in this area (see Scott et al. 2002b).

4. Use of models as planning tools - GAP models are famous (and to some, infamous) for being "coarse-filter" models and numerous example applications exist (see Crist and Maxwell 2000). While coarse-filter approaches will not be sufficiently precise for some applications, we feel they are underutilized as a guide for sampling frameworks. One of us (LS) has successfully used models (both GAP and finer-scale versions) to guide survey efforts for the pygmy rabbit, a lesser-known species recently proposed for listing under the Endangered Species Act.

One of the original goals of GAP was, and still is, to facilitate conservation planning. While much has been done in this arena, much is left to do. Coarse-filter models may be sufficiently accurate to be used for "What If" analyses of different changes in land use (e.g., Matthews et al. 2002) in the way that population viability analysis is used to predict changes in viability under different management alternatives. Changes in species distributions due to climate change are occurring (Root et al. 2003), and GAP models may provide input into predicting these changes. Further assessments of the vulnerability or risk to biodiversity from human impacts such as roads and urban expansion are needed.

5. Education and awareness - If any of the information gathered, produced, and reported by GAP is going to make a difference in the overall conservation of biodiversity, the chasm between researchers and data users (land managers, nonprofits, etc.) must be crossed. As Wiens (2002) states, the variability, complexity, and contingencies that fascinate ecologists are not so appealing to managers, who seek simple and timely solutions. Not only is it important that we continue to educate ourselves to new ideas in the fields of conservation biology, biogeography, and statistics, but also to test, refine, and apply these ideas. As we stated earlier, publicly available data sets will be used in a variety of ways beyond their original intent, and those data will only be as valuable as the skill of the user. It is our responsibility as the GAP community to develop and implement methods to facilitate learning.

6. Facilitation - With thirty years since Landsat satellites were launched, and with more than two dozen space-borne sensors dedicated to recording land cover, it is time to take a hard look at how successful we have been in mapping the world's land cover. Practitioners from around the world undoubtedly have much to share. Emerging research suggests that using data from more than one sensor can appreciably improve accuracy of our maps. GAP, as a leading practitioner of the art of land cover mapping, can facilitate retrospective analyses of common practices by hosting an international symposium where researchers from around the world are invited to present and discuss results of past research efforts and future research directions. This approach proved fruitful at the Snowbird, Utah, symposium on predicting species occurrences, which was born in part

out of questions raised by GAP investigators (Scott et al. 2002b). It is important that all points of view are represented, and attendees should be asked to document what has and has not worked, explore emerging methods, identify the really tough issues, and critically address their assumptions.

We wish to reiterate that we agree with virtually all of O'Connor's points. However, we chose to focus our comments on what the GAP program as a whole should do in light of these criticisms, because GAP is more than habitat modeling. As pointed out repeatedly in Scott et al. (2002b), there are no "silver bullet" methods of predicting species occurrences. Improved model performance will come with increased understanding of species ecology. Though our enthusiasm for the new and improved should push us to look for better solutions, we must also be cautious about trading old problems for new ones.

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Prioritizing Conservation of Biodiversity Using a Multispecies Approach

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Introduction

The conservation of ecosystems focuses on evaluating individual sites or landscapes based on their component species. Building on successful single species evaluation methods (e.g., habitat suitability analysis and population viability analysis), I developed a method for estimating the value of a particular site based on its ecological components, i.e., species, and the threats facing it. The method has two important features: it assigns an ecological value based on many species and facilitates multispecies assessments of ecological effects. The goal is to minimize the extinction risk and maximize habitat quality for the component species; the viability of the populations, rather than just the species' presence, is considered. As a demonstration I applied my method to a set of California species that are included in the California Gap Analysis Project (Davis et al. 1998).

Methods

I combined habitat suitability maps for each species with the extinction risk faced by each species in a single map of multispecies conservation values (MCVs). Using the risk of extinction as a weighting factor means the more imperiled a species is, the more priority is given to its habitat requirements. A high value for the MCV (e.g., 9 or 10 on a scale of 1 to 10) represents the highest-quality habitat for the set of species with the highest risk of extinction or decline.

Many types of models can be used to estimate the risk of extinction and the contribution of each cell; the model choice depends on the species and the data available. In this example I constructed spatially explicit population models, using RAMAS GIS (Applied Biomathematics, Setauket, New York; Akçakaya 1998), for a set of species in the 10 southern counties of California (Root et al. 2003). This method, though, is not limited in the number of species or the size of the area that can be included; I chose only six species and a reduced area to simplify the computations.

The six species used for this analysis were California Gnatcatcher, Cactus Wren, California Spotted Owl, desert tortoise, Stephens' kangaroo rat, and San Joaquin kit fox. For each species, I created a raster map of habitat suitability based on the California Gap Analysis database with values of 0 through 5, with 5 being the most suitable (Davis et al. 1998). These maps were imported into RAMAS GIS (Akçakaya 1998) and served as the basis of the spatial structure of the metapopulation or population.

Based on the available data, I constructed a female-only, stage-based, stochastic, spatially explicit model for each species (Root et al. 2003) using published data and models wherever possible (see Table 1 for references). I assumed populations were limited by both the quality and the quantity of habitat, and dispersal and correlation among populations was distance-dependent. The contribution of each cell to the overall risk of extinction was estimated as the difference between the risk of extinction with all populations included minus the risk with the population (that the cell belonged to) removed. Therefore, the MCV for each cell j was the sum of the products of habitat suitability for species i at location j (S_{ij}), risk of extinction in 50 years (P_i) and contribution of location j to the viability of species i (C_{ji}) divided by the sum of all of the extinction risks:

$$\mathrm{MCV}_j = \frac{\sum_{i=1}^{n}\left(S_{ij} \times P_i \times C_{ji}\right)}{\sum_{i=1}^{n} P_i},\ \text{(Root et al. 2003).}$$

For comparison, I also examined an alternative measure of risk, the risk of a 50% decline in abundance in 50 years.

Table 1. Six species that were selected, their vulnerability status as assigned by the U.S. Fish and Wildlife Service (federal) or California Fish and Game Commission (state), and the sources for species-specific demographic data and models.

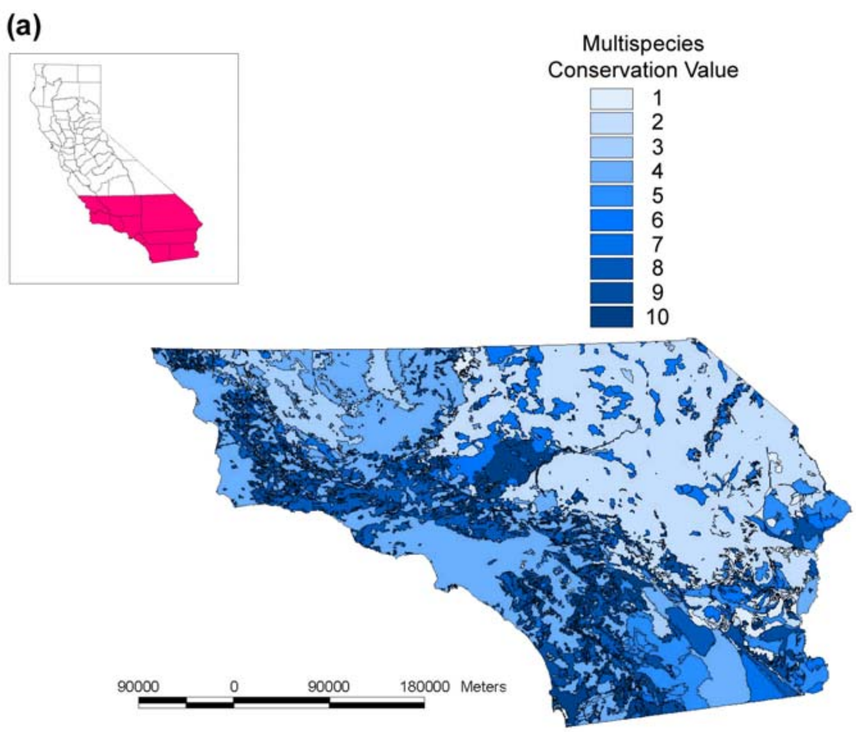
Common Name	**Scientific Name**	**Federal Status**	**State Status**	**Sources**
Coastal California Gnatcatcher	*Polioptila californica californica*	Threatened	None	Akçakaya 1997; Akçakaya & Atwood 1996, 1997; Bontrager 1991
Cactus Wren	*Campylorhynchus brunneicapillus*	None	None	Akçakaya and Atwood 1996
Northern Spotted Owl	*Strix occidentalis caurina*	Threatened	None	Call et al. 1992; Lahaye et al. 1994
Desert Tortoise	*Gopherus agassizii*	Threatened	Threatened	Doak et al. 1994; Luke et al. 1991; O'Connor et al. 1994; Root 1999; Turner et

				al. 1986
Stephens' Kangaroo Rat	*Dipodomys stephensi*	Endangered	Endangered	Price and Kelly 1994; Price et al. 1994
San Joaquin Kit Fox	*Vulpes macrotis mutica*	Endangered	Threatened	Disney and Spiegel 1992; White and Garrott 1997

Results

Based on these models, the MCV map (Figure 1a) revealed valuable habitat patches scattered across the 10 southern counties of California. Nine percent of the polygons (5.3% of the total area) had a value in the top category of the MCV values, and 24.1% (12.4% of the total area) were in the top two categories of the MCV values. Approximately 29% of the polygons (38.9% of the area) had a negative MCV value, which occurred when a particular location, if included, increased the overall risk of extinction (e.g., a sink population).

When the alternative risk measure, i.e., risk of a 50% decline, was used in estimating the MCV, the resulting map showed a few changes (Figure 1b). In this case there were fewer negative MCV values. Only 7.7% of the polygons (9% of the total area) had a negative MCV value. The top two categories of the MCV values included 19% of the polygons (7.9% of the total area), and the top category included 18% of the polygons (7.7% of the total area).



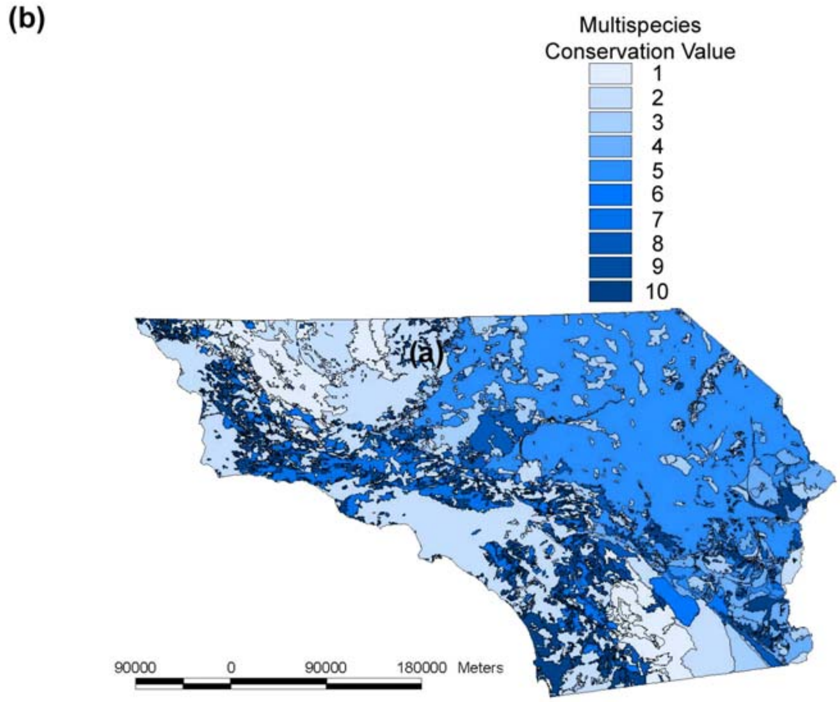


Figure 1. Multispecies conservation values maps of the southern 10 counties of California for 6 species based on their habitat suitabilities from the California Gap Analysis (Davis et al. 1998) weighted by (a) the probability of extinction for each species, or (b) the probability of a 50% decline in abundance for each species, estimated from population models. The categories shown represent ten intervals of equal area; a larger value indicates a higher conservation value.

Discussion

The resulting MCV maps highlight regions of conservation importance for the six species that were included. Sites with higher MCVs (e.g., 9 or 10 on a scale of 1 to 10) had, in general, higher habitat suitability for species with a higher risk of extinction or decline. The regions where there was the greatest overlap among the six species were also where many of the highest MCV values were found. The most valuable locations, in general, were along the eastern side of the state, which closely reflects the higher risk of extinction for the species found in these areas. The valuable sites along the eastern side correspond with the highly endangered coastal sage scrub habitat included in reserves designs of Natural Community Conservation Planning Program (Akçakaya and Atwood 1997; Davis et al. 1998).

It is interesting that the map based on the risk of a 50% decline rather than risk of extinction shows a slightly different pattern. Areas on the western side of the state had a higher MCV value under the risk of decline compared with the MCV value under the risk of extinction. Species may have a very high risk of a large decline but a negligible risk of complete extinction and would be valued higher in this weighting. The risk of a decline may provide an important early warning for species that are not currently considered threatened or endangered but may be quite vulnerable to changes in their environment.

Using a model to explicitly measure the risk of extinction or decline is generally preferable to using an index when data are available (Root et al. 2003). The amount of data needed is driven by the choice of model for estimating the risk of extinction and the contribution of each location; a simple unstructured population model will require far less data than an individual-based simulation model. There are also methods for estimating the risk of extinction of a species using only presence-absence or siting data (see Solow 1993a, b; Burgman et al. 1995, 2000). An important advantage of models is that they can highlight which parameters have the most influence on the risk of extinction, warranting further study, and guide future research efforts. For many of the species included in this example, the adult survival value had the greatest influence on the population growth rate and subsequent risk of extinction or decline.

The risk-based multispecies conservation value is also flexible in terms of scale. Both the habitat suitability analysis and metapopulation models can be developed at a scale appropriate for the individual species. Many more species can be readily accommodated with this method than the six I used in this test case. Dynamic elements can be explored, such as the effects of fires, timber harvest, drought, and other factors. One can incorporate a potential effect in the metapopulation model, estimate the risk, and compare the resulting MCV map to the map without an effect. Potential changes also can be incorporated into the habitat suitability maps that reflect planning choices so that the outcomes of different plans can be compared. This method (now implemented in software; Root 2002) provides a quantitative and spatially explicit conservation value useful for such applications as a multispecies recovery plan, a regional habitat conservation plan, or an evaluation of local management alternatives.

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Improving Vertebrate Modeling in Gap Analyses: Incorporating Minimum Viable Populations and Functional Connectivity in Patchy Environments

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Introduction

High resolution maps of broad extent, such as those generated for gap analyses (Scott et al. 1993), create new problems in species mapping, especially by potentially inflating errors of commission—the chance of erroneously including the presence of a species in a habitat where it is absent. On high-resolution maps, commission errors are likely to be high when creating species models based simply on species-habitat associations. A habitat patch as small as 30 m^2 (though in practice GAP maps have a much larger MMU) may be identified as a discrete unit. However, a discrete 30 m^2 patch (or one much larger) in isolation will not support an individual of many vertebrate species, and even considerably larger patches will not support viable populations of most vertebrates (Allen et al. 2001).

Protecting biodiversity requires sustaining populations of species into the foreseeable future. Protecting species requires sufficient habitat to support a minimum viable population (MVP) over time. Incorporating information on the spatial use of habitat by species should increase the accuracy of species models by reducing the commission error rates. Information on the home range and dispersal distances of mammals has been incorporated to estimate minimum critical areas (MCA) to support MVPs for each mammal species in Florida (Allen et al. 2001). However, while those models were an improvement, better models are attainable. Patches of suitable habitat too small to support a MVP may still be occupied if multiple patches within the species' dispersal capabilities form a network that, in aggregate, is large enough to support a viable population. These patches may be considered "functionally connected." Here we describe our ongoing efforts to refine GAP vertebrate models by incorporating MCA methods across multiple patches and functional connectivity.

Methodological and Conceptual Framework

Although the habitat of a species may be fragmented, linkages between local populations may maintain a functional connection across the landscape if individuals are sufficiently able to disperse among patches. Keitt et al. (1997) introduced a computational procedure to evaluate the functional connectivity of a network of patches relative to the dispersal capabilities of the organism. They applied their methodology to evaluating functional connectivity of habitat patches for the Mexican Spotted Owl (*Strix occidentalis lucida*). They used "correlation length," a measure of connectivity inspired by percolation theory. They demonstrated that connectivity jumps abruptly as the dispersal ability of the organism crosses a critical threshold, and that certain patches play a disproportionately large role in maintaining connectivity, and thus population viability. This measure of connectivity can be applied if we have an estimate of dispersal ability for the species. For mammals, such estimates are generally available (e.g., Allen et al. 2001). For species for which estimates are not available, Sutherland et al. (2000) have derived a series of allometric relationships for predicting natal dispersal distances of birds and mammals based on body size. It may not be able to assess functional connectivity for many reptile and amphibian species because of the limited number of studies of home range and dispersal for these species.

Although there has been discussion in the scientific literature devoted to the problem of determining minimum viable population numbers for species, the determination of a "viable" population size is still wrought with uncertainty. Franklin (1980) stated that determining effective population size (N_e; the number of individuals in a population breeding and contributing to the gene pool) is paramount, not the census population size (i.e., all individuals in a population). However, determination of effective versus census population size is difficult. Allen et al. (2001) used an estimated minimum population size of 50, the estimated size necessary to avoid extinction due to demographic stochasticity. However, to avoid the loss of genetic heterozygosity resulting from inbreeding and genetic drift, MVP size may be in the order of 500 individuals (Franklin 1980, Soulé 1980). Our interest in incorporating measures of MCA and functional connectivity into GAP models is not to determine the true viable population size, but to decrease commission errors in our models and produce models that are more accurate and biologically defensible. Our current modeling efforts in South Carolina will utilize MVP estimates of both 50 and 500.

<u>Determining Minimum Critical Area</u> - Minimum critical area is determined based on species home range size estimates from peer-reviewed literature, using the following simple equation:

$$MCA = \frac{[(\text{home range area})\ N_e]}{2}$$

where "2" accounts for intersexual overlap of socially interactive species (e.g., most mammals) and N_e is either 50 or 500 (Allen et al. 2001).

<u>Determining Dispersal Distances</u> - Dispersal distances for many species are available in peer-reviewed literature. Where there is no value available, published allometric equations based on trophic level and body mass are available (Sutherland et al. 2000).

<u>Building Models Incorporating MCA and Functional Connectivity</u> - For each species, patches of suitable habitat too small to support viable populations are eliminated by selecting only those patches > MCA. Those methods are described in Allen et al. (2001). Dispersal is incorporated in two ways (Figure 1). First, patches ≥ MCA are buffered by species dispersal distance, and those patches < MCA but within a species dispersal range from a large patch are included as occupied habitat. Second, a buffer equivalent to the dispersal distance for a species is applied to all patches. Networks of patches that are individually < MCA but in aggregate ≥ MCA and connected by dispersal are also included as occupied habitat.

Figure 1. Illustration of minimum critical area and functional connectivity for the eastern harvest mouse in South Carolina. Patches too small to support a MVP in isolation may in aggregate support a MVP, if functionally connected.

Population Viability Analyses and Risk - For selected species at risk of extinction or local extirpation, where demographic parameters are available from previous studies, it is possible to incorporate population viability analyses (PVA) as part of the Gap Analysis process. Population viability analyses are particularly relevant to populations in fragmented habitat, where loss of functional connectivity may have serious consequences for population viability. Viability may be assessed by running metapopulation models utilizing current distributions of the target species. Simulations may be conducted using RAMAS/GIS modeling software (Akçakaya 1998). A stage-classified population growth model can be used to project population dynamics, with demographic parameters derived from the literature (if possible) or expert judgment. Dispersal between patches can be modeled as an exponentially declining function of distance up to a maximal cutoff. Risk is expressed as the probability of local extinction for each habitat patch based on Monte Carlo simulations (e.g., many iterations as run in RAMAS/GIS) of metapopulation dynamics. The Monte Carlo approach allows uncertainties to be propagated through the model so as to produce a distribution of risk estimates.

Identification of Critical Patches - Some patches are disproportionately important in maintaining functional connectivity within networks of patches (Keitt et al. 1997) or between large blocks of habitat. Identification of these patches is important for biological conservation, as they are necessary to maintain connectivity within a landscape. Note that the identification of these critical patches depends upon the species of interest, its scale of environmental use, and in particular its dispersal capabilities. Figure 2 illustrates the concept of functionally important patches in two contexts.

Figure 2. The identification of functionally critical patches. Animal dispersal between preferred habitat patches is shown by double-ended arrows. The smaller circles represent a number of "small" patches (i.e., area less than MCA value) which, on their own, cannot support a MVP but in aggregate form a functionally connected cluster that adds up to meet or exceed MCA requirements. These clusters, along with the "large" patch (i.e., area greater than or equal to MCA value) may be functionally connected to each other by one or more small patches. These small patches are of interest because they are important for maintaining connectivity and thus genetic flow and variation; loss of such patches may be detrimental to the (meta)population as a whole. For rare species, identifying these patches may be crucial in order for conservation efforts to be effective.

Preliminary Results

We ran models incorporating minimal critical areas and functional connectivity for a taxonomic and geographic subset of South Carolina (ten mammals in Oconee, Pickens, and Greenville counties: star-nosed mole *Condylura cristata*, black bear *Ursus americanus*, eastern cottontail *Sylvilagus floridanus*, grey squirrel *Sciurus carolinensis*, bobcat *Felis rufus*, grey fox *Urocyon cinereoargenteus*, eastern harvest mouse *Reithrodontomys humulis*, mink *Mustela vison*, white-tailed deer *Odocoileus virginianus*, and Eastern wood rat *Neotoma floridana*).

Our results indicate that minimum patch size models generally decrease the area modeled as occupied by a species (Table 1, MCA area). Minimum patch size models coupled with functional connectivity considerations may increase the area modeled as occupied compared to models with minimum patch size criteria only. For species with long-range dispersal capabilities, simple GAP habitat affinity models and models with minimum critical area and functional connectivity may be identical (Table 1, Total functional area). However, for species with limited dispersal capabilities, GAP models overestimate occupied area, presumably leading to increased commission error rates (Table 1, Eastern harvest mouse, Star-nosed mole). These methods may be most useful for medium-sized mammals; large mammals have long dispersal capabilities, and entire landscapes may be functionally connected for such species, and small mammals may have such limited dispersal capabilities that few patches are connected. However, patchiness not only depends upon the organism in question, but also the resolution of the mapping effort (i.e., land cover) and the natural scale of patchiness upon the landscape.

Table 1. The area occupied by selected species in three South Carolina counties, based on simple Gap Analysis species-habitat associations (GAP area), models that incorporate minimum patch-size criteria (MCA area), and models that incorporate minimum patch size and functional connectivity of habitats. Minimum patch-size models generally decrease the area modeled as occupied by a species. Minimum patch-size models coupled with functional connectivity considerations increase the area modeled as occupied compared to models with minimum patch size criteria only.

Species	**GAP area (ha)**	**MCA area (ha) (change in area from GAP)**	**Total functional area (ha) (change in area from GAP)**
Black bear	227,413	0 (Δ -227,413)	227,413 (Δ 0)
Bobcat	7,319,872	7,318,443 (Δ -1,429)	7,319,872 (Δ 0)
Eastern cottontail	4,607,701	4,607,313 (Δ -1,817)	4,607,701 (Δ 0)
Eastern gray squirrel	357,876	343,046 (Δ -14,830)	357,876 (Δ 0)
Eastern harvest mouse	138,777	105,836 (Δ -32,941)	117,730 **(Δ -21,047)**
Eastern wood rat	259,339	218,379 (Δ -40,960)	259,339 (Δ 0)
Gray fox	3,832,915	3,776,801 (Δ -56,114)	3,832,915 (Δ 0)
Mink	195,956	76,447 (Δ -119,509)	195,956 (Δ 0)
Star-nosed mole	37,718	32,442 (Δ -5,276)	37,357 **(Δ -361)**
White-tailed deer	476,422	475,029	476,422

		(Δ -1,393)	(Δ 0)

Discussion

Characterizing minimum critical areas in patch networks, functional connectivity across habitat patches, and metapopulation dynamics for key species will allow the identification of landscape patches key to the viability of target species, and thus the patches most critical for the conservation of viable populations. That, in turn, provides the basis for exploring the consequences of landscape changes in terms of risk to species and overall biodiversity.

The methods we are developing may have general and specific utility and will demonstrate the usefulness of approaches that incorporate the consideration of minimum areas for viable populations and critical patches of habitat. Our methodology to account for viable populations based on minimum critical areas and improved to include areas in networks of patches can be incorporated simply into all gap analyses. Determination of functional connectivity and the identification of patches critical for maintaining functional connectivity will have more specific application in guiding and weighing land use and conservation decisions applied to particular patches. We expect to conduct an accuracy assessment of a subset of the vertebrate models to compare standard GAP methods versus our methods incorporating MCA and patch networks.

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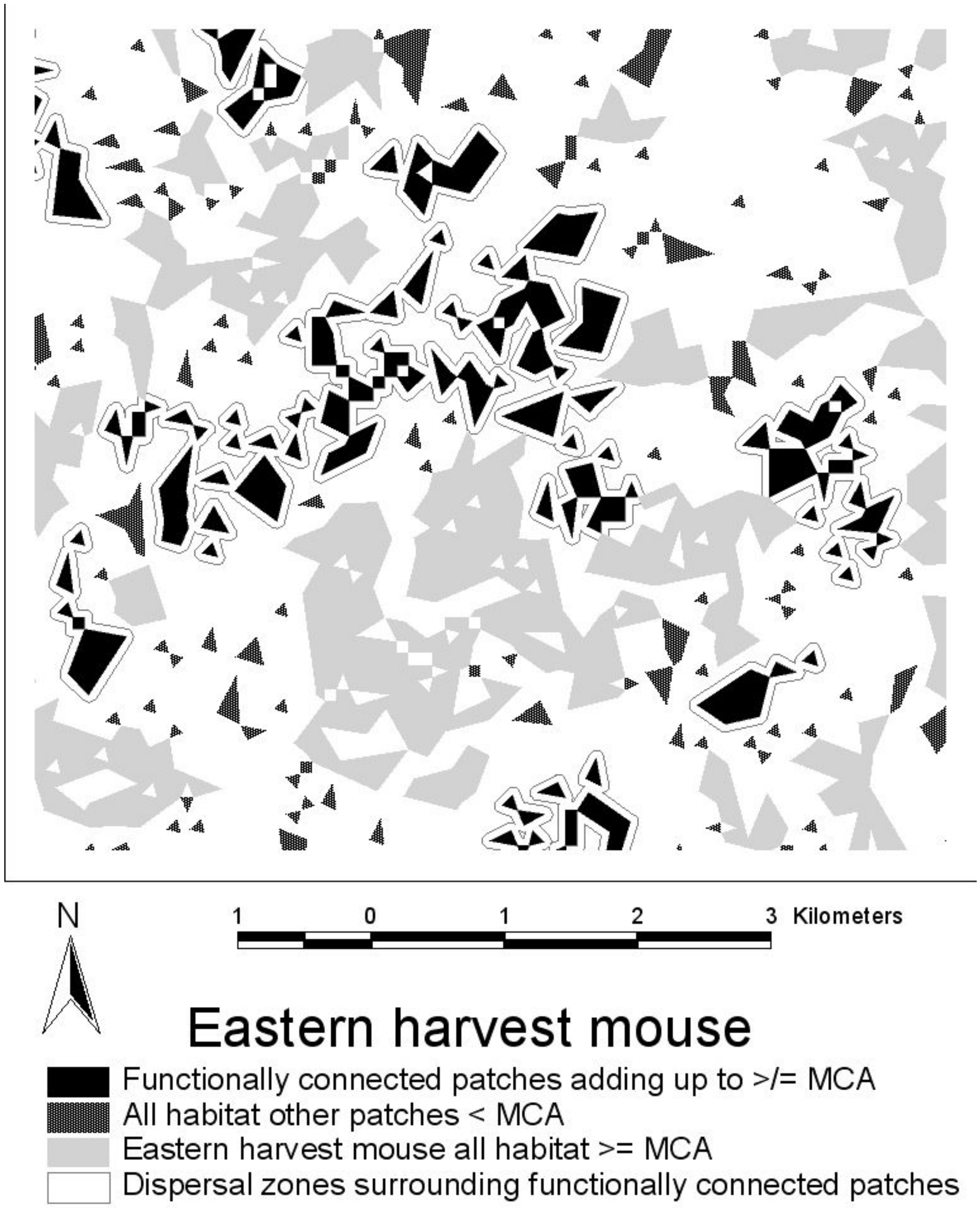
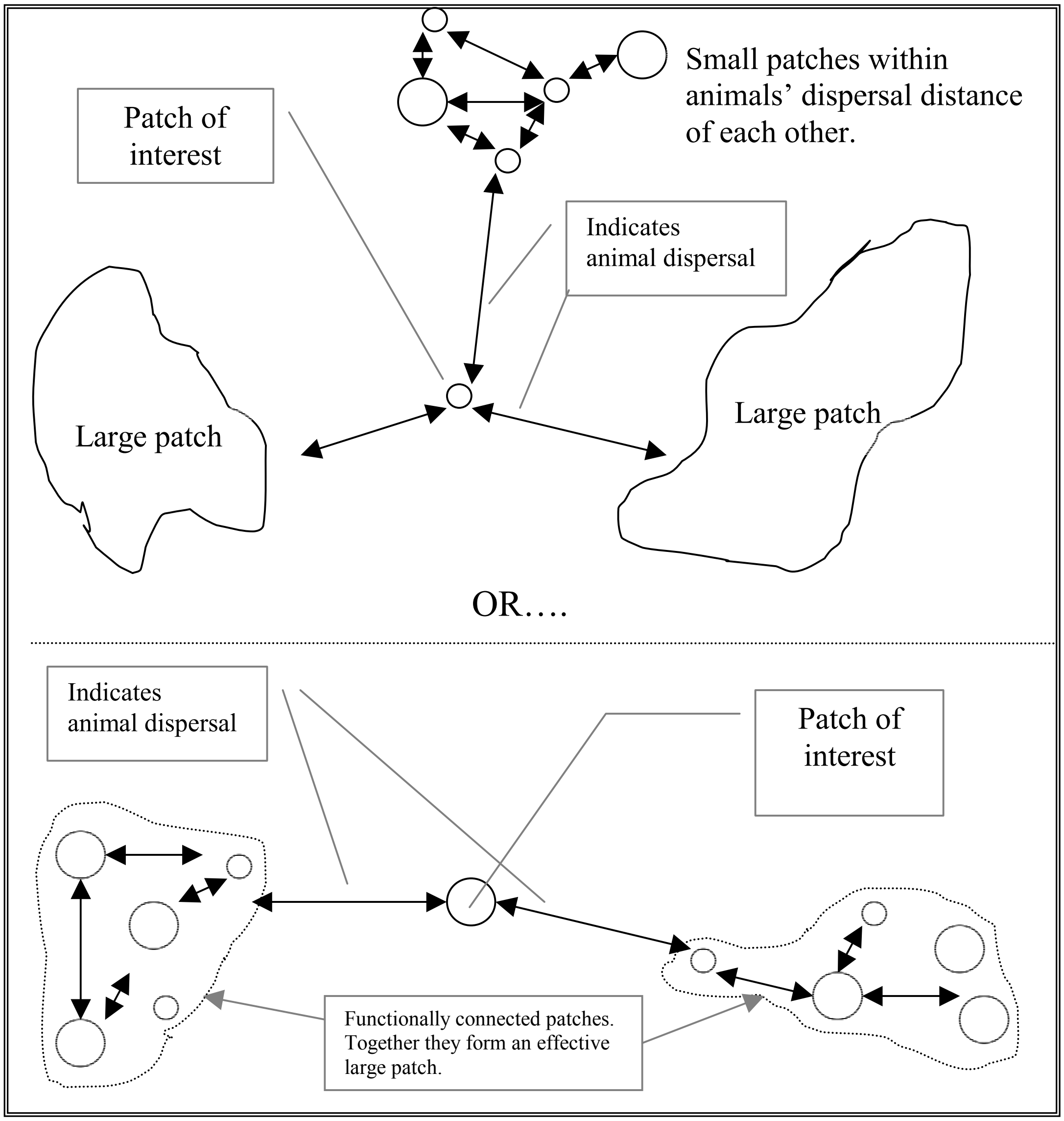

N
1
0
1
2
3 Kilometers
Eastern harvest mouse
Functionally connected patches adding up to >/= MCA
All habitat other patches < MCA
Eastern harvest mouse all habitat >= MCA
Dispersal zones surrounding functionally connected patches



Description and Application of an Accuracy Assessment Method for Gap Analysis Models

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Introduction

Gap Analysis uses literature-based information on vertebrate habitat affinities to determine areas of high species richness. Predictive models for vertebrates are created based on literature and expert review to predict species' occurrences and overall richness of vertebrate diversity. However, these models need validation based on fieldwork to assess their accuracy.

Accuracy assessment of animal spatial models is crude and poorly developed and requires quantification of both commission and omission errors. Boone and Krohn (2000) found that the most common accuracy assessment method used for GAP models is to compare the predicted species for an area such as a U.S. National Park or National Wildlife Refuge to checklists of breeding species available for such areas. Omission errors (occurrence when absence was predicted) are relatively easy to document, but commission errors (absence when occurrence was predicted) are more difficult to determine. These different error types may have weighted costs associated with the ecological "value" of the species in terms of conservation priorities. In a model used to define protected areas, failure to correctly predict positive locations (omission error) may be more "costly" than commission errors (Fielding 2002).

Recent accuracy assessments of GAP vertebrate models have stressed the importance of separation of *actual* commission errors (species is not present on the site) from *apparent* errors (incomplete field inventories falsely omit the true species occurrence on the site) and an *a priori* species ranking of occurrence, placing common, density-dependent species above rare ones in terms of the likelihood of the model being correct (Boone and Krohn 1999, Schaefer and Krohn 2002). Boone and Krohn (1999) developed a multivariate method to correct commission errors in GAP models by predicting how likely a species would be seen in future surveys, called Likelihood of Occurrence Ranks. They showed that variables such as size of survey site, duration of surveys, natural history of the species, and quality of species distribution models influence the validity of accuracy assessments.

The development of vertebrate monitoring programs allows for the validation of model predictions. Long-term sampling decreases errors associated with spatial and temporal variability in animal-habitat use and increases the odds of detecting rare species, thus monitoring programs provide ideal data for assessing the accuracy of GAP models.

Our goals are (1) to describe our methods of accuracy assessment, (2) to assess the accuracy of the South Carolina Gap Analysis Project's (SC-GAP) vertebrate models in predicting reptile and amphibian (herpetofauna) and mammal species richness as compared to capture-based models, and (3) to determine the spatial correspondence between the nodes of highest richness for herpetofauna and mammals separately and combined.

Methods

Study Area - Our study sites were located within the 78,000-hectare Savannah River Site (SRS) near Aiken, South Carolina. The site was closed to the public in 1951, and the USDA Forest Service planted pine seedlings on former crop and pastureland, beginning in 1952, as an initial forest restoration effort. By 1963, about 90% of the area was covered by young forests (Golley et al. 1965).

SRS Land Cover - We modified an existing digital land cover classification (Imm 1997) by grouping similar land cover classes into seven cover types: bottomland hardwood, swamp-edge, mixed forest, hardwood slope, planted pine, Carolina bay, and sandhill.

GAP Land Cover - A habitat-based, 27-class raster land cover map with a resolution of 30 meters was produced by Clemson University and South Carolina Department of Natural Resources personnel using a combination of remote sensing image interpretation and ground-truthing from Landsat TM imagery dating from 1991-1993.

The Savannah River Site was clipped from the SC-GAP coverage. The SRS area included 22 of the 27 GAP land cover classes, but only 10 of those were natural terrestrial classes (swamp, bottomland/floodplain forest, closed-canopy evergreen forest/woodland, needle-leaved evergreen mixed forest/woodland, pine woodland, dry deciduous forest/woodland, mesic deciduous forest/woodland, dry mixed forest/woodland, mesic mixed forest/woodland, and wet evergreen).

The GAP classification differed from the SRS classification. Therefore, we created a crosswalk table that converted GAP land cover into SRS land cover to provide comparison between the two classifications using SRS land cover as the base map. SRS land cover also was cross-walked into GAP land cover using the GAP land cover as the base map.

Vertebrate Sampling - We trapped herpetofauna and small mammals at five replicates of each of the seven land cover types in the fall of three years (1999-2001). Small mammals were sampled utilizing Sherman live traps, tomahawk traps, and pitfall-drift fence arrays. Herpetofauna was sampled using pitfall-drift fence arrays and visual captures for all three years, with the addition of funnel traps, cover boards, and PVC pipes in 2001.

SRS Sample-based Model - We built presence/absence habitat-association models only for the species that were most abundant over three years, including four reptile species, seven amphibian species, and six mammal species. Because we focused on terrestrial species, our capture data only apply to a 200-meter swamp-edge buffer rather than the entire swamp land cover type at SRS. We limited our assessment to common species and set a criterion that captures within a given land cover must account for > 5% of the captures for a species to be considered present in that land cover. A key assumption is that this sample-based model reflects the “real” distribution of both presence and absence of species, because it is based on actual trapping data for the most abundant species.

GAP Model - GAP-generated habitat affinities for herpetofauna and mammals were determined primarily from literature review. These animal-habitat associations were cross-walked into the SRS land cover. This information was used to build a matrix of species x land cover for the seventeen species for which we had adequate data. These species were predicted to be present or absent in each land cover type, using both the SRS and GAP land cover classifications as our base maps.

Species Richness - Composite species richness maps for herpetofauna, mammals, and both taxa combined were produced by adding the individual species maps to produce a composite map of overall sample-based richness for the SRS land cover and predicted richness for the GAP land cover.

Spatial Correspondence - We compared the GAP predictive model to our sample-based model, using both the SRS and GAP land cover classifications as our base land cover maps to determine spatial correspondence of species richness. The SRS sample-based richness model was subtracted from the GAP-predicted richness model. Values of zero occurred where the levels of species richness between GAP-predicted and SRS captures were equivalent. High positive values occurred where GAP-predicted species richness was high relative to SRS capture richness (GAP commission errors), and high negative values occurred where SRS capture richness were high relative to GAP-predicted species richness (GAP omission errors) (Allen et al. 2001b).

Commission and omission errors also were calculated for individual species, including the percentage of area and percentage of land cover agreed upon by GAP prediction and capture success. An area or land cover type was considered in spatial agreement between the GAP and SRS models if both predicted the species to be either present or absent within that land cover type or area. This was calculated using both land cover classifications as base maps:

$$A = (\Sigma (AA)/TA)*100$$

$$L = (\Sigma (LA)/TL)*100$$

where A is percent agreement, AA is area of agreement of the base map, TA is total area of the base map, L is percent land cover agreement, LA is land cover agreement, and TL is total number of land cover types (SRS=7, GAP=10). These values are calculated using both land cover base maps. To find the omission errors, we added the area where a species was present but not predicted to occur:

$$O = (TOA/TA)*100$$

$$LO = (TO/TL)*100$$

where O is percent omission error, TOA is the total omission area, TA is the total area of the base map, LO is the percent land cover omission error, TO is the total land cover types omitted, and TL is total number of land cover types. To find the commission errors, we added the area where a species was predicted to occur but not present:

$$C = (TCA/TA)*100$$

$$LC = (TC/TL)*100$$

where C is percent commission error, TCA is the total commission area, TA is the total area of the base map, LC is the percent land cover commission error, TC is total land cover types with commission error, and TL is the total number of land cover types.

<u>Nodes of Highest Richness</u> - The explicit focus of gap analyses are not single species, but the identification of areas of high species richness. Therefore, we determined the correspondence between nodes of highest richness (top 20%) (Allen et al. 2001b) for each taxon. To qualify as the top 20%, 5 of the 6 mammal species, 9 of the 11 herpetofauna species, or 14 of the 17 total species must be present in a land cover type.

Results

<u>SRS Land Cover as a Base Map</u> - Species richness based on our monitoring program varied from 4 to 10 species per land cover type for herpetofauna, from 1 to 6 species for mammals, and from 5 to15 species for the two groups combined. GAP-predicted species richness ranged from 6 to 11 species for herpetofauna, from 2 to 6 species for mammals, and from 8 to 17 for the two combined.

There was spatial correspondence of overall herpetofauna species richness between species captured and those predicted by gap analysis in the planted pine land cover. The swamp-edge land cover showed actual species richness higher than predicted. Predicted species richness was higher than actual species richness in the remaining land cover types, ranging from two more species to seven more species (Figure 1).

There was spatial correspondence of overall mammal species richness between species captured and those predicted by gap analysis only in the swamp-edge land cover. Captured species richness was higher than predicted in the planted pine and Carolina bay classes. Predicted species richness was higher than captured in the remaining four land cover types.

There was no spatial correspondence between sampling and GAP models for mammals and herpetofauna combined. Actual species richness was higher than predicted in the planted pine, swamp-edge, and Carolina bay classes. Predicted species richness was higher than captured in bottomland hardwood, mixed, hardwood slope, and sandhill land cover types. The commission error rates were higher than omission error rates (Table 1).

GAP Land Cover as a Base Map **-** Herpetofauna species richness based on our monitoring program varied from 4 to 10 species per land cover type, while mammal species richness varied from 1 to 5 species, and combined captured species richness varied from 5 to 15 species. GAP-predicted herpetofauna species richness varied from 1 to 11 species, predicted mammal species richness ranged from 2 to 6 species, and combined predicted species richness ranged from 3 to 16 species.

There was spatial correspondence of herpetofauna species richness between species captured and those predicted by gap analysis in closed-canopy evergreen mixed forest/woodland. Captured species richness was higher than predicted in only the swamp-edge and wet evergreen classes. Predicted species richness was higher than captured in the remaining land cover types (Figure 2).

There was spatial correspondence of mammal species richness in the swamp-edge land cover only. Captured species richness was higher than predicted in two land cover types, while predicted species richness was higher in the remaining seven land cover types, ranging from one to four more species.

For overall richness, there was no spatial correspondence for any land cover type. Captured species richness was much higher than predicted in the wet evergreen, closed-canopy evergreen mixed forest/woodland, and swamp-edge classes. The predicted species richness was higher than actual richness in the remaining land cover types. The commission error was higher than omission error for both the area and land cover calculations, with the exception of percent agreement area for mammals (Table 2).

Nodes of highest richness - Using the SRS land cover base map, five of the seven land cover types were predicted to be within the node of highest richness, but only one land cover type (swamp-edge) qualified based on captures. Mammals were predicted to have five species-rich land cover types, while only three occurred (bottomland hardwood, Carolina bay, and swamp-edge). Herpetofauna was predicted to have six species-rich land cover types, while only one (swamp-edge) occurred (Table 3).

In the GAP base map, eight of the ten applicable land cover types were predicted to be species-rich, while only one (swamp-edge) qualified based on captures. Mammals were predicted to have seven species-rich land cover types, while only three occurred (swamp-edge, bottomland floodplain, and wet evergreen). Herpetofauna were predicted to have eight species-rich land cover types, while only one (swamp-edge) occurred (Table 4).

Discussion

Conserving areas of high species richness is the most efficient and cost-effective way to retain maximal biological diversity (Scott et al. 1987). The high commission rate we documented suggests a need to refine the GAP vertebrate modeling process. However, given that Gap Analysis is a tool for predicting vertebrate distributions for use in conservation planning, Edwards et al. (1996) argue that commission error is preferred over omission error. High omission error could possibly lead to the exclusion of species from conservation plans. The best assessment of a model's accuracy is to test it with some independent data. Therefore, we modeled species within the SRS area that were commonly captured to test the SC gap analysis. South Carolina was under drought conditions for the duration of this study, which may have affected species abundance and trappability. Animals captured within a land cover class harboring < 5% of the total individuals of that species were assumed to be transient in that land cover class, which could lead to an additional source of commission error. For example, captures of 20 eastern narrow-mouthed toads in Carolina bays and 23 in bottomland hardwood sites were insufficient (i.e., 5% of 515 captures = minimum of 26 animals) for inclusion of these land cover types as occupied by the species. On the other hand, if a certain land cover patch was located between a breeding site and the resident land cover type, it could be a secondary habitat for that species. Failure to detect a species on a site may simply be due to trapping difficulty, natural rarity, or spatial or temporal variability in habitat use rather than the absence of the animal.

Different classification schemes aggregate differently within and among land covers. Thus, converting between classification systems can increase the commission and omission errors of the models. For herpetofauna and mammals combined, the range between predicted and captured richness was greater (by six species) when cross-walking SRS land cover into GAP land cover than when converting GAP to SRS. There were several land cover classes that were not clearly delineated in the SC gap analysis, which may have led to failure of animal-habitat associations to predict occurrence within the correct spatial area. For example, SC-GAP could not reliably separate the land cover types of swamp and bottomland hardwood. Also, none of the 194 Carolina bays (786 ha) known to occur on the SRS area were present on the SC-GAP map; therefore, we could not include that class in the GAP-based model.

One way to improve vertebrate models is to determine the sources of commission errors. Two possible sources are that habitat associations may be incorrect, or species models are too simplistic. If the former is the case, monitoring and sampling programs can provide information with enough spatial and temporal breadth to refine associations and hence improve models. In the latter case, models can be improved utilizing current knowledge that blends landscape ecology and population viability. Inclusion of landscape metrics may improve species models and give the user more confidence in management decisions based on output of the models. For example, Allen et al. (2001a) incorporated minimum critical area criteria into species models to reduce commission errors arising from considering an animal as present in a patch too small to support a population of that species. Most likely, commission errors propagate from a combination of these sources. Further refinement of the vertebrate modeling process will improve the accuracy of predictive models.

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Table 1. Error table based on the SRS land cover base map.

	AREA			LAND COVER		
Common name	% area agree (A)	% omission error (O)	% commission error (C)	% land cover agree (L)	% land cover omission (LO)	% land cover commission (LC)
marbled salamander	53.94	0.00	46.06	42.86	0.00	57.14
eastern narrow-mouthed toad	17.66	0.00	82.34	28.57	0.00	71.43
southern cricket frog	20.62	0.00	79.38	42.86	0.00	57.14
southern toad	75.03	0.00	24.97	85.71	0.00	14.29
slimy salamander	23.80	14.94	61.26	57.14	14.29	28.57
southern leopard frog	25.70	36.28	38.02	57.14	14.29	28.57
eastern spadefoot toad	43.69	0.00	56.31	57.14	0.00	42.86
fence lizard	31.11	55.84	13.05	42.86	42.86	14.29
southeastern crowned snake	63.72	36.28	0.00	85.71	14.29	0.00
ground skink	94.92	0.00	5.08	85.71	0.00	14.29
green anole	25.70	36.28	38.02	57.14	14.29	28.57
eastern woodrat	81.28	1.06	17.66	57.14	14.29	28.57
golden mouse	17.66	1.06	81.28	28.57	14.29	57.14
opossum	75.03	0.00	24.97	85.71	0.00	14.29
cotton mouse	32.60	37.35	30.05	42.86	28.57	28.57
raccoon	50.67	36.28	13.05	71.43	14.29	14.29
southern short-tailed shrew	34.13	40.89	24.97	57.14	28.57	14.29
Average/species	45.13	17.43	37.44	62.18	9.24	28.57
Average herpetofauna accuracy	43.26	16.33	40.41	61.04	6.49	32.47
Average mammal accuracy	48.56	19.44	32.00	64.29	14.29	21.43

Table 2. Error table based on the Gap Analysis land cover base map.

	AREA			LAND COVER		
Common name	% area agree (A)	% omission error (O)	% commission error (C)	% land cover agree (L)	% land cover omission (LO)	% land cover commission (LC)
marbled salamander	59.99	0.00	40.01	50.00	0.00	50.00
eastern narrow-mouthed toad	5.93	0.00	94.07	40.00	0.00	60.00
southern cricket frog	18.12	0.07	81.81	30.00	10.00	60.00
southern toad	78.60	0.07	21.33	70.00	10.00	20.00
slimy salamander	24.53	0.07	75.40	60.00	10.00	30.00
southern leopard frog	24.30	54.13	21.57	50.00	20.00	30.00
eastern spadefoot toad	27.26	0.00	72.74	60.00	0.00	40.00
fence lizard	34.14	65.71	0.15	50.00	30.00	20.00
southeastern crowned snake	39.60	60.40	0.00	70.00	30.00	0.00
ground skink	92.30	0.07	7.63	70.00	10.00	20.00
green anole	24.30	54.13	21.57	50.00	20.00	30.00
eastern woodrat	94.07	0.31	5.62	60.00	20.00	20.00
golden mouse	5.93	0.00	94.07	40.00	0.00	60.00
opossum	78.67	0.00	21.33	80.00	0.00	20.00
cotton mouse	16.91	54.13	28.96	40.00	20.00	40.00
raccoon	45.62	54.06	0.31	70.00	10.00	20.00
southern short-tailed shrew	38.68	61.29	0.03	40.00	50.00	10.00
Average/species	41.70	23.79	34.51	56.47	12.94	30.59
Average herpetofauna accuracy	39.01	21.33	39.66	54.55	12.73	32.73
Average mammal accuracy	46.65	28.30	25.05	60.00	13.33	26.67

Table 3. Correspondence of nodes of highest richness (top 20%) using SRS land covers. Provided in the body of the table is the number of species captured and the number of species predicted and whether or not that places richness in that land cover within the top 20% of actual or predicted richness ("yes" or "no").

	Number of Species Captured			Top 20%[1]			Number of Species Predicted			Top 20%[1]		
Land cover	Herpetofauna	Mammal	Total	Herpetofauna	Mammal	Total	Herpetofauna	Mammal	Total	Herpetofauna	Mammal	Total
Bottomland hardwood	6	5	11	NO	YES	NO	10	6	16	YES	YES	YES
Carolina bay	7	6	13	NO	YES	NO	9	3	12	YES	NO	NO
Hardwood slope	6	4	10	NO	NO	NO	11	6	17	YES	YES	YES
Mixed forest	7	4	11	NO	NO	NO	11	6	17	YES	YES	YES
Planted pine	6	4	10	NO	NO	NO	6	2	8	NO	NO	NO
Sandhill	4	1	5	NO	NO	NO	11	5	16	YES	YES	YES
Swamp	10	5	15	YES	YES	YES	9	5	14	YES	YES	YES

[1]Top 20% = 14 of 17 total species, 9 of 11 herpetofauna species, and 5 of 6 mammal species

Table 4. Correspondence of nodes of highest richness (top 20%) using GAP land covers. Provided in the body of the table is the number of species captured and the number of species predicted and whether or not that places richness in that land cover within the top 20% of actual or predicted richness ("yes" or "no").

	Number of Species Captured			Top 20%[1]			Number of Species Predicted			Top 20%[1]		
Landcover	Herpetofauna	Mammal	Total	Herpetofauna	Mammal	Total	Herpetofauna	Mammal	Total	Herpetofauna	Mammal	Total
S	10	5	15	YES	YES	YES	9	5	14	YES	YES	YES
BF/F	6	5	11	NO	YES	NO	9	6	15	YES	YES	YES
CCEF	6	4	10	NO	NO	NO	6	2	8	NO	NO	NO
NEMF	4	1	5	NO	NO	NO	11	4	15	YES	NO	YES
PW	4	1	5	NO	NO	NO	11	5	16	YES	YES	YES
DDF	6	4	10	NO	NO	NO	10	5	15	YES	YES	YES
MD	6	4	10	NO	NO	NO	9	6	15	YES	YES	YES
DMF	7	4	11	NO	NO	NO	9	5	14	YES	YES	YES
MMF	7	4	11	NO	NO	NO	9	6	15	YES	YES	YES
WE	5	6	11	NO	YES	NO	1	2	3	NO	NO	NO

[1]Top 20% = 14 of 17 total species, 9 of 11 herpetofauna species, and 5 of 6 mammal species

[2] S=swamp-edge, BF/F=bottomland floodplain forest, CCEF= closed canopy evergreen forest/woodland, NEMF=needle-leaved evergreen mixed forest/woodland, PW=pine woodland, DDF=dry deciduous forest/woodland, MDF=mesic deciduous forest/woodland, DMF=dry mixed forest/woodland, MMF=mesic mixed forest/woodland, WE=wet evergreen

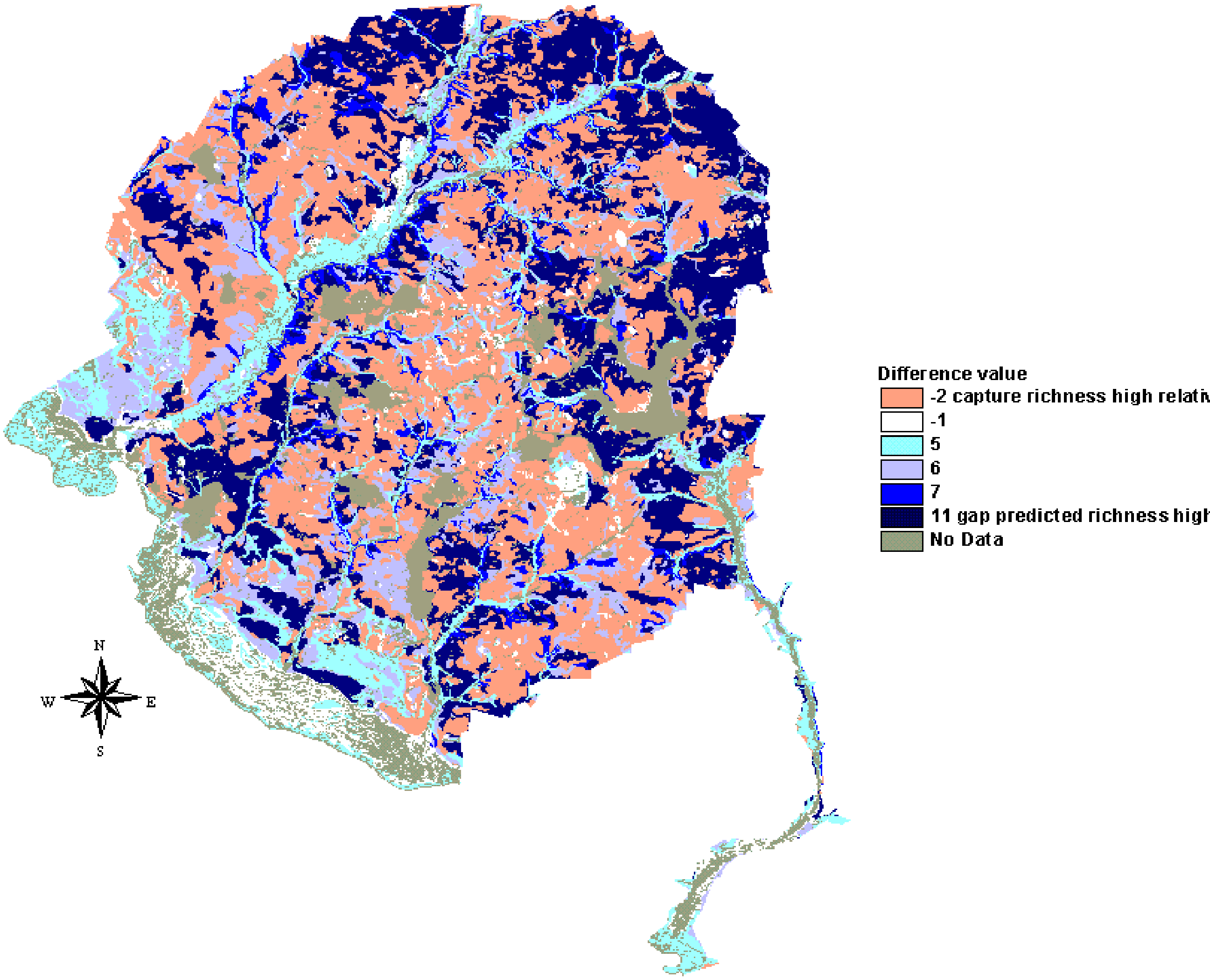

Figure 1. Spatial correspondence of species richness using SRS land cover.

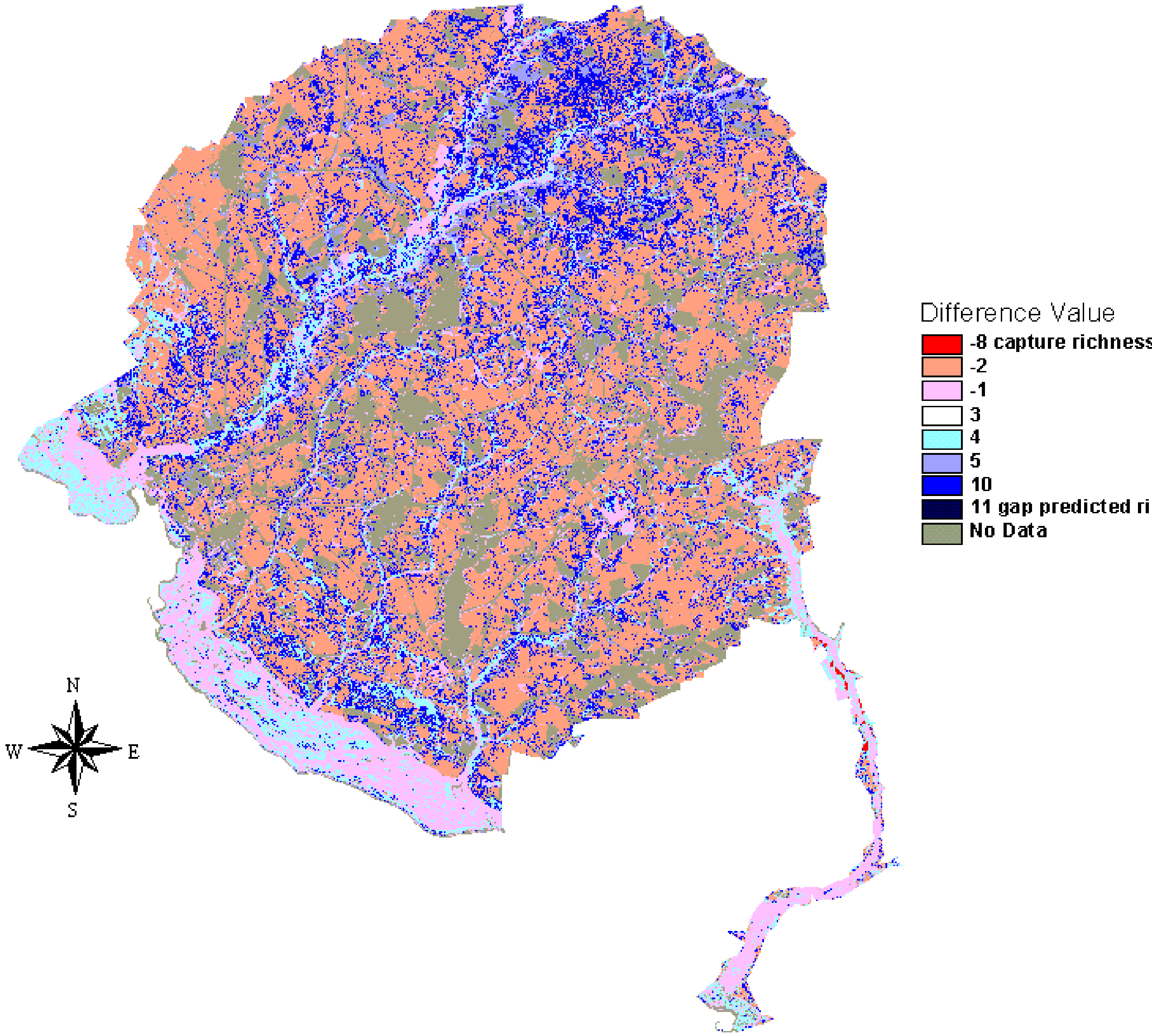

Figure 2. Spatial correspondence of species richness using GAP land cover.

Modeling Avian Habitat from Species Occurrence Data and Environmental Variables: Assessing the Effects of Land Cover and Landscape Pattern

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Introduction

The Nebraska Gap Analysis Project (NE-GAP) has used recursive partitioning to develop statistical models that relate species occurrence data (in the form of museum voucher specimens or curated surveys) with a suite of environmental variables (Henebry et al. 2001). Here we describe the results of using different kinds of land cover data in the development of habitat models for ten bird species.

Methods

To generate the habitat models we used QUEST (Quick, Unbiased, & Efficient Statistical Trees; Loh and Shih 1997), a recursive partitioning algorithm similar to CART (Classification & Regression Trees; Breiman et al. 1984, De'ath and Fabricius 2000). QUEST has several advantages for habitat modeling: it is much faster than CART, variable selection is unbiased, handles categorical predictor variables with many categories, and uses automated cross-validation (Shih 2002). The motivation for using this strategy is two-fold. Not only are the resulting trees of decision points and values that form the models understandable, debatable, and tunable, the nonparametric modeling can handle the multimodalities likely to be found in species occurrence data.

Species occurrence data was gathered from route-level composites of the USGS Breeding Bird Survey (BBS; www.pwrc.usgs.gov/bbs) and circle composites of The National Audubon Society's Christmas Bird Count (CBC; www.audubon.org/bird/cbc/) for the period 1970-2000. Given the intensive repeated observations, if a species was not reported along a sampling unit during the study period, it was considered absent.

The suite of environmental variables (land cover, climate, soils, terrain) included in the modeling process are described in Henebry et al. (2001). Modeling was performed across a hexagonal grid produced by the EPA EMAP program with a cell resolution of about 40 km^2 within Nebraska. Each variable was rescaled from its raster resolution (30 m for land cover, soils, and terrain data and 1500 m for climate variables) to the coarser hexagonal coverage. Continuous variables were rescaled by area-weighted averaging. Categorical variables were represented as a compositional vector. All environmental variables contained within the hexagons that intersected BBS routes or CBC circles were associated with the species occurrence data at those sampling locations.

Two separate land cover classifications were used: the NE-GAP land cover product and the USGS National Land Cover Data (NLCD). We also included the several variables from the National Land Cover Pattern Data (NLCPD), which is based on the NLCD (Riitters et al. 2000). We used five of the landscape metrics in the NLCPD: contagion, forest fragmentation, forest-area density, human-use index, and land cover diversity (cf. Riitters et al. 2000). Spatial filters or fixed-area windows were applied to the NLCD map to generate the NLCPD maps. A pixel in a pattern map incorporates information from the surrounding 65.61 ha (27 x 27 window) in the original NLCD map (Riitters et al. 2000).

The pattern metrics were reclassified from continuous indices on the unit interval [0, 1] to a categorical scheme that indicates landscape connectivity. Forest-area density and human-use index were regrouped using the critical thresholds (CT) predicted from percolation theory for random maps using various neighborhood rules (Turner et al. 2001). As neighborhood size grows, the CT for the emergence of high landscape connectivity drops. The 4, 8, 12, and 24-neighbor rules were calculated individually for these metrics and given a value of 0 (no value), 1 (below the CT), or 2 (above the CT). A Landscape Connectivity Indicator (LCI) was produced using the four neighborhood rules for both the forest-area density and human-use index (Table 1). For example, forest-area density LC class 1 portrays wooded areas that are highly fragmented or isolated, since all of the values are below the CTs. As LCI class increases, the CT decreases, and the likelihood of landscape connectivity increases. The other pattern metrics (contagion, land cover diversity, forest fragmentation) were reclassified by quartiles. All landscape pattern indices were represented at compositional vectors within hexagons.

Table 1. Landscape Connectivity Indicator built from neighborhood rules. 0 = no value; B = below CT, no connectivity predicted; A = above CT, connectivity predicted.

	Neighborhood Rules			
LCI Class	**4**	**8**	**12**	**24**
0	0	0	0	0
1	B	B	B	B
2	B	B	B	A
3	B	B	A	A
4	B	A	A	A
5	A	A	A	A

Ten bird species native to Nebraska were considered. Of the six woodland species modeled, two species—gray catbird (*Dumetella carolinensis*) and song sparrow (*Melospiza melodia*)—utilize riparian areas, red-breasted nuthatch (*Sitta canadensis*) is found primarily in coniferous woodlands, and the remaining three species—eastern wood-pewee (*Contopus virens*), great crested flycatcher (*Myiarchus crinitus*), and red-bellied woodpecker (*Melanerpes carolinus*)—occur mainly in deciduous woodlands. We modeled two wetlands species—black tern (*Chlidonias niger*) and black-crowned night heron (*Nycticorax nycticorax*)—and two grassland species—eastern meadowlark (*Sturnella magna*) and greater prairie-chicken (*Tympanuchus cupido*).

Species were modeled using the following land cover information: (1) the NE-GAP land cover product; (2) the NLCD alone; or (3) the NLCD plus the NLCPD. Occurrence data and associated environmental variables for each species were submitted to QUEST. Resulting statistical trees were trimmed or pruned interactively by querying the hexagonal coverage of environmental variables to evaluate the sensitivity of the tree splits and assess model generality. The final tree served as the wildlife-habitat relationship model. It was inverted to produce the predicted habitat distributions for each species. Model fitness was evaluated in two ways: the proportion of the occurrences explained and the visual appearance of the predicted range distribution.

Results

Half of the NLCD models showed no significant difference from the NE-GAP models, and the other half exhibited worse fits (Table 2). Inclusion of the landscape pattern variables degraded the predicted range distribution in most cases. However, a forest-area density class improved the range predictions for one woodlands bird (great crested flycatcher) and one grasslands bird (greater prairie-chicken). Although land-cover diversity was the pattern variable most frequently selected by QUEST, it failed to improve range predictions. Inclusion of the human-use index, which is keyed to agriculture land use, also did not yield improvements over the NE-GAP model. Neither contagion nor forest fragmentation was selected for inclusion in any model.

Table 2. Fit of models using the NLCD or the NLCD+NLCPD compared to the model using the NE-GAP land cover product. Legend: + = better than NE-GAP; NC = no significant change; - = worse than NE-GAP.

Species	NLCD	NLCD + NLCPD	Habitat Type
Eastern Meadowlark	-	-	Grasslands
Greater Prairie-Chicken	-	+	Grasslands
Black Tern	NC	-	Wetlands
Black-crowned Night Heron	-	-	Wetlands
Eastern Wood-Pewee	NC	NC	Woodlands
Gray Catbird	NC	NC	Woodlands
Great Crested Flycatcher	-	+	Woodlands
Red-bellied Woodpecker	-	-	Woodlands
Red-breasted Nuthatch	NC	NC	Woodlands
Song Sparrow	NC	NC	Woodlands

Conclusions

1. The land cover classification scheme does indeed make a difference in habitat modeling. Models developed using the NLCD alone performed as well as or worse than the models developed with the NE-GAP land cover. The principal reason for this performance difference is the greater thematic resolution available in the NE-GAP land cover. The NLCD uses 21 classes for the entire conterminous US; in contrast, NE-GAP uses 20 classes in Nebraska alone. In the NLCD, over half of Nebraska is assigned to the "Grassland/Herbaceous" cover type. This broad brush obliterates distinctions between grassland communities that are very different in terms of species composition, canopy structure, and net primary productivity. The additional discrimination among grasslands communities produces more specific habitat models that yield predicted ranges that are more restricted geographically.

2. Spatial information available through the NLCPD can provide useful additional variables for the modeling process. However, their utility needs to be evaluated on an individual basis. Inclusion of our Landscape Connectivity Indicator based on the NLCPD forest-area density variable yielded improvements in two cases. However, for most species inclusion of landscape pattern variables failed to improve and even degraded range predictions.

3. Developing habitat models using statistical trees generated from species occurrence data and environmental variables can lend a greater degree of objectivity to modeling process, but there is still considerable subjectivity in the pruning stage that is necessary for model generality.

Acknowledgments

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Cross-Border Species Distribution Modeling: An Invitation for Partners from the United States

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A new project is under way in Canada aimed at developing potential distribution maps of thousands of native and horticultural plant species (http://g4.glfc.cfs.nrcan.gc.ca/ph_main.pl). The approach is to develop a climatic profile for individual species using new continent-wide climate models. These climatic profiles will be mapped, giving an indication of the possible range of species in relation to meso-scaled climate. We are inviting participation from plant professionals, Master Gardeners, and the public in both Canada and the United States. This note provides some general background information and history behind the project and finishes with an invitation to participate.

Potential Species Distribution Modeling in Canada—"Gaps" and Opportunities

At this stage, prospects for undertaking a full-fledged Gap Analysis-type program in Canada similar to that under way in the United States seem limited. Canada is a large country with over 400 million hectares of forest land out of a total land area of over 900 million hectares (see http://www.nrcan-rncan.gc.ca/cfs-scf/national/what-quoi/sof/sof02/overview_e.html for additional statistics). It also has fewer biologists and fewer roads than the United States. Though Canada has no formal "Gap" program, there continues to be growing interest in species modeling generally (see Lipset-Moore et al. 2003 for a summary of a recent workshop on the subject of multi-scale species modeling needs and opportunities in Ontario). Most species modeling occurs under the aegis of forest or environmental management planning initiatives or species-at-risk planning and is therefore targeted at particular species.

A new project led by the Canadian Forest Service (CFS) in Sault Ste. Marie called "Going Beyond the Zones" is aimed at developing potential distribution maps for a large number of native and nonnative tree, shrub, perennial flower, and grass species. Ouellet and Sherk (1967) developed a plant hardiness zone map for Canada based on 7 different climatic variables and field trials at 108 locations across the country for 174 plant species. (The U.S. Hardiness Zone map is based on average extreme minimum temperature.) While work on plant hardiness has continued in several locations across Canada over the years, no new national mapping has occurred until recently (McKenney et al. 2001). That work applied the original plant hardiness model/formula but used more recent climatic data and more modern climate interpolation methods. Changes and obvious limitations in the old and updated zones has kindled interest in developing potential range maps based on more modern species modeling methods.

It is generally well accepted that climate imposes a constraint on plant distributions (Woodward 1987). A bioclimate envelope approach to species mapping has been developed by Henry Nix and colleagues at the Australian National University and has resulted in a set of tools now called ANUCLIM (http://cres.anu.edu.au/outputs/anuclim.html). Nix first applied this approach to the problem of mapping distributions of elapid snakes in Australia (Nix 1986; see also Busby 1991). The approach involves obtaining accurate location data for the plant or animal of interest. These data are used to generate a "bioclimatic profile" of the species using high-resolution climate models. The profile itself is mapped using grids of each of the variables in the profile. Only places that match the profile are mapped. Elith and Burgman (2002) compare ANUCLIM to several other species modeling/mapping approaches. They make the point that species model assessments should be based on the desired application. Our maps can be interpreted as estimates of the climatic domain of the species—a *potential* range as driven by meso-scale climate, based on estimates of climate where the species is known to occur. Presence-only data are required.

Lindenmayer et al. (1996) provide a good review of the ANUCLIM approach and an application to several commercially important eucalypt species in Australia. Scott et al. (2002) provide a more recent and richer source of literature associated with species modeling generally. The ANUCLIM approach has been successfully used for many ecological studies in Australia and a few other countries and is now being applied to various native and nonnative forest insects and diseases, birds, reptiles, and amphibians in Canada. The approach is described in a Canadian context in McKenney et al. (1998) with some results for reptiles and amphibians on-line at http://www.glfc.cfs.nrcan.gc.ca/landscape/herp_e.html.

Going North American

Significant effort has now been put into developing seamless climatic and topographic databases to run the ANUCLIM model throughout North America. For example, the USGS Digital Elevation Model (DEM) has been combined with a new Canadian DEM built by the CFS in partnership with the Canada Centre for Topographic Information. Most importantly, seamless climate models have been developed using thin plate smoothing splines as implemented by ANUSPLIN (http://www.glfc.cfs.nrcan.gc.ca/landscape/climate_models_e.html; Hutchinson 1995). ANUCLIM requires spatially continuous climate surfaces to generate bioclimatic profiles.

An important motivation behind the development of this capacity is increased concern over exotic, invasive species and prospects of rapid climate change. However, another appealing application is the development of potential distribution maps for native species and species of more general horticultural interest—our plant list includes both.

The greatest challenge for this project will be to obtain accurate and reliable location data. We are attempting to make use of the power of the Internet, public data, and expert knowledge and data. Our Plant Hardiness Web site enables location and survival data to be entered by experts and the public. Users identify the latitude and longitude of their location. If not provided, elevation, which is essential to achieve accurate climate estimates at each location, will be estimated using a DEM. Users identify which plants are surviving (at least three years) at that location from a comprehensive, but not exhaustive, plant list (currently ~ 6,500 species). Experience in the early stages of this project will influence decisions about adding other plants to the list. We are also asking users to enter some additional basic data about soil conditions and exposure, but this is not essential.

Experts and researchers who have larger quantities of data can contact us directly if they would like to contribute and would prefer to simply e-mail spreadsheet or flat files. Contributions can be confidential and their use restricted to this specific application. Any maps showing location data will only be coarsely georeferenced to no less than 5-10 km resolution to ensure confidentiality. We would also be most willing to provide climate estimates/profiles to scientific contributors, if desired (see http://www.glfc.cfs.nrcan.gc.ca/landscape/climate_models_e.html for a listing of sample variables). Such climate estimates can be useful for other scientific research.

Maps and Updates

Once sufficient data are entered, climatic profiles for individual species will be generated using several temperature- and precipitation-based variables. Range maps will be posted on our Internet mapping system. Thirty to fifty well-distributed observations are sometimes all that is required to generate reasonable, stable results. An important point, however, is that the maps can be updated relatively easily. Our hope is that both experts and the public will be enticed to contribute, especially if they see their particular area is not well represented.

Over time we will also develop at least two sets of climatic range maps. One set will be based on data from experts and the other based on the data from both experts and the public. We feel it is important to keep these data sources separate, because mistakes in plant identification are possible. We will strive to ensure data quality from all sources. If there appear to be discrepancies, these data will not be used. We will also generate models based on temperature variables only and temperature and precipitation variables combined.

Invitation to Provide Data

We hope the project is of interest to both Canadians and Americans. Plant data from the United States will greatly aid in developing more robust climatic profiles of individual plant species. To encourage participation from the United States, the potential range maps will include the United States. Already some data from the United States have been contributed, and plans are under way to extend some of the Tree Atlas work of Louis Iverson (USFS) and colleagues (http://www.fs.fed.us/ne/delaware/atlas/index.html) into Canada. More information on this project can be found on the “Going Beyond the Zones” Web site (http://g4.glfc.cfs.nrcan.gc.ca/ph_main.pl).

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Species Mapping for Conservation

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Efforts to protect a species or its habitat usually require that we know where it occurs and its likely abundance. Where management actions might harm a species of concern, it may be important to be sure that the species is absent from or rare at particular sites. The development of population models that are used for management often requires information on the distribution and abundance of species (Akçakaya et al. 1995). Broad-scale conservation planning, such as embodied by the Gap Analysis Program, also depends on information on the presence or abundance of species within large geographic areas (Possingham et al. 2000). Therefore, maps of the distribution and abundance of species are important tools for conservation management. In this article, we discuss the development, use, and evaluation of such maps.

Our article focuses on maps of species that are based on generalized linear models (GLMs), a particular class of statistical methods that includes simple linear regression and ANOVA. By including nonlinear terms, GLMs can incorporate nonlinear relationships between species and their habitat. Generalized additive models (GAMs), which are closely related to GLMs, can be used as an alternative to model nonlinear relationships. Details about GLMs and GAMs can be found in a range of sources (McCullagh and Nelder 1989, Hastie and Tibshirani 1990, Austin et al. 1984, Yee and Mitchell 1991, Guisan et al. 2002, Austin 2002). Most of our discussion about GLMs is also relevant to GAMs. We have focused on the use of GLMs partly because it is a method of species mapping with which we are familiar, but also because we believe it has clear advantages over alternative methods such as subjective judgement, envelope analysis, genetic algorithms, regression trees and neural networks (Elith and Burgman in press). GLMs provide a rigorous and statistically robust method for predicting the occurrence or abundance of species. The models are explicit and can be analysed for their ecological rationality (Austin 2002). They have the capacity for modeling complex relationships, including interactions, competition and population trends (Austin 2002, Fewster et al. 2000). Uncertainty in the predictions of GLMs can be assessed using confidence intervals, and the predictions can be tested (Guisan and Zimmerman 2000).

GLMs use data on the presence or abundance of species at sites. They relate these data to attributes of the sites, which become the explanatory variables of a regression model. The result is an equation that predicts the abundance or occurrence of a species based on the set of site attributes. For example, Parris (2001) developed a logistic regression equation for the probability of encountering the cascade treefrog (*Litoria pearsoniana*) at night along a 100-meter section of stream within forests of eastern Australia.

$$p = 1 / [1 + \exp(10.48 - 2.204.\log_{10}(C) - 2.037P)],$$

where C is the annual volume of rain falling in the watershed above the stream, and P=1 if palms are present at the site and 0 otherwise. Cascade treefrogs are found more frequently in moist forest, as indicated by the presence of palms, and at larger streams (Figure 1). Maps of species can be developed by extrapolating the predictions to other sites based on the site attributes (Figure 2).

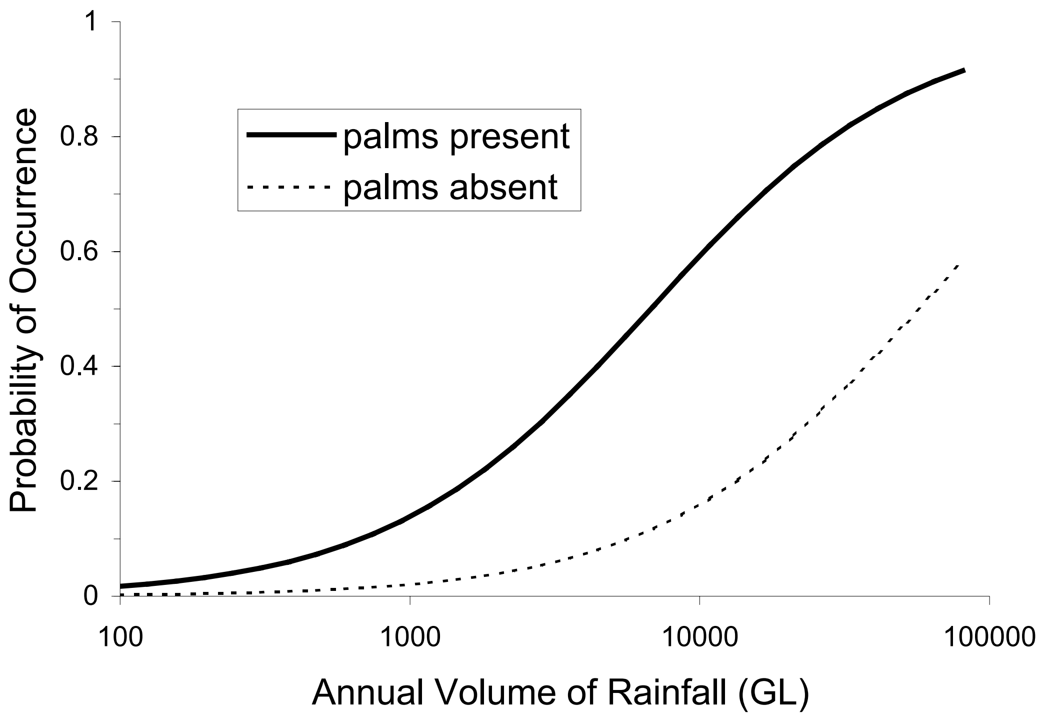

Figure 1. Logistic regression model of the probability of occurrence of the cascade treefrog (*Litoria pearsoniana*) as a function of stream size, measured by the annual volume of rainfall in the watershed upstream of the site and the presence or absence of palms (from Parris 2001).

There are numerous methods for determining which explanatory variables should be included in a regression model. For example, stepwise variable selection algorithm can be used to determine inclusion or exclusion on the basis of statistical significance. There are numerous philosophical and practical reasons, however, why this should not be done (Harrell 2001, Steyerberg et al. 2000). Stepwise variable selection will lead to biased estimates of the regression coefficients and their standard errors (Harrell 2001) and result in meaningless p-values for those variables that remain. An alternative method for variable selection is to use experts to choose the appropriate variables and then use the available data to estimate the parameters of the regression model. This approach is likely to produce better predictions than using statistical significance to determine whether a variable should be included in the model (Steyerberg et al. 2000). Where there is some uncertainty about which variables to include in the regression equation, multiple models can be developed and degrees of belief can be assigned to each (Burnham and Anderson 1998, Hilborn and Mangel 1997). In all cases, the ecological rationale behind the use of each variable needs to be clear. The best predictors are those that have a causal influence on species distribution at the scale of interest (Austin 2002).

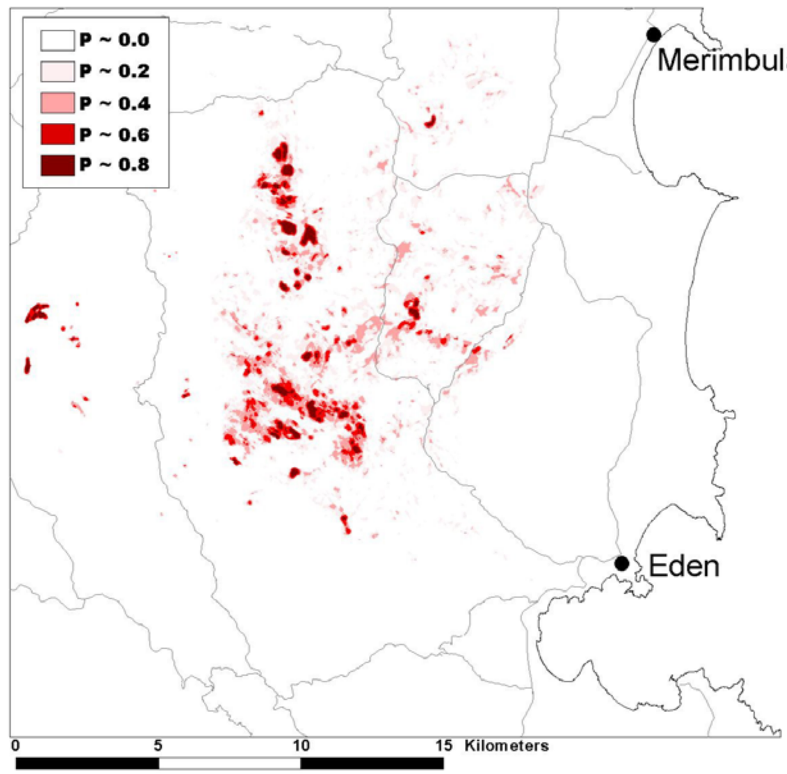

Figure 2. Spatially explicit prediction of the probability that *Leionema ralstonii*, a rare shrub associated with rocky outcrops of south-eastern Australia, will be present in a 25 m grid cell. The predictions were derived from a GLM with explanatory variables based on topography, mapped rock type, and aerial photo interpretation of the amount of outcropping rock in the vicinity of each site (from Elith 2002).

One question that must be addressed when developing a regression model is how many data points are necessary. One rule of thumb is that for each explanatory degree of freedom (df) there should be *a minimum* of 10 informative observations (Harrell 2001). When modeling abundance data, this is equivalent to 10 survey sites for each explanatory df. When using presence/absence data it is equivalent to 10 absence records or 10 presence records, whichever is least common. An alternative approach to determining the level of survey effort is to determine how the precision of the predictions varies with sample size. An appropriate sample size will depend on the acceptable level of precision and the available resources. An approximate rule of thumb is that the standard errors of the regression coefficients will be halved for each quadrupling of the sample size. Surveys that are stratified to cover the range of variation in the explanatory variables, with allocation of samples designed to minimize variances, are necessary for estimating the real relationships and are likely to require fewer samples for the same level of precision compared to simple random samples (Austin 1989, Guisan and Zimmerman 2000).

Maps of the distribution of species invariably contain errors. Because the predictions of GLMs are based on a statistical model, precision in the predictions can be quantified by constructing confidence intervals (Elith et al. 2002). Interpreting such confidence intervals depends on the level of risk that is acceptable to the resource managers and where the burden of proof lies. For example, in order to protect habitat of endangered species, developers might be required to ensure that the upper confidence interval of the predicted probability of occupancy is below a prescribed threshold. Alternatively, habitat might be protected only if we are reasonably sure that it is utilized by the species of interest, i.e., if the lower confidence interval is above a prescribed threshold. The actual choice will depend on the management objectives, the costs and risks of action or inaction, and the acceptability of different levels of risk. Development of statistically based habitat maps allows these risks to be determined more easily than with alternative methods.

Evaluating the quality of predictions is often an important part of any modeling exercise. We have chosen not to use the term validation, because it might imply to some readers that the aim is to prove the predictions to be true (or false). Clearly, such an aim is meaningless, because we know *a priori* that any prediction will be incorrect to at least some degree. Evaluating the predictions indicates the level of bias in the predictions (calibration) and whether the accuracy of the relative ranking of occupied versus unoccupied sites (discrimination). Different statistics are required for these different types of evaluation, e.g., logistic calibration equations (Miller 1991), area under the Receiver Operating Characteristic curve (Hanley and McNeil 1982), Kappa (Cohen 1960), and correlation (Zheng and Agresti 2000). It is also necessary to consider the source of the data that are used. Ideally, data would be derived from further survey, but various resampling methods, such as bootstrapping, can be used to good effect where cost is prohibitive (Steyerberg et al. 2001).

One of the main reasons that GLMs are not used for species mapping is that most of the available data are not suitable. The data should be collected in an unbiased fashion; however, for most species presences are more likely to be recorded than absences. In GLMs, absences are as important as presence records. It is possible to use presence-only data (Zaniewski et al. 2002), but this can only provide relative predictions of occupancy or abundance, not actual values. However, this is in one way an advantage of GLMs; they emphasize that unbiased predictions require rigorous data collection. Any biases in the data, such as a failure to detect a species when it is present, will propagate through to the predictions. Although there are some recent examples where researchers have attempted to estimate and compensate for these sorts of errors (Tyre et al. in review, Wintle et al. in review), it is important to be mindful of the possible biases that are likely to occur.

The confidence intervals developed using GLMs quantify the uncertainty in the predictions that arises due to random sampling error. They do not address error associated with incorrect model specification, biases in the data, errors in the explanatory variables, or ambiguity. However, such uncertainties could be quantified with multiple models and sensitivity analyses (Elith et al. 2002). A final word of caution is that occupancy or abundance may not reflect the habitat quality of the species (Tyre et al. 2001). In cases where habitat quality can be measured at sites (e.g., by measuring survival and/or reproductive rates), it is possible to construct a GLM of habitat quality.

In a conservation planning framework, the required level of detail and reliability of a predictive map should be determined primarily by the management context. This then has repercussions for data quality, selection of predictor variables, evaluation of predictions, and for how we communicate information about the final species map.

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AQUATIC GAP

Progress of the Aquatic GAP Project in the Lower Missouri River Basin

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The development of Aquatic GAP in the Lower Missouri River basin has involved the cooperation of scientists from Iowa, Kansas, Missouri, and Nebraska. The framework for this project was developed by the MoRAP Aquatic GAP pilot project, which has developed a hierarchical approach to classification of aquatic systems in Missouri. The objective of the joint effort in the Lower Missouri River basin is to work cooperatively among states and with various stakeholders from state, federal, private, and academic institutions to develop standardized methods to prioritize conservation of aquatic systems in this region. Our current goals are to (1) classify stream reaches in terms of habitat quality for aquatic species, (2) define range extent and habitat affinity of aquatic species using existing collection data, (3) develop models predicting presence of aquatic species, (4) generate predicted distributions of these species in the region, and (5) guide conservation planning by evaluating regions of predicted species occurrence in relation to riparian land use and stewardship.

Aquatic habitats in the Lower Missouri River basin are unique and represent a wide range of community and habitat types. The High Plains and Till Prairies have been markedly influenced directly or indirectly by glaciation and typically have low-gradient streams and rivers. Streams that transect the Sand Hills in Nebraska are low-gradient systems but are dominated by groundwater input with very little organic loading and were historically clear-flowing systems. In contrast, streams that are associated with loess hills or alluvial plains are more turbid and have higher organic loads. Hydrologic conditions in the region are quite dynamic, and the life histories of species occupying these streams reflect their evolutionary history under these conditions. Species living in western river systems, such as the Platte and Kansas Rivers, are particularly adapted to extreme changes in climate that includes severe flooding as well as prolonged droughts. In contrast, organisms living in the Flint Hills and Ozark Plateau in Kansas and Missouri are adapted to clear, spring-fed streams and rivers. The highest faunal diversity in the region occurs in the Ozark Plateau, where precipitation patterns and an abundance of springs provide a more stable environment for aquatic life.

Human intervention in the form of pumping aquifers, changes in land use, construction of impoundments, and the introduction of nonindigenous species has stressed the organisms living in these already harsh systems, and many are in need of conservation. In particular, large-bodied fishes in major river systems, such as pallid sturgeon (*Scaphirhynchus albus*), blue sucker (*Cycleptus elongatus*), and several species of redhorse (*Moxostoma* spp.), have suffered major range contractions. Small-bodied fishes that occupy large plains streams (e.g., flathead chub, *Platygobio gracilis*) and spring-fed Ozark streams (e.g., Niangua darter, *Etheostoma nianguae*) are also threatened by human activities. Perhaps the fish species that is most indicative of changes to aquatic systems in this region is the Topeka shiner (*Notropis topeka*), which was once widespread and now only occurs in disjunct and isolated populations. Finally, freshwater mussels are perhaps the most highly endangered aquatic fauna in this region. For example, 60% of the native mussels in Kansas are in serious decline. A first step in conservation of this region will be to identify important biotic communities and habitat types.

Methods of classifying stream reaches for the Lower Missouri River were developed by MoRAP's Aquatic GAP pilot project. The classification of streams is a hierarchical approach with the finest scale of stream valley segments being nested within subsequently larger watersheds that are defined by both ecological and hydrogeomorphic characteristics. The base GIS layer that includes the stream network is based on the USGS/EPA 1:100,000 scale National Hydrography Dataset (NHD). Because there are a number of inconsistencies in these layers, a large effort has been put forth by all states to edit these coverages. Several tools have been developed to facilitate the processing of these layers; they are available on the Kansas Aquatic GAP Web page (http://www.ksu.edu/ksaquaticgap). Once properly formatted, there are numerous GIS tools, primarily developed by MoRAP and The Nature Conservancy, to characterize physical habitats of stream reaches. To date, NHD stream networks for Missouri and Kansas have been formatted, and GIS tools have been used to define various stream reach characteristics including stream size, gradient, and connectivity to higher-order streams. Coverages are to be completed for Iowa and Nebraska in 2003.

Another goal of the Aquatic GAP projects in the Lower Missouri has been to compile species distribution data and link collection sites to stream valley segments in the NHD. MoRAP has assembled species distribution data for fish, mussels, crayfishes, and snails and has validated much of this information through a peer-review process. Other states are in the process of compiling those data. To date, Kansas has compiled standardized fish and mussel community data from the Kansas Department of Wildlife and Parks and Kansas Department of Health and Environment from approximately 2,000 locations. Additionally, all records from the University of Kansas Museum of Natural History and Ft. Hays Natural History Museum have been acquired and are in the process of being linked to the stream network. Iowa also has compiled a large database of fish collections that includes 4,160 community fish samples dating from 1926-2002, with a total of 40,196 species occurrence records. These data will be included in the Iowa Rivers Information System (IRIS), a central data base that is accessible via the Internet. Once completed, there will be comprehensive lists of species distributions and conservation status for fishes in the entire Lower Missouri River basin.

A final challenge for the Lower Missouri GAP project will be to develop predictive models of species distributions. This task is the most daunting because of the complex effects of stream landscapes and confounding effects of zoogeography on determining species distributions. Additionally, many aquatic systems in this region are highly dynamic, and populations are quite variable. Preliminary results from MoRAP are promising and suggest stream systems can be accurately classified based on predicted species distributions. The MoRAP program is completing work on classifying streams into Aquatic Ecological Systems (AES) using a combination of ecological data from their species database, previous delineations of ecoregions, and hydrogeomorphologic data. This classification scheme will allow classification of aquatic systems that are distinct in both faunal composition and geomorphology, thus allowing managers to prioritize systems based on unique stream habitat types and unique faunal composition.

In summary, development of a standard conservation approach for the Lower Missouri River basin transcends state boundaries and will provide an ecologically meaningful scale to develop management strategies for aquatic system in this region.

Great Lakes Aquatic GAP Project

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Introduction

The goals of aquatic Gap Analysis are to map the biodiversity and habitats of aquatic species and to determine the gaps in the representation of these species and habitats within protected areas. Aquatic Gap Analysis is a relatively new component of the U.S. Geological Survey's (USGS) National Gap Analysis Program (GAP). Aquatic GAP pilot projects in Missouri, Ohio, and South Dakota are either well under way or nearing completion. In 2001, the USGS, in cooperation with several state resource-management agencies, began a regional Aquatic GAP project in the Great Lakes Basin (GL Aquatic GAP).

There are several reasons why an aquatic Gap Analysis is being undertaken in the Great Lakes Basin. This basin is a 196,520 square-mile, geographically distinct, and biologically rich region of the United States (U.S.) and Canada. It contains over 11,000 miles of coastline, a large concentration of wetlands, diverse forests, and hundreds of tributary streams of various sizes (U.S. Environmental Protection Agency and Government of Canada 1995; Figure 1). In the U.S., the drainage area includes parts of Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin.

Figure 1. The Great Lakes Basin in the United States and Canada. The shaded area represents the Great Lakes Basin.

The Great Lakes Basin is globally important because it contains approximately 18% of the Earth's fresh surface water (U.S. Environmental Protection Agency and Government of Canada 1995) and supports more than 30 communities of plants and animals found nowhere else (The Nature Conservancy 1997). The rivers, streams, wetlands, and coastal habitats of the Great Lakes Basin contain over 300 species of fish and are of major economic and ecological importance because critical life-history stages of many fish and other species depend on them (Greeley 1940, Jude and Pappas 1992, Whillans 1990). In 1996, 2 million anglers fished the Great Lakes and added more than $1 billion to the regional economy (Michigan Sea Grant 2000). The commercial fish harvest in the basin was 63 million pounds in 1996, bringing in more than $43 million (Michigan Sea Grant 2000). Although abundant data on assemblages of fishes and aquatic macroinvertebrates are available for the region, knowledge of the aquatic biodiversity is incomplete.

Despite the value of the aquatic resource, anthropogenic influences have reduced the availability of aquatic habitat and access to historical fish-spawning grounds and nurseries in the tributary streams, wetlands, and coastal margins of the Great Lakes. Preservation of biological diversity is a regional priority because of its strong connection to the economy and health of the surrounding human population and wildlife resources through tourism, recreation, fisheries, and water use for human needs and ecosystem function (Governments of Canada and the United States 2002, U.S. Environmental Protection Agency 2002, U.S. Policy Committee 2001).

Project Description

The goal of GL Aquatic GAP is to map the species distributions and diversity of fish and other aquatic species and their habitats and to identify gaps in the conservation of these species and associated habitats within the eight states in the Great Lakes Region. The seven project objectives are listed below.

1. Delineate and map ecologically similar drainage areas of the Great Lakes.
2. Classify aquatic habitats in rivers, streams, and in selected coastal margins and wetlands using regionally consistent methods.
3. Develop aquatic biological databases at state and regional scales.
4. Map the known and predicted occurrence and distribution of fish and other aquatic species in streams and selected coastal and wetland habitats.
5. Complete a gap analysis of fish and selected aquatic invertebrate species.
6. Serve these data and products on the Internet and on CD-ROM.
7. Analyze, synthesize, interpret, and publish results at statewide, lakewide, and basinwide scales.

The study team consists of biologists, hydrologists, and geographers from the USGS and several state agencies in Michigan, New York, Ohio, and Wisconsin. Due to the size of the Great Lakes Region, studies must be performed in stages, with future studies planned to start in other Great Lakes states when current studies are near completion. Studies that began in 2001 in Michigan, New York, and Wisconsin are planned for completion in 2006. The Ohio pilot study began in 2000 and is planned for completion in 2005 (see separate status report on Ohio in the State Project Reports section).

Each state-level gap analysis consists of work in three habitat types: streams and rivers, coastal margins, and wetlands. The latter two components are being investigated as pilot studies in 2001-06. Gap analyses of the open waters of the Great Lakes and inland lakes are not currently part of GL Aquatic GAP.

State-level and pilot studies begin with a low-intensity planning year that is followed by four years of intensive database development, analysis, animal-modeling activities, and gap analysis. Major products and publications are completed in the final (fifth) year. Active partners to date include the Michigan Department of Natural Resources (MDNR), New York State Department of Environmental Conservation (DEC), Ohio Lake Erie Commission, Ohio Environmental Protection Agency, Ohio Department of Natural Resources, U.S. Fish and Wildlife Service, and Wisconsin Department of Natural Resources.

Methods

Regional requirements for consistent and integrated information are being developed to allow synthesis of findings at statewide, lakewide, and basinwide scales. Many of the methods used in the pilot studies in Missouri and Ohio are used in GL Aquatic GAP. One of these methods uses Valley Segment Types (VSTs), a classification system based on channel characteristics, riparian zone features, total catchment area, other hydrogeomorphic features, and temperature (Missouri Resource Assessment Partnership 2000, Lammert et al. 1997). VST classification forms the basis for species modeling when coupled with data on known species occurrence and distribution.

The approach under development for the classification of coastal habitats, as for streams, is based primarily on physical features. For example, wetlands in the Ohio portion of the Lake Erie Basin are classified based on hydrology and vegetation, in cooperation with Ohio's terrestrial GAP study.

A centralized biological database is being developed in Oracle™ using data collected by government agencies or academic institutions and quality-assured by the USGS.[1] The centralized database will contain and serve aquatic species occurrence and abundance data at the basinwide scale. The ITIS (Integrated Taxonomic Information System) codification and naming system for fish species is used for standardization across the basin. The centralized database will serve GL Aquatic GAP biological data to the National Biological Information Infrastructure.

[1] The use of trade names is for identification purposes and does not constitute an endorsement by the USGS.

In preparation for gap analysis, the occurrence and distribution of aquatic species will be predicted for all stream segments and for selected wetland and coastal areas in the region. Predictive models of species occurrence in streams will incorporate existing species occurrence data and aquatic habitat characteristics (VSTs). Habitat models vary from simple extrapolation models to sophisticated multivariate models. The Genetic Algorithm for Rule-set Production (GARP; Stockwell and Peterson 1999), desktop version (Scachetti-Pereira 2002), is a statistical modeling approach being used for Ohio streams.

Progress and Preliminary Findings

In 2001, data acquisition was a priority in the Michigan, New York, and Wisconsin GAP studies. Map layers acquired include land cover (1994); surficial and bedrock geology; elevation (30-meter National Elevation Data); hydrography (National Hydrography Dataset [NHD], 1:100,000 scale); and ecoregions. In 2003, the VST classification will be developed from these layers. The original VST classification completed by the MDNR-Institute for Fisheries Research (IFR) in 1999 (Zorn et al. 2002) was recently updated to replace the RF3 river-reach file with the 1:100,000 NHD.

The centralized database under development will eventually contain data on aquatic species from well over 175,000 sampling sites in Michigan, New York, Ohio, and Wisconsin. Data from approximately 25% of these sites were collected from 1980 to 2001. Data from Michigan are available for 145 fish species collected from approximately 8,620 sampling sites. Data from New York are available for 179 fish species collected from approximately 135,400 sampling sites. Data from Ohio are available for 160 fish species collected from approximately 5,500 sites, 8 species of freshwater mussels collected from approximately 2,900 sites, and 20 species of crayfish and 2 species of freshwater shrimp collected from approximately 5,000 sites. Data from Wisconsin are available for 130 fish species collected from approximately 22,000 sites.

In 2002, coastal shoreline and bathymetric data for Lakes Erie and Ontario were acquired from the National Oceanic and Atmospheric Administration and from the U.S. Army Corps of Engineers. Potential pilot-study areas are being investigated; one in Lake Ontario and two each in Lakes Erie and Huron. From these candidate areas, three will be selected for a coastal gap analysis based on the amount of available data. Much of the available fish-occurrence data for nearshore areas of eastern Lake Ontario, a potential pilot-study area, have been obtained from the New York DEC and USGS.

In Ohio, biological database development and VST classification were completed in 2000 and 2001. The occurrence and distribution of 150 fish species were mapped, modeled, and compared in 2002 using simple extrapolation methods and GARP methods. Species modeling of Ohio crayfish and freshwater mussels are planned for 2003. In 2004, gap analysis will be undertaken in Ohio and will include an evaluation of diversity patterns of aquatic species in relation to human and natural factors as well as a comparison of the degree to which aquatic species are represented in protected areas versus unprotected areas.

Outreach and Publications

A Web site was established in August 2002 at the URL http://www.glsc.usgs.gov/GLGAP.htm. A USGS Fact Sheet on GL Aquatic GAP is planned for publication in 2003. A journal publication and a final report on gap analysis of fish, freshwater mussels, and crayfish in Ohio are planned for 2004 and 2005, respectively.

In October 2002, investigators from GL Aquatic GAP and the Missouri Resource Assessment Partnership met to discuss common methods and approaches to aquatic gap analysis. Semiannual meetings with state and local stakeholders and frequent presentations at scientific meetings and at Great Lakes regional workshops are important for communication of progress and to obtain feedback on the project.

In cooperation with The Nature Conservancy and the International Joint Commission, a daylong session entitled "Biodiversity Conservation in the Great Lakes Region" is planned at the 46th annual meeting of the International Association for Great Lakes Research (IAGLR) in Chicago, Illinois, from June 22 to 26, 2003. Presentations from the GAP Operations office; New York and Upper Midwest terrestrial GAP projects; the GL Aquatic GAP project; and from several U.S. federal and Canadian provincial agencies and nongovernmental organizations are planned.

For more information on GL Aquatic GAP, contact Donna Myers, Coordinator, U.S. Geological Survey, Columbus, Ohio, at dnmyers@usgs.gov or (614) 430-7715.

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Aquatic GAP: Regional Analysis of Biodiversity in the ACT/ACF Basins

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Justification

We are developing Aquatic GAP applications for two centers of aquatic biodiversity, the Alabama-Coosa-Tallapoosa (ACT) and Apalachicola-Chattahoochee-Flint (ACF) river basins. The ACT and ACF basins span broad ranges of physiographic settings and harbor exceptionally high levels of species richness and endemism, providing ideal opportunities for testing and refining approaches to predict species occurrences and community attributes in relation to physical variables. The ACT basin (58,708 km^2) originates in the Blue Ridge province of the Southern Appalachian Mountains in Georgia and Tennessee, drains extensive portions of the Valley and Ridge and Piedmont provinces in west Georgia and east Alabama, and of the Coastal Plan in lower Alabama and southwestern Georgia (note: most of the lower Flint River is in the Coastal plain). Physiographic and climatic diversity, combined with a geologic history of isolation punctuated by interbasin dispersal and protection from Pleistocene glaciation, have fostered development in the ACT of some of the highest levels of aquatic faunal diversity and endemism recorded in temperate freshwaters. At least 184 native freshwater fishes occur in the ACT (Warren et al. 2000). The Coosa River system alone contains at least 15 endemic fishes as well as remnants of an exceptionally diverse molluscan fauna (Bogan et al. 1995, Burkhead et al. 1997, Neves et al. 1997). The Chattahoochee and Flint Rivers (our focus in the ACF) together drain 44,607 km^2 of Georgia and east Alabama, including the Blue Ridge, Piedmont and Coastal Plain provinces. Fish and molluscan faunas are distinct from those in both Atlantic Slope drainages to the east and the ACT to the west and include at least 97 native fishes and 32 native mussel species (Couch et al. 1996, Brim Box and Williams 2000). One fourth of the native ACF mussel fauna is endemic to the basin (Brim Box and Williams 2000), along with at least six fish species (Warren et al. 2000).

The need for an Aquatic GAP application in these river systems is no less than urgent. At least 114 aquatic species in the ACT, Chattahoochee, and Flint rivers are considered imperiled as a result of habitat degradation and loss (Ziewitz et al. 1995). Federally listed animals include 6 mussels and 1 fish native to the Chattahoochee and Flint systems, 14 ACT mussel and snail species, and 10 ACT fishes. Levels of species imperilment likely underestimate the actual extent of loss for unique stream types with high water quality and faunal integrity. Conversion from forest to agriculture, urban growth, and river impoundment for hydropower and navigation have altered stream and river habitat throughout much of the basins. For example, dams and reservoirs impound approximately 44% of the ACT mainstem rivers and 64% of the Chattahoochee mainstem. Presently, parts of the region are experiencing some of the highest population growth rates in the nation, resulting in urban sprawl, impervious surface proliferation, and increasing pressures on streams for water supply. At least 16 water supply reservoirs are planned for construction on streams in the Coosa, Tallapoosa, Chattahoochee, and Flint systems in Georgia. Georgia, Florida, and Alabama are locked in an interstate controversy over water use and water allocation in these systems. Georgia has recently enacted legislation to facilitate removing some irrigated lands from production during extreme droughts in order to protect stream flows in the Flint River system. The intense and growing competition for water in these systems—to support population growth, expanding agriculture, industry, and hydropower and to provide for healthy stream communities—reflects the urgency with which scientifically sound tools are needed to facilitate landscape-level planning and biodiversity conservation.

Objectives

Our goal for this project is to develop methods and define appropriate scales for application of Aquatic GAP to all states by integrating terrestrial GAP with Aquatic GAP. Our specific objectives are to

1. define and build appropriate data layers for Aquatic GAP;
2. build and test predictive models for aquatic fauna distribution using hierarchical models and other statistical techniques; and
3. develop a decision support system for natural resource agencies.

Methods

This regional project will be conducted in the subbasins of the ACT/ACF basins, located primarily in eastern Alabama and western Georgia. As described above, these basins are diverse in both habitat (on multiple scales) and aquatic biodiversity. We will specifically conduct this research in the Upper Coosa River (above Weiss Reservoir), the Tallapoosa River, and the Flint River basins.

Full integration with the terrestrial GAP projects will be maintained through interaction with project steering committees and oversight committees for each of the activities. We will build data layers at various scales for use in developing faunal distribution models. In addition to using existing layers produced from AL- and GA-GAP projects, we will build on existing hydrography layers and create other layers that will be used in predictive models of aquatic species distributions.

Hydrographic Data - Within the study basins, subwatersheds (U.S.Geological Survey 6th code, 12-digit, hydrologic units; mean size 7,800 ha) comprise one basic unit for our landscape-level analysis. In addition, subwatershed boundaries have been delineated by hand based on digital raster graph (DRG) images or digital elevation models (DEM) of 1:24,000 and 1:100,000 USGS topographic quadrangles. In some cases, subbasins have been delineated by agencies (e.g., NRCS, AL). Definition of subwatershed boundaries at fine scales has been determined based on position in the drainage network, especially relative to features such as dams. Digital hydrography will be obtained either from USGS or from other agencies (e.g., 1:24,000 Georgia DOT linear hydrography files). Again, to determine appropriate scale of assessment, both 1:24,000 and 1:100,000 data will be used. Nested within each subwatershed, perennial streams will be divided into segments (*sensu* Frissell et al. 1986).

Landscape Data - We are in the process of determining landscape variables for each 12-digit HUC, delineated subwatershed, and stream segment. Various data layers have been obtained from the terrestrial components of GAP and include land use/land cover and stewardship coverages. Because the Alabama GAP LU/LC is not complete, we are using 1992 MRLC data as a basis for most models that include these layers. We are calculating landscape indices relative to these coverages, using either traditional methods or software such as FRAGSTATS (Cunha 2000). In addition, various features of terrestrial and aquatic landscapes have been related to distribution of aquatic fauna. Therefore, we are assembling other data layers from various sources. As examples, these include road density, dam density, point source discharges, and terrestrial nutrient sources located within 100 m of a stream (e.g., poultry farms). Landscape features identified on the stream segment scale include position in the drainage network (e.g., link magnitude and stream order), mean elevation, valley confinement, gradient, and flow regime (e.g., regulated versus unregulated).

Faunal Data - Faunal data will include fishes, aquatic reptiles and amphibians, and key groups of aquatic invertebrates depending on data coverage and availability. We have identified data regarding faunal distribution through a review of gray and published literature and through direct contact with biologists working throughout the region. We have made a particular effort to locate data that provide a broad geographic representation within the basins. Data from faunal collections in basins have been obtained from numerous sources. Observations were included in the database when they met several criteria: (1) sampling methods were documented either through written work or direct correspondence with the principal source, (2) the sampling site was spatially located either with direct geographic coordinates or by designation on a typical topographic quad, (3) the sampling date was recorded, and (4) aquatic species were principally targeted and recorded during sampling. We are matching historical data with contemporary records. Where data gaps exist (e.g., sites with historical but not current data), we will conduct surveys.

Because data quality can significantly affect analyses, we have examined various aspects of data quality. Rule sets have been developed for including data collected for previous studies and for weighting observations for analyses. For example, incorporating misleading evidence (i.e., false negatives) into distribution models can bias the models. Therefore, zero catch data will be weighted by an estimate of the probability of detecting a species or groups of species (e.g., Bayley and Peterson 2001).

Development and Testing of Predictive Models - We will compare and contrast several approaches for evaluating species status distributions and identifying unique or important areas, and estimate the relative accuracy of these approaches via 5-fold cross-validation (Breiman and Spector 1992). Responses of fauna to landscape variables will be assessed via hierarchical (aka multilevel) models. Fully hierarchical Bayes models and conditional models can use landscape data and segment-level characteristics simultaneously. Thus, the landscape data are used to provide "context" for the observed smaller scale (stream reach) phenomenon (e.g., aquatic community integrity/species status). For example, Dunham and Rieman (1999) found that some trout species did not occur in small landscape catchments although there was appropriate habitat. Explicitly incorporating this context has also been shown to increase the accuracy of empirical fish species detection estimates. Hierarchical models will allow for assessment of appropriate scales for application of Aquatic GAP.

To identify unique or important areas in terms of fish species diversity and the integrity and composition of fish communities, we will fit models relating landscape and stream segment characteristics (henceforth, predictors) to three basic community responses. First, we will estimate the degree of change in native community composition using the historical and current number of native taxa as dichotomous dependent variables and relate these to the predictors via logit (Agresti 1990) and hierarchical logit models (Bryk and Raudenbush 1992) in which segments are nested within subwatersheds. Second, we will estimate an index of biotic integrity (IBI) of each site and relate these to the predictors via simple linear and hierarchical linear models. The third approach will be to relate the distribution or status (*sensu* Thurow et al. 1997) of sensitive target taxa to the predictors via logit or similar categorical modeling techniques (e.g., Haas et al. in press). Comparisons will be made among the approaches by identifying critical areas based on the estimates from each technique (i.e., low degree of community change, high IBI score, strong populations of target taxa) and examining the degree concordance among predictions.

Development of a Decision Support System - Resource agencies require decision support tools for managing aquatic resources. The landscape-scale models developed in our project will provide a basis for developing tools for making decisions regarding future land management and sampling/monitoring decisions. For instance, we have recently (2002) initiated a concurrent project, funded by the Georgia Department of Natural Resources (GADNR), to develop quantitative decision models to assist the assessment and planning of river regulation and water resource development activities in the Flint River Basin. These spatially explicit tools will combine predictive models of current species distribution (from GAP) with flow, habitat, and aquatic community response models. To explicitly incorporate uncertainty, relationships between current species distributions, streamflow, habitat, and the aquatic community response will be modeled as conditional dependencies and recast as probabilistic networks (see Peterson and Evans 2003 for an example). The probabilistic network format then will allow us to integrate the model into user-friendly software that will be used by the GADNR to evaluate various flow scenarios. We also plan to develop similar Web-based decision support systems for other resource agencies managing aquatic resources in the ACT/ACF basins.

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Expanding South Dakota Aquatic Gap Analysis to the Upper Missouri River Basin

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The South Dakota Gap Analysis team has completed both the terrestrial and aquatic gap analysis for South Dakota, and a draft of the final report was submitted to the GAP Operations office in August 2002. We are now expanding our aquatic gap analysis to the Upper Missouri River Basin, which includes watersheds in Montana, Wyoming, North Dakota, South Dakota, Iowa, Minnesota, Alberta, and Saskatchewan (Figure 1). We are using fish species distributions to evaluate biodiversity at the watershed (10-digit hydrologic unit) and valley segment scale. Our methodology is based on that proposed by the Missouri Resource Assessment Partnership (MoRAP), who is working on a similar Aquatic GAP project for the Lower Missouri River Basin.

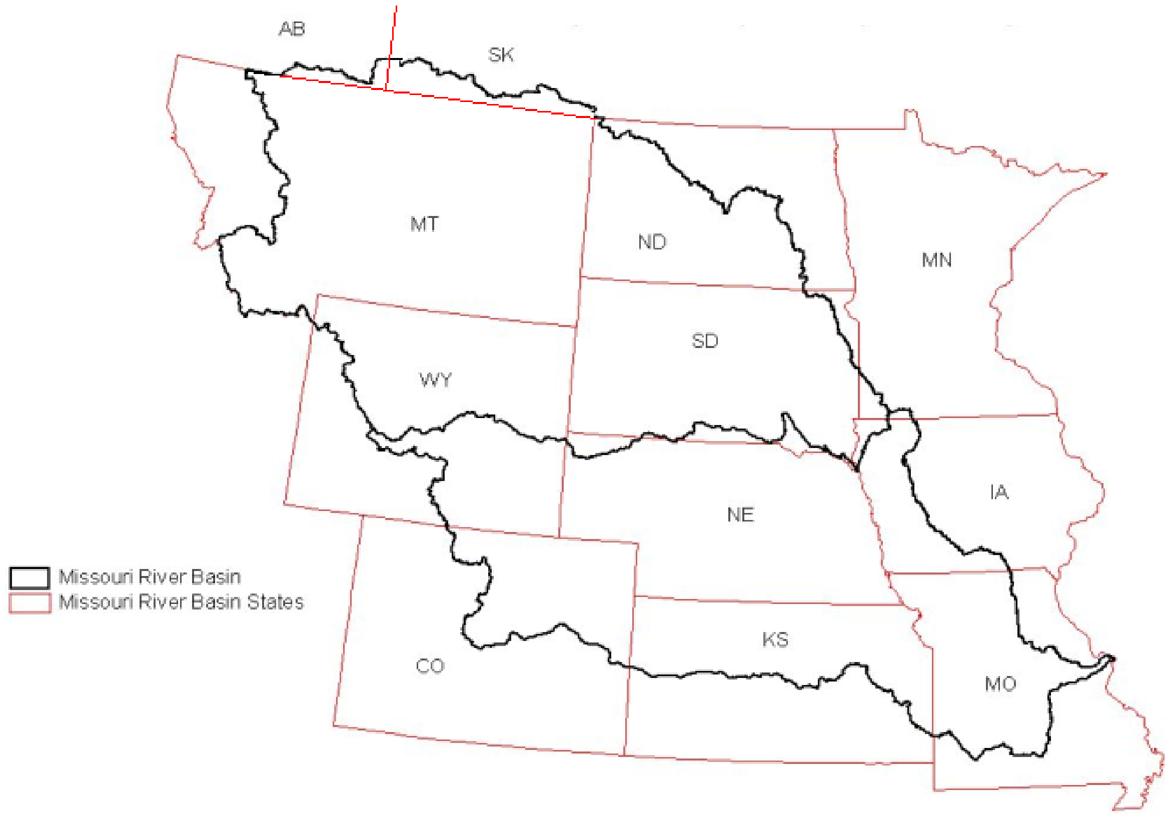

Figure 1. Missouri River Basin. The Upper Missouri River Basin includes portions of Montana, Wyoming, North Dakota, South Dakota, Minnesota, and Iowa, as well as Alberta and Saskatchewan in Canada.

There are essentially four steps to our project: (1) coordinate with various organizations across state and international boundaries to acquire necessary databases, (2) attribute fish species distribution and physical habitat features affecting fish distribution to stream (valley) segments, (3) predict the distribution of fish species at the valley segment and watershed scale based on physical habitat features and water quality, and (4) perform a gap analysis. Specific objectives are to

1. define range extents for all fish species within 10-digit hydrologic units occurring in the Upper Missouri River Basin based on collection data,
2. determine species richness by 10-digit hydrologic units,
3. define habitat affinities for each fish species occurring within the Upper Missouri River Basin based on literature review,
4. predict occurrence of each fish species in river reaches by similarity of stream properties to habitat affinities and fish collection sites,
5. determine protection offered each fish species by hydrologic unit and river reach using stewardship layers available from states and provinces,
6. coordinate with MoRAP to merge the Upper and Lower Missouri River Basin analyses.

Data Collection

For a gap analysis of this magnitude, over 30 agencies and organizations, some across state and international boundaries, had to be contacted to locate necessary data sets (Table 1). The completion of the South Dakota Gap Analysis Project made many data sets available and gave us a head start on data processing and analysis. GAP products from other states within our study area also supplied many data sets. Our base data sets include the National Hydrography Dataset (NHD), digital elevation models (DEM), surficial geology (1:500,000), 10- and 8-digit hydrologic units and equivalent-sized watersheds from Canada, land cover, land stewardship, ecoregional boundaries, and fish distributions from various state and federal agencies. We have collected most of the data sets for each state and province. A digitized data set of 10-digit hydrologic units for North Dakota was incomplete, and we are cooperating with the North Dakota Department of Health and several federal and state agencies to digitize 10-digit hydrologic units for our study area. Land cover and stewardship maps are not yet complete for North Dakota but will be completed by ND-GAP in time for our project.

Table 1. Data sets collected for the Upper Missouri River Aquatic GAP Project and organizations supplying the data.

Data Set	Montana	Wyoming	North Dakota	South Dakota	Minnesota	Iowa	Al
DEM	EROS	EROS	EROS	EROS	EROS	EROS	Di ho
Geology	MT BMG	WY Geological Survey	ND Geological Survey	SSURGO database	MN Geological Survey	IA Geological Survey	Al Su
Hydrography	EPA NHD	EPA NHD	EPA NHD	EPA NHD	EPA NHD	EPA NHD	Di ho
Fish data	MT RIS, MT FW&P, MT Coop	WY G&F, WY GIS, UWY, WY NDD	ND G&F, UND	SDSU, SD Coop, EDWDD, EMAP	MN DNR, BMNH	IA -GAP	Al Al Al
10-digit HUC	MT NRCS	WY GIS	Coordinating with ND DH	SD-GAP	MN NRCS	IA NRCS	PF
Land Cover	MT-GAP	WY-GAP	ND-GAP	SD-GAP	MN-GAP	IA-GAP	Di TM
Stewardship	MT-GAP	WY-GAP	ND-GAP	SD-GAP	MN-GAP	IA-GAP	Al
Ecoregions	EPA	EPA	EPA	EPA	EPA	EPA	El

PFRA = Prairie Farm Rehabilitation Administration, Agriculture Canada
EROS = Earth Resources Observation Systems
EMAP = US Geological Survey Environmental Monitoring and Assessment Program
EPA NHD = US Environmental Protection Agency National Hydrography Dataset
MT RIS = Montana Rivers Information Systems
MT FW&P = Montana Department of Fish, Wildlife and Parks
MT NRCS = Montana Natural Resources Conservation Service
UND = University of North Dakota
SDSU = South Dakota State University
SD Coop = South Dakota Cooperative Research Unit
EDWDD = East Dakota Water Development District
IA NRCS = Iowa Natural Resource Conservation Service
MN DNR = Minnesota Department of Natural Resources
BMNH = Bell Museum of Natural History

MT Coop = Montana Cooperative Fisheries Research Unit
MT BMG = Montana Bureau of Mines and Geology
WY G&F = Wyoming Game and Fish Department
WY GIS = Wyoming Geologic Information Systems Center
UWY = University of Wyoming
WY NDD = Wyoming Natural Diversity Database
ND G&F = North Dakota Game and Fish Department
ND DH = North Dakota Department of Health
MN NRCS = Minnesota Natural Resource Conservation Service
AB ESD = Alberta Environmental Sustainable Development
AB F&W = Alberta Fish and Wildlife Service
AB FMIS = Alberta Fisheries Management Information Systems
SK ERM = Saskatchewan Environment and Resource Management
SK CD = Saskatchewan Conservation Data Center
ISC = Information System Corporation of Saskatchewan
TM 7 = Thematic Mapper 7 Satellite Imagery

A digitized land cover for areas in Canada was not available at a scale compatible to land cover digitized in the USA. We produced a digitized map of land cover for our study area in Alberta and Saskatchewan from Landsat 7 Thematic Mapper (TM) imagery and are presently matching this coverage to the digitized land cover from Montana. The map has five land cover attributes important to aquatic ecosystems; these five categories match well with the trees, cropland, grasslands, water, and urban areas of Montana.

One problem we encountered when acquiring data sets from Canada was differences in licensing agreements. Many GIS data sets have been privatized in Canada, and we were unable to secure a licensing agreement that would allow us to possess or redistribute data derived from original data sets. We also experienced the same problem with data sets from the Canadian government. Fortunately we were able to negotiate a license agreement that suited our needs for the majority of our project area. For areas where we were unable to obtain usable data sets, we used topographic maps to digitize hydrography to match the NHD at a scale of 1:100,000. We also used contour lines to determine elevation and channel slope.

Stream Habitat Attributes

We are using the valley segment as our base stream unit for modeling fish distributions (Sowa 1998). A valley segment is a length of stream (typically 3 to 30 km long) that is relatively homogeneous with respect to hydrogeomorphic features such as hydrology, geology, and elevation. We are attributing valley segments with ten physical habitat affinities that affect fish distribution, including temperature, stream size, flow regime, channel gradient, size discrepancy, floodplain interaction, geology, elevation, stream connectivity, and groundwater input. Valley segment attribution and delineation are based upon a hierarchical classification system (Lammert et al. 1996) and procedures outlined by Sowa (1998). We are using GIS tools and procedures developed by The Nature Conservancy Freshwater Initiative (2002) and MoRAP for stream habitat classification, as well as our own innovations.

The NHD stream reach files were preprocessed to remove braided and ponded reaches not previously accounted for in the NHD data set. Stream segments within the USA have been attributed with all the above habitat affinities, with exception of groundwater input.

We have added attributes to most stream segments in Canada with exception of floodplain influence, flow regime, and groundwater input. We are using the Darcy groundwater model (Baker et al. 2000) developed by the Michigan Rivers Inventory (MRI) to attribute groundwater delivery to streams within the glaciated landscapes of our study area. For unglaciated landscapes, we are using GIS coverages of springs to estimate potential for groundwater delivery to streams based upon spring density and spring surface-depth. When we complete the attributing of habitat features, we will begin grouping features into classifications that represent the diversity of the entire region.

The stream data for South Dakota were processed using River Reach 3 hydrography (RF3) before the NHD data (which is now the national standard hydrography layer) became available. Transfer of RF3 data to NHD data with the help of procedures developed by The Nature Conservancy is 95% complete.

Fish Distribution

Fish location data have been obtained for all states and provinces within our study area. Wyoming and Montana supplied fish locations attributed to NHD, and other states and provinces provided point locations, which saved us much time. We have fish location data attributed to NHD reaches for all the states, with exception of fish locations for the Missouri River in North Dakota. We are also working on transferring fish location data to stream reaches in Canada. Known fish locations will be used in the production of species distributions by 10-digit watershed and in the valley segment-scale models.

Field Surveys

In the summer of 2000 two graduate students began a survey of an 8-digit hydrologic unit in North Dakota and Wyoming. They also will survey 8-digit units in Canada and Montana in the summer of 2003. Students stratified their effort by stream size (headwater, creek, small river, and large river) to survey a minimum of four sites of each stream size class and were able to survey about 16 sites in each 8-digit unit. Students also have collected water quality data and land cover data for each of the sites. This information will be used in our accuracy assessment of the predictive models by fish species. These and other data collected for the state of South Dakota (new data since South Dakota Aquatic GAP) will provide a separate data set not used in the production of our models to perform the accuracy assessment.

Analysis

Gap analysis of aquatic diversity has been completed for South Dakota. We modeled distributions of 116 fish species across South Dakota and assessed biodiversity of fish species and habitat in relation to land conservation. We found that the fishes of South Dakota have more protection than terrestrial animals. A few areas proposed for protection of mammals have the potential to provide additional protection for many aquatic species. However, the state is far from meeting any acceptable level of protection of all species and habitats for the entire state needed to conserve biodiversity.

Valley segment, species, and aquatic richness by 10-digit hydrologic unit have been completed for South Dakota Aquatic GAP (Figure 2). The valley segment richness map represents the number of unique valley segments by 10-digit hydrologic unit. The fish richness map represents the number of fish species predicted to be in each 10-digit hydrologic unit. These two richness maps were summed to produce the aquatic richness map that displays aquatic biodiversity in South Dakota. We plan to expand these procedures to map aquatic biodiversity for the entire Upper Missouri River Basin by 10-digit hydrologic unit. Our Web page located at http://wfs.sdstate.edu/sdgap/aquaticgap.htm has links to fish distributions by 10-digit hydrologic units, fish habitat affinities, and fish-habitat models by stream reach for South Dakota.

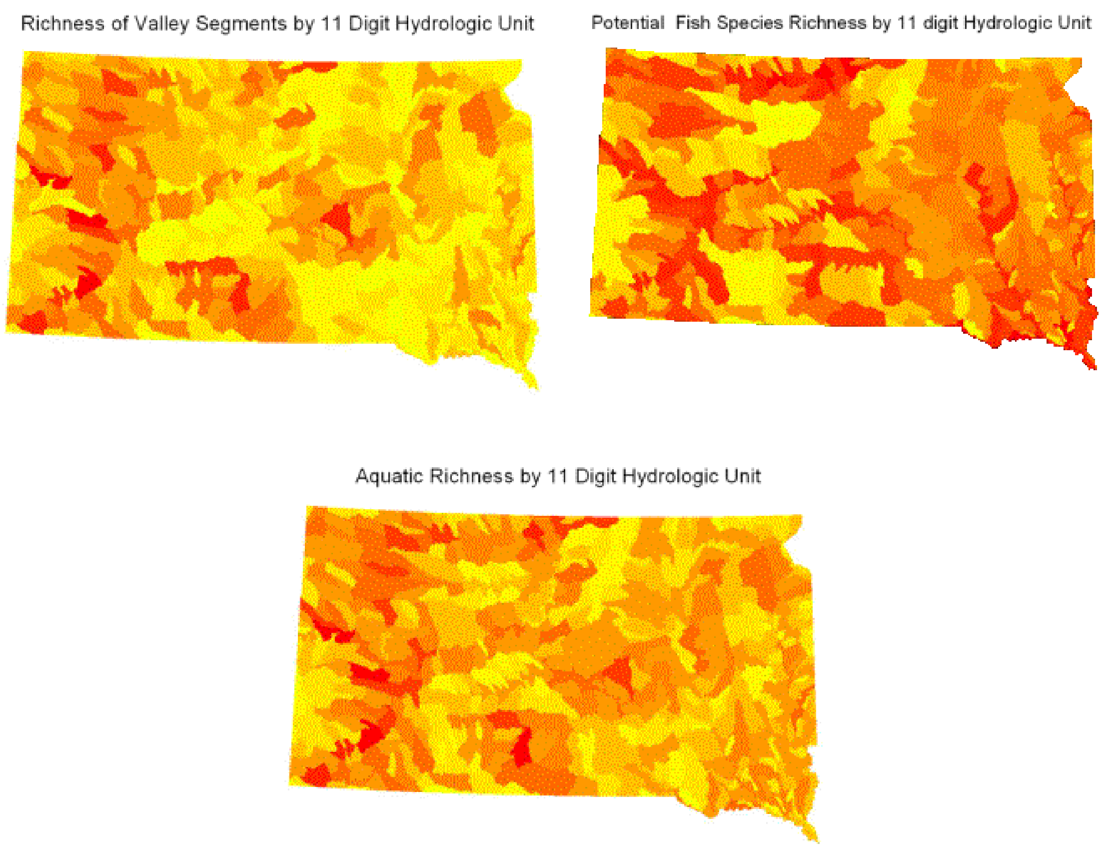

Figure 2. An example of valley segment (habitat) and fish species richness by 10-digit hydrologic unit for South Dakota from SD-GAP Project. Valley segment richness and fish species richness were combined to produce an aquatic richness map by 10-digit hydrologic unit showing aquatic biodiversity across the state.

Future Plans

We plan to complete attribution of physical habitat features and fish locations to individual valley segments by the end of March 2003. We will then complete a quality check and begin fish-habitat modeling. We are working with The Nature Conservancy to delineate ecoregional drainage units based upon ecoregions and major drainages to further classify fish distributions.

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APPLICATIONS

Building on GAP Land Stewardship Analysis: A Partnership Application with Local Government

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Introduction

In order to assist county governments in Washington State that are conducting wildlife protection planning as required by the state Growth Management Act (GMA), the Washington Cooperative Fish and Wildlife Research Unit, in collaboration with the University of Washington's Department of Urban Design and Planning (UW-UDP), has implemented a series of pilot projects that explore the utility of Gap Analysis at the local level.[i] The second project in this series was conducted in cooperation with Pierce County, Washington, and included the mapping of biodiversity resources, an analysis of the levels of protection being provided under existing policies and regulations, and a strategy for increasing that protection.[ii] This article specifically discusses how the land stewardship analysis and mapping methods developed by GAP were substantially modified to form the basis of a new stewardship analysis and to inform the development of a stewardship strategy applicable to local governments.[iii]

The GAP Handbook, in its introduction to *Mapping and Categorizing Land Stewardship* states:

> Two primary goals of GAP are to provide an assessment of the management status for certain elements of biodiversity (vegetation communities and animal species) throughout their U.S. range, and to provide land stewards with information on the representation of these elements on their land so they can make informed decisions about their management practices regarding biodiversity. To accomplish this, the mapped distribution of vegetation communities … is compared to a map of land stewardship. In GAP, the land stewardship map combines attributes of ownership, management, and a measure of intent to maintain biodiversity. As explained in the Analysis chapter ... *these comparisons do not consider viability, but are a start to assessing the likelihood of future threat to a biotic element from habitat conversion*—the most obvious cause of biodiversity decline (Noss et al. 1995) (emphasis added).

Collectively, local governments regulate vast areas of land, predominantly privately owned, that include immense biodiversity resources. Gap Analysis can make a significant contribution toward protecting such resources, but in order for local governments to utilize Gap Analysis data to help better manage lands for biodiversity protection, significant modifications to the standard Gap Analysis for stewardship are necessary.

First, we hypothesized that the concept of habitat conversion normally would remain meaningful, though less than ideal, if analyzed for "degrees of habitat conversion" rather than the preferred condition of "no conversion". We then discarded the premise that all private lands be considered homogeneously in a single protection class, such as Gap Stewardship Analysis currently considers the private lands over which counties and cities exercise their regulatory prerogatives. Instead consider that such lands have highly varied levels of protection, development, and use, including the degree to which they are protective of habitat.[iv] Moreover, the minimum 40-hectare mapping unit (100 ha land cover, 40 ha for wetlands) was discarded in favor of the significantly smaller-scaled parcels common to the fragmented ownership of rural and urban private lands.

We also identified a number of issues that were critical for bringing the benefits of these methods to local governments. First, there is a need for the inclusion of land use planners on teams performing this type of Gap Analysis, because they have the skills necessary to analyze the complex and diverse regulatory structures, which vary on a county-by-county and state-by-state basis. They are also well suited to bridging the "communication gap" between biologists, scientists, and local government. While it may seem trivial, it is essential that plain English be used in presenting the Gap Analysis methodology to local governments, as highly technical terminology tends to obscure the process for the citizens and politicians whose partnership is being solicited. Opportunities for partnerships utilizing these methods are thus lost.

Goals

A high priority was placed on designing a project that would provide a practical planning document useful to Pierce County for regulatory purposes. Additional goals were (1) to develop a repeatable Gap Analysis stewardship methodology for private land governed by counties in Washington State, (2) to assess the management status of private lands governed by the county's regulations, and (3) to develop a long-range implementation plan that integrates biodiversity stewardship values into the county's policies and land use regulations. The work described in this article explains the stewardship analysis aspects of the Pierce County project and its outcomes in relation to the above goals. (Mapping of high priority habitat was accomplished in an earlier phase by other team members).[2]

Methods

The project began with a review of the available GAP literature, with particular attention given to the criteria and assumptions underlying the GAP protection status classification scheme using Status 1-4. These assumptions included an assessment of the permanence of protection for natural vegetation, the amount of land managed specifically for such vegetation, the inclusiveness of the management for all species, type of management for natural factors, and relative strength of legal and institutional framework. The research team also reviewed the best available scientific research regarding habitat protection planning, conservation biology, biodiversity, landscape ecology, as well as contemporary innovations in conservation land use planning. Every effort was made to incorporate principles of conservation biology as a foundation of the stewardship analysis, as well as the principles incorporated into methods used in the GAP stewardship categorization scheme.[v]

In order to understand the land management options available to local government, statewide policies and laws that create the legal foundation for Pierce County's environmental and land use regulations were identified and analyzed. These included the Washington State Growth Management Act (GMA), the Shoreline Management Act (SMA), and the State Environmental Policy Act (SEPA). The Pierce County Comprehensive Plan policies and associated development regulations (e.g., zoning, critical areas, shorelines, etc.) were also analyzed for their ability to provide protection to identified biodiversity management areas.

The current stewardship chapter of the GAP handbook contains two objectives: (1) to develop a complete digital map of public land ownership categories and biodiversity management boundaries, and (2) to attribute each mapped land unit with categories of management Status 1 through 4.[vi] This model identifies private land (Status 4) as a single homogeneous category and then drops these lands out of further analysis or consideration (i.e., by assuming no level of protection). Unfortunately, those assumptions do not work well for a local government whose area of influence is primarily over private lands. For example, in the Pierce County pilot project 59% of lands in the biodiversity network proposed fall within Status 4 categorized lands. In order to develop a methodology more relevant for stewardship at the county level, the first step was to expand objective one to include all private lands. The second GAP objective was then refined to recognize different categories of private lands. This was achieved by breaking the Status 4 (private lands) category into meaningful subcategories of lands that are regulated in various ways by a local government.

Four different subcategories of private land ownership were established: 4a - most highly protected, 4b - moderately protected, 4c - slightly protected, and "inconsequential" - where little or no effective protection is offered. Status 1, 2 and 3 lands were discussed in terms of representing partnership opportunities with other governing land managers, e.g., partnering with the Washington Department of Natural Resources on permit conditions for forest practice activities within identified biodiversity management areas.

The research team borrowed GAP's four criteria for determining levels of biodiversity protection (permanence, land unit size, inclusiveness of management, and degree of protection) to inform the analysis of local Pierce County policies and regulations. The general concept of land unit size had to be reinterpreted as a function of relative size and degree of density allowed. For example, a Rural 40 zoning designation—one dwelling unit per 40 acres—would be considered relatively protected. Inclusiveness of management referred to the practice of managing for multiple species (proactive management vs. the reactive management of managing only for threatened and endangered species). Relative permanence was considered as a function of long-range planning policies.

The ability to map these attributes was also a key factor in their selection. A typical Gap Analysis requires three primary pieces of information for the stewardship layer: (1) geographic boundaries of land ownership, (2) the manager/owner attributes of each mapped unit, and (3) the biodiversity management status of each mapped unit.[vii] In Pierce County, GIS parcel data provided both boundary and ownership information. Since there are tens of thousands of parcel owners, these data were discarded in favor of an analysis of the regulatory authority of the local government that was the client. Maps that detailed a nexus between physical features and political boundaries, such as zoning, provided a logical substitution for parcel ownership.

Earlier literature reviews had identified positive and negative habitat characteristics as well as a palette of land use planning implementation tools. For example, zoning densities, setbacks, clustering, construction methods and best management practices, levels of impervious surface allowed, vegetation protection requirements and so forth have specific impacts upon wildlife. Similarly, shoreline designations regulate the types of activities permissible at a certain distance from the water. This affects shoreline habitat and access for wildlife. Critical areas rely heavily on buffer requirements, particularly for riparian features, wetlands, and documented point locations for certain biological and natural features.[viii]

From this it was determined that certain types of land use regulations provide the best opportunity to protect identified biodiversity management areas.[ix] Three regulations provided the primary foundation for protection: zoning regulations (govern allowable uses and densities); critical area regulations (regulate uses within wetlands, fish and wildlife habitat conservation areas, aquifer recharge areas, frequently flooded areas, and geologically hazardous areas)[x]; and shoreline regulations (establish land uses and densities in designated shoreline environments).

Within each set of regulations, matrices were developed that juxtaposed habitat values against regulatory classifications. Thus zoning regulations were reviewed for the relative amounts of corridor potential, buffering potential, impervious surface, resistance to conversion, roadedness, and size of units. Shoreline management regulations were reviewed for the numbers of specific activities allowed in each of the classified zones. These activities were not weighted for the degree of relative impact on the environment, though that is certainly suggested in future work. However, even this simple analysis revealed that the shoreline classification “Conservancy,” which implied a fair degree of protection, in fact allowed 18.5 of the 24 possible uses and included such high-impact uses as dredging and mining. Critical-area buffers were also reviewed against the actual buffers recommended by Washington State’s Departments of Fish and Wildlife (WDFW) and Ecology (WDOE), the frequency and basis for “variances” from the requirement, the standards for allowed activities, the presence of clauses protecting threatened and endangered species, and the strength of any enforcement mechanisms present. These matrices provided scoring systems against which certain geographic areas could be evaluated for degree of protection.

Certain regulations that provide protection for habitat and its natural functions were not able to be mapped as they dealt with permitted activities that could take place in a variety of locations. Regulations and policies of that nature were reviewed for impacts on habitat. Ultimately, strategies for improving protection were identified for both broad policies and specific regulations, whether or not they could be geographically mapped. These included the adoption of adaptive management principles, adoption of policies that support water-based zoning, creation of an open space/wildlife protection overlay zone, increases for buffers, reduction in allowed uses, elimination of inconsistencies and conflicts, and much more.

The work of the stewardship and biodiversity mapping teams were then merged into a single volume and presented to Pierce County.[2] As a result of the biodiversity richness mapping process done earlier in the project, Pierce County established a Biodiversity Management Network, identifying the areas important for the protection of fish and wildlife within the county. This biodiversity network was adopted into the Comprehensive Open Space Plan in 1999. However, the county is still working at incorporating the biodiversity network into its critical area regulations. It is also conducting an even finer resolution mapping and habitat verification of the core Biodiversity Management Areas (BMA), and refining the BMA analysis to establish a long-term strategy for monitoring, priorities for conservation and acquisition efforts, and an education and public outreach process. These future efforts (Phase III) again involve partnerships with the UW's WA-GAP and *NatureMapping* programs and the WDFW's Priority Habitat Species (PHS) Program, as well as a new partnership with Metro Parks Tacoma/NW Trek/Pt. Defiance Zoo. Pierce County also envisions potential partnerships with other federal and state agencies, tribal entities, and nongovernmental organizations (NGOs) to accomplish these goals. More details on this may be provided in a subsequent article.

On a larger scale, Washington State passed legislation in 2002 (ESSB 6400) that authorizes a comprehensive review to identify the state's needs for biodiversity data and to establish the framework for the development and implementation of a statewide biodiversity conservation strategy.[xi] This legislation is intended to augment the single-species or single-resource protection programs and regulatory mechanisms currently being utilized throughout the state. The Gap Analysis methods, as modified for county government in the Pierce County pilot project described in this article, could potentially be adopted for use by local governments statewide.

Conclusions

The current stewardship chapter of the GAP handbook states that "…the process of categorizing (land) management can be confusing and daunting." That complexity is even more pronounced at the local level, where numerous land units and a myriad of regulations must be considered. No less confusing and daunting to local governments who may be considering biodiversity planning are the Gap Analysis concepts. These must be presented to local governments and citizens in language that is meaningful with respect to the tools (policy, regulatory, programmatic) they have available and are familiar with. Researchers helping local governments implement the GAP data and concepts to identify biodiversity management areas and develop a long-term protection strategy may look to the Pierce County pilot project for ideas on how to overcome barriers currently impeding implementation at the local level.

This research effort brought a number of issues into sharper focus and also identified areas for refinement and improvement in future research. The following areas are of particular concern:

- GAP identifies the importance of the stewardship map as the base map from which future—and hopefully rational—designs for the conservation network will come. This indicates the need for an iterative interaction between the biological and stewardship analyses. However, in this project, particularly as the local planning stewardship analysis method was in the process of being developed, such iteration presented a timing problem. Future projects could develop an iterative process that would help co-locate biodiversity management areas where greater protections already exist.
- The national Gap Analysis Program has a goal of standardizing descriptors of land management at the national level based on public ownership such as *1501 - Dept. of Energy - Ecological Reserve*. Because of the variability of local planning environments, conducting a similar effort at the local level would not be practical. However, a state-by-state effort that takes state law into consideration could facilitate standardization for local governments and their consultants.
- Creation of a stewardship map is central to GAP's analysis method. However, this project revealed that there may be a need to further accommodate the diversity and complexity of management influences. In particular those environmental laws that pertain to actions rather than places are difficult to map. Some unanswered questions include: What is the appropriate degree of mapping at the local level? Cumulative effects were not adequately analyzed in this effort.
- Because county governments are fairly dynamic political environments, GAP's concept of "permanence of protection" presents difficulties. GAP defines permanence as "permanence of protection from conversion of natural land cover to unnatural … human-induced barren, cultivated exotic-dominated, or arrested future succession." This is an important concept to carry over to local government planning. However, in the privately owned, highly fragmented, human-populated lands typical of county jurisdictions, such permanence might perhaps be redefined. Certainly, large-scale zoning or other protections offer some degree of permanence but are not identical to the GAP concept. This project bore in mind the general concept, but the authors feel this issue is ripe for further discussion. Future research may more closely examine the meaning of "permanence" in this context.
- Based on the nature of the "Urban-Rural Continuum," it may prove useful to develop a concurrent method for identifying opportunities for strategic restoration in addition to protection.

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Successful Integration of GAP Databases into Town Planning: The Maine Experience[1]

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Introduction

The Maine Gap Analysis Project (ME-GAP) was completed in 1998 (Krohn et al. 1998), with a major conclusion being that more emphasis should be given to conserving lands in southern Maine. This finding was contrary to the focus of most conservationists at the time—Maine's North Woods. However, with data showing that southern Maine was the region of the state with the highest concentration of endangered and threatened terrestrial vertebrates, highest richness of terrestrial vertebrates and woody plants, fewest conservation lands, and a human population that was moving out of the cities and towns into the countryside (i.e., sprawl), focus on only northern Maine was unreasonable. When the Maine State Planning Office expressed its concerns for the social, economic, as well as the environmental effects of sprawl (O'Hara 1997), and when estimates were published that by the year 2050 southern Maine would gain urban land while losing 569 mi^2 of agricultural and forestlands (Mauldin et al. 1999), southern Maine became a high conservation priority.

[1] In September 2002, the nine organizations involved in this effort, termed "Beginning With Habitat–An Approach to Conserving Open Space," were awarded a Teamwork Award by Maine's Governor, Angus King. Such awards are normally only given to State of Maine employees, but in this case employees of private organizations as well as federal agencies were recognized.

Land Ownership Patterns and Town Governments

Approximately 55% of Maine is owned by 15 forest management companies. These forestlands, located in the eastern, northern, and western portions of the state, are inhabited by few people, and generally do not have town governments. Land use, including forestry practices, in these so-called "unorganized" townships is managed by a state agency, the Maine Land Use Regulation Commission. In contrast, southern Maine supports a much higher human population, with densities generally increasing to the south. In this region of the state, town governments play the critical role in land conservation. Specifically, organized towns in Maine implement shoreland zoning ordinances, develop growth management plans, and enforce various land development laws (for details, see Appendix A of Venno [1991]).

Towns receive financial support from the state for their growth management planning if their plans are consistent with 10 goals. These goals include a wide range of economic and environmental concerns, including considerations for maintaining open space and "wildlife and fisheries habitat." In addition, Maine's Endangered Species Act (MESA) requires the Maine Department of Inland Fisheries and Wildlife (MDIFW) to identify and conserve essential habitats for endangered species. Similarly, the state's Natural Resources Protection Act (NRPA) gives the MDIFW authority to identify and protect specific types of wildlife habitats, including deer wintering areas and waterfowl and wading birds habitats. Thus, specific wildlife habitats identified in law and mapped by the MDIFW, combined with a town planning process that specifies inclusion of wildlife habitats, potentially provide a meaningful mechanism to improve wildlife habitat conservation at the local level.

Initial Attempt

To realize the potential of improved habitat conservation in southern Maine, a method was needed to provide habitat data to towns in a form that was consistent with their needs, based on readily available information, and easy to apply and understand. In 1991, the University of Maine, Maine Cooperative Fish and Wildlife Research Unit (MCFWRU), MDIFW, Maine Audubon Society, and Maine Natural Areas Program developed a booklet, entitled "Integrating Wildlife Habitat into Local Planning: A Handbook for Maine Communities" (Venno 1991). The methodology in this booklet was consistent with town needs and conceptually easy to understand, and hence was an excellent first step. However, it did not include town-specific data. Furthermore, to implement the habitat assessment method presented in the handbook, towns were not only required to assemble their own data, but also to make numerous Mylar overlays for data presentation and analysis. With the increased capabilities of Geographic Information Systems (GIS), we saw the possibility of centralizing data analysis, thus allowing towns to focus on data interpretation and on-the-ground implementation of results. And with digital data on wildlife habitats coming both from ME-GAP (i.e., predicted distributions of vertebrates), and site-specific data for habitats of legal concern from the MDIFW, the issue of accessible town-specific habitat data was solved.

Goal and Methodology

In 1999 the MDIFW, seeing an opportunity to counter sprawl in southern Maine through improved open-space planning by town governments, assembled a Wildlife Habitat Committee. Committee members, consisting of wildlife biologists from MDIFW's Wildlife Division, were familiar with both the relevant laws and the operations of many individual towns. The Committee contracted with the MCFWRU to advise them on various habitat assessment approaches and to develop a GIS system that would provide wildlife habitat information useful in town planning. This system had to depend on digital habitat data collectively available from ME-GAP and the MDIFW. Once an initial method was developed, the MDIFW assembled an interagency group to review it. Reviewing agencies and organizations included the Maine Audubon Society, Maine Natural Areas Program, and the U. S. Fish and Wildlife Service. Interagency reviews focused on the soundness of the underlying concept, potential addition of other habitat data in digital form, and the usefulness of the system in the context of town planning.

The goal of the method was to identify habitats that, if conserved in the focus town and adjacent towns, would maintain viable populations of terrestrial vertebrates that regularly breed in southern Maine, based on 1990-2000 data. The methodology was conceptually similar to what Venno (1991) had developed earlier, and thus would be familiar to towns. The first step in the method was to identify and conserve habitats immediately adjacent to all waterways and water bodies. The Committee recognized not only that watersheds are critical as the backbone of ecosystems, but that this initial step was also consistent with the emphasis of many of Maine's conservation laws (e.g., shoreland zoning). Added to this backbone were the habitats that the Maine Legislature, by passing the MESA and NRPA, considered worth conserving. According to predicted vertebrate occurrences from ME-GAP, these first categories of habitat supported 80-90% of the wildlife species inhabiting southern Maine. However, these habitats did not capture upland areas needed by some larger birds and mammals with extensive spatial requirements. To identify potential habitats for these species, blocks of agricultural and forestlands not intersected by roads, railroads, pipelines, or other features were identified. General guidelines were developed on how to identify and integrate these upland blocks into an open space plan. For additional details on the methodology, see Krohn and Hepinstall (2000).[2]

Implementation

Before working with individual towns, MDIFW went back to the agencies and organizations mentioned above to modify the method as needed and, most critically, develop documents and procedures for working with towns. At this point, plant communities and wildlife habitats of interest to the Maine Natural Areas Program and the U.S. Fish and Wildlife Service were added to the above method. The technical information was simplified to be more user-friendly (e.g., the project was named "Beginning With Habitat"), and MDIFW hired a biologist to work with towns as they did their comprehensive and open-space planning. A supporting document describing and justifying methodology was developed (Anonymous, In Press) for distribution to project

[2] A limited supply of this report is available, and interested readers should contact the senior author for a copy.

participants. The interagency group provides on-the-ground support to users, as needed, and makes presentations to towns and local land trusts.

Beginning in early December 2002, project staff provided maps and follow-up presentation to many towns in southern Maine and made maps for a number of organized towns (and watersheds in a few cases) in central and eastern Maine (Figure 1). Available staff and funds to support the effort limit the progress of the project. Towns have been prioritized based on data needs for ongoing planning efforts. However, the adage that "the squeaking wheel gets attention" applies here. So those towns showing immediate interest in using the data and maps received follow-up presentations.

Figure 1. Organized towns (gray) in Maine included in the Beginning With Habitat Project. Towns that have received maps and presentations by project staff (cross-hatch), towns with presentations done (right-hatch), maps done (left-hatch) and watersheds mapped (horizontal-hatch) by the project are indicated. (Map created by Amy L. Meehan, MDIFW, Bangor).

While it is too early to measure the on-the-ground success of the project, the interest in the project from town planners up to the governor's office indicates an information need is being met by the project. Only time will tell how much land is conserved as a result of this effort, but accomplishments to date are encouraging. Example uses of these wildlife data are as follows:

- The town of York has displayed Beginning With Habitat maps in the town planner's office for public inspection at a predevelopment screening.
- North Berwick has used these data to bolster a planning-board decision not to reduce 250-foot stream buffers in shoreland zoning.
- Land trusts in southern and mid-coast Maine are using these data to prioritize and direct their land conservation efforts.
- Scarborough's land acquisition committee is using data from Beginning With Habitat to help prioritize lands targeted for purchase or easements using $1.5 million in local tax appropriations.

Conclusions

It's highly unlikely that the goals and objectives of a state GAP project and a local planning effort will be identical. Thus, the final results of a Gap Analysis Project will be rarely, if ever, directly usable for conservation planning at the local level. Implementation of GAP results for wildlife habitat conservation at this, or any, level must involve careful analysis of numerous legal, institutional, technical, and social constraints. As we learned from the Maine experience, GAP data are useful in local land use planning, but only after being fitted to the needs of actual users, especially as related to specific laws pertaining to wildlife habitats and other environmental features. We were fortunate in that Maine has specific laws and regulations that, when considered as a whole, provided a logical framework amenable to wildlife habitat conservation at the local level. Nevertheless, we did not attempt to implement ME-GAP results directly but instead gave serious thought to how best to mold and present available data so that they were relevant and useful to existing institutions with stakes in wildlife habitat conservation. It's critical to have long-term institutional arrangements so that through time the application, refinement, and reapplication of the habitat data is ensured. Because land-use changes occur over years and even decades, it's unrealistic to think that meaningful habitat conservation efforts of any shorter duration will be effective.

We anticipate that as Maine towns become more familiar with GIS and wildlife habitat planning, the need for more detailed and up-to-date habitat information will increase. At a time of exceptionally limited federal, state, and local government budgets, GAP increasingly needs to be aware of state and local needs for wildlife habitat data, so that various levels of government can utilize the information coming from GAP. Not only will this maximize the efficient use of limited funds, but it will increase the effectiveness of habitat conservation efforts at multiple scales.

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Long-Term Implementation Strategies for Biodiverse Lands

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Introduction

In order to assist county governments in Washington State who are drafting plans for wildlife and habitat as required by the state Growth Management Act (GMA), the University of Washington's Department of Urban Design and Planning (UW-UDP) in collaboration with the Washington Gap Analysis Project (WA-GAP) and Washington Department of Fish and Wildlife (WDFW) has been implementing a series of pilot projects that explore the utility of GAP analysis at the local level. The Pierce County pilot project provides a springboard for exploring stewardship opportunities and protection methods within private lands in greater detail (Grue et al. 1999). A multi-disciplinary team from the UW Washington Cooperative Fish and Wildlife Research Unit, WDFW, Metro Parks Tacoma, and Pierce County Planning and Land Services is approaching implementation of the defined biodiversity management area (BMA) Network. Implementation will be a long-term project designed to educate and affect local land use decisions and includes ongoing monitoring and assessment.

Goals

The primary goals of assessing long-term implementation of the BMA Network are to (1) educate and involve local governments and the public on the biodiversity planning process, (2) establish new surveys and monitoring programs where necessary, (3) empower citizen scientists to collect monitoring data through The *NatureMapping* Program, (4) provide a level of quality assurance through the use of experts, and (5) develop biodiversity management plans that will provide detailed information on habitat quality and species presence/viability, restoration opportunities, and priorities for conservation and land acquisition for each defined BMA.

Methods

<u>Education and Public Involvement</u> - There are multiple components of education and public involvement. Through regional meetings, county and city planners will be informed of the Pierce County biodiversity planning process and its use in updating critical-area regulations. County- and state-sponsored workshops will be held to educate local governments throughout Washington State. The goal of the workshops will be to inform and garner support of the BMA Network and the finer detailed biodiversity management plans. Federal and state legislators will be introduced to the GAP methodology, as applied in their districts within Pierce County. They will be educated about how this biodiversity planning process could be utilized in other counties throughout the state and how it could be integrated into existing Washington State legislation for the development and implementation of a statewide biodiversity strategy (Iolavera et al., this issue).

The *NatureMapping* Program will organize existing data collection efforts conducted by land trusts, Audubon chapters, local watershed groups, and schools. These volunteer groups, our citizen scientists, will be given training to increase their data collection and monitoring skills. Their work will complement the ongoing fieldwork of agency experts. Citizen scientists will do more than collect data for experts; they will be encouraged and trained to conduct their own scientific projects, thus expanding the biodiversity research efforts. A network of training centers will help accomplish this task and provide experts for quality assurance. Metro Parks Tacoma facilities such as Point Defiance Zoo, Northwest Trek, and Tacoma Nature Center have agreed to become N*atureMapping* training centers and serve as local contacts and resources for the public and schools. Over time, additional training/data collection centers (e.g., national parks, state parks, wildlife refuges) will be added throughout the county and state.

<u>Monitoring and Quality Assurance of Data</u> – Pierce County includes 1,793 square miles of land area that encompasses a geographic diversity ranging from the lowlands of Puget Sound at sea level to the summit of Mount Rainier at 14,411 feet. The BMA Network covers 29% of the county. Citizens who are concerned with their communities and their quality of life can provide important data from locations inaccessible to wildlife managers, assist with monitoring programs, and identify areas that need further inventorying by experts.

Rather than starting from scratch, monitoring efforts will build upon the WA-GAP and WDFW data sets. WA-GAP implemented the National Gap Analysis methodology at a finer resolution. Although the minimum mapping unit (MMU) was 100 hectares, coastal islands and Nature Conservancy lands were mapped well below the MMU. WA-GAP searched museums throughout the US for historical species location records. More than 360,000 historical and current records (e.g., museum specimens, Breeding Bird Atlas, research projects, private databases, WDFW Heritage data, etc.) were used to build and assess the habitat-relationship models using an iterative process; first to identify habitats occupied by individual species, then to assess and improve the habitat-relationship models with new data.

An analysis comparing predicted species distributions to WA-GAP specimen records, updated WDFW Heritage and Priority Habitats and Species data (PHS; administered by the WDFW to collect species occurrence data), and *NatureMapping* data was conducted for Pierce County. A total of 247 species were predicted to occur in the county. More than 8,600 specimen records were collected for 234 species. Fifty-nine percent of all the updated WDFW Heritage/PHS data points for the county fell within the BMA Network. WA-GAP identified 80 species-at-risk throughout the state, of which 24 (30%) were predicted to occur in Pierce County. This may be because the geographic area of the county spans such a wide range of elevations. Of the 24 species-at-risk, 3 species of salamanders did not have supporting data within the county. At-risk species are poorly adapted to development, agriculture, and logging; declining for reasons other than habitat loss (e.g., overtrapping, competition by nonnative species); or have poorly known habitat requirements, especially species with limited distribution in the state (Cassidy et al. 1997).

New survey needs within the Pierce County BMA network, such as Breeding Bird Survey routes and banding stations, have been identified. Additional mammal, butterfly, and amphibian/reptile surveys will allow wildlife managers to confirm "predicted" species and record unpredicted species that may occur or may be invasive or expanding their range. *NatureMapping* data collected by citizen scientists for these surveys will complement professionally collected data. Finally, new species information obtained through monitoring will be integrated into state and local data sets.

Biodiversity Management Plans - Biodiversity management plans will bring together all monitoring and habitat/species assessment information; analyze this information to determine habitat quality, species presence and viability, restoration needs and opportunities, protection status and vulnerability to development pressures; and outline options for protection and restoration goals. The planning process will involve all key stakeholders including but not limited to tribes, federal and state agencies, local jurisdictions, environmental groups, university researchers, park districts, and zoos. The authors envision dividing the BMA Network into five discrete areas and writing a management plan for each area. This phase will take approximately five years to complete.

Conclusions

The National Gap Analysis Program and WA-GAP provide a good starting point for identifying potential priority areas for biodiversity within a given geographical boundary. But for this initial work to be meaningful at the local level, it must be incorporated into land use management policies and practices. It must also prioritize educating everyone who will be affected by these policies. The finer-resolution mapping and habitat quality assessment is funded for completion in 2003. However, the county is still seeking funding sources to complete the biodiversity management plans, monitoring, and public education and outreach programs described in this paper.

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How Can We Produce Educational Products with GAP Data?

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Like most states east of the Rocky Mountains, the majority of land ownership in Kansas (> 98%) is private (Figure 1). Publicly owned lands in Kansas typically do not have conservation as a primary goal or mandate. For example, the two largest public parcels

(Fort Riley Military Reservation and Cimarron National Grasslands) have a GAP conservation status code of 3, as do most public lands (66.6%) in Kansas (for codes, see Crist 2000). Only 0.034% of publicly owned lands are categorized as code 1 and 11.7% as code 2. Lack of publicly held lands and infrequency of conservation goals suggest that most of Kansas represents a gap relative to protected habitats and species.

Figure 1. Stewardship map from the KS-GAP Project. Lands owned by conservation agencies and publicly owned land included both land and water acreages.

We propose a model for effective conservation efforts in states such as Kansas, which need to be different than those used in states with large public holdings. In states with little public land, it is not possible to contact enough individual landowners to effect management decisions for large tracts of land; conservation strategies will require a long-term approach to effect change (Figure 2). Therefore, we suggest a conservation strategy that directly educates and trains wildlife managers in charge of management decisions about the limited extent of federal and state lands. Further, we propose that educational materials be distributed in public places to encourage citizens, including private landowners, to appreciate the heritage and conservation value of wildlife resources. Finally, we suggest that to effect change indirectly, Internet programs need to be developed that can be used by interested adults and children in public places (e.g., museums, nature centers, and state parks) and by children in classrooms. Additional education of kindergarten through 12th-grade students could increase their knowledge of the natural world, which a recent study by Balmford et al. (2002) suggests is lacking. Based on this study, children had a greater ability to identify Pokémon figures than common plants, invertebrates, mammals, and birds living in the environment around them. This lack of knowledge likely is perpetuated in later life because appropriate information and insights were not gained in the formative years.

Figure 2. A proposed conservation strategy for states with few public lands.

The short-term objectives of the Kansas Gap Analysis Program (KS-GAP) Education Project are to educate elementary students and to use classroom lessons to elicit conversations between students and their parents or grandparents. The long-term objective is to give students an appreciation of natural habitats and wildlife resources in Kansas, so they become conservation-conscious adults. To accomplish this, we tested the feasibility of developing educational modules for 6th graders from data (e.g., land cover, stewardship, and predicted vertebrate distributions) collected by the KS-GAP project.

Module Development
We conducted Internet searches for Kansas to assess conservation and environmental education programs, to identify science education standards, and to locate media files for vertebrates. We identified Web sites that provided information for teachers, students, and potential state projects (e.g., resources, links, and examples). Search results will be published in the KS-GAP Education State Project Resource Manual upon completion of this project. Further, examination of Kansas Science Education Standards revealed that, in Kansas, certification of our program was not required (Dr. J. Staver, personal communication) and that we could develop modules that encompassed five of the seven standards (KSESWC 2001). Finally, photographic images of species and their sign, as well as habitats, and audio files of calls for vertebrates were assembled and copyright releases obtained. Currently, we have 1,285 images of animals, 309 calls, and 154 images of vertebrate sign.

We assessed the KS-GAP vertebrate database/decision support system for information content, usability, and convertibility to an output/exploration system for students. Because so much information was not relevant to the education project, we created a new relational database (KS-GAP Education Program database) tailored to module development. Microsoft Access™ database information can be served by Data Access Pages™ or by simulation of these pages using HTML on the Internet.

We took a bottom-up "listen and learn" approach and worked with local teachers to develop educational products by forming partnerships with "trial" schools. We chose communities that varied in size (small-rural, medium-rural, and small-urban) and communities that were under-served (including schools in rural areas and those that varied in minority enrollment). Following selection of three rural and seven urban schools, letters were mailed to principals requesting the school's participation and names of science teachers. Subsequently, teachers were personally invited to participate in our pilot project. We visited "trial" schools and demonstrated prototype products we could develop to help them meet the state science education standards. Our presentations generated much enthusiasm, and we gained valuable information and insight. Eighteen classes in seven schools in three school districts agreed to participate in the pilot project. Teachers lent textbooks to assist us in developing classroom materials. In contrast to the idea that all schools would be teaching the same science curriculum at the 6^{th}-grade level (J. Staver, personal communication), we found that each school district made independent decisions. Therefore, we needed to develop several modules for each school district that related to topics taught at the 6^{th}-grade level at each specific school. Modules were constructed independently of each other, so teachers could choose among the lessons used. Our modules are (1) Science is…, (2) Animals, (3) Classification of Vertebrates, (4) Environments and Biomes, (5) Local Landforms, (6) Application of Technology for Society, and (7) Knowledge in Action. Modules 1-6 each contain 4 to 7 lessons, and module 7 involves a field trip.

Future Directions
Following teacher and student evaluations, changes in modules and creation of additional modules will be considered. Because much of the pilot project is restricted to three

counties, it will be necessary to expand informational content so that modules are available to any elementary school in the 105 Kansas counties. Therefore, we must automate queries and provide county-specific information for any school accessing the education database via the Internet. We need to develop materials for younger and older students to allow maximal exposure to environmental information relevant to their daily lives. We also should develop more content for casual Web visitors, both adults and children, using the site independent of a "trial" school. To this end, we have posted a number of engaging activities as "Sample Lessons." Finally, we also want to implement additional phases of the proposed model to provide environmental information in other public places for use by interested citizens in a state with few protected or conservation lands.

An expanded version of this paper may be found at www.ksu.edu/kansasgap/KS-GAP-Ed/Publications/GapEdProducts.pdf.

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INTERNATIONAL

Gap Analysis Program: Potential to Support Conservation Initiatives in the Republic of Georgia

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While GAP is being implemented throughout the U.S., scientists from many other countries are interested in applying GAP methodology in their regions. The Gap Analysis Program represents an effective tool for identifying underprotected species and ecosystems to be targeted for conservation and management activities. In the process of accomplishing its main task, GAP generates a number of products that can be used to address various political, economical, social, legal, and educational challenges, which will lead to increased awareness of biodiversity and more effective conservation. GAP would provide a major advance to biodiversity and habitat conservation and management to the Republic of Georgia. Below I identify potential applications of GAP in Georgia.

The Republic of Georgia (Figure 1) is located in Transcaucasia on the eastern Black Sea coast (population 5.3 million, area 69,700 sq km [26,900 sq mi], elevation 0-5,500 m; capital Tbilisi). Its location and physico-geographical conditions have contributed to the richness and diversity of its wildlife and ecosystems. Georgia participates in a number of regional or international agreements and conventions on environmental conservation and has responsibility to protect biodiversity by improving the effectiveness of conservation initiatives.

Figure 1. Location maps of transcaucasion region.

Environmental management and the conservation of biological diversity in Georgia have suffered since the collapse of the USSR and continued socioeconomic hardship. On the other hand, rapid economic growth threatens long-term survival of species and ecosystems. Georgia's diverse habitats, noted for their biological diversity, can become threatened by development activities. Existing topographic and land cover maps of Georgia are outdated. In the situation of expected economic expansion, agricultural change, and urban/industrial development, the lack of reliable land cover, habitat, and species distribution maps is a severe handicap for Georgia's environmental managers.

There are a number of conservation projects in Georgia currently under way with significant support from international funding institutions. In fact, we have implemented a protected areas system of Georgia under which a number of protected territories were designated and are currently being established. Application of GAP would facilitate assessment and assist in the identification of a biologically defensible protected areas network. Besides, it could provide spatial mapping support for designing protected areas and planning management activities within those protected areas currently being established.

The Caucasus region was designated by Conservation International as one of 25 biologically rich areas around the world under significant threat of destruction (biodiversity hotspot). The area includes parts of Georgia, Armenia, and Azerbaijan and small portions of Russia, Iran, and Turkey. The ecosystems that comprise the Caucasus hotspot contain more than twice the animal diversity found in adjacent regions of Europe and Asia. The potential of successful application of GAP for identification and targeting of conservation and management measures in the hotspots is very high.

I represent the Black Sea Regional Activity Centre for Biodiversity Conservation (Batumi, Georgia). I am in the United States on a grant under the Contemporary Issues fellowship program funded by the U.S. Department of State, Bureau of Educational and Cultural Affairs, under the Freedom Support Act, administered by the International Research and Exchanges Board (IREX).

The main objective of my research is to understand how GAP objectives and methodology are applied in private cases. The survey methodology includes interviewing and consulting the reserve identification, selection, and design specialists involved in the execution of GAP at different levels. The cooperation and assistance of the Idaho Cooperative Fish and Wildlife Research Unit (CFWRU) and the National GAP Program will be invaluable. The subjects of discussions, among other things, are project management, data acquisition, image classification, wildlife habitat relationship models, data assessment and oversight, validation, and usability.

Part of my focus is to familiarize myself with information (articles, Internet resources) available on both terrestrial and aquatic GAP. The Web site of the National Gap Analysis Program contains a useful overview of the program and methodology. It provides links to all the state GAP Web sites, which have detailed descriptions of the project methodology and workflow for each particular state and therefore provide a wide variety of examples/solutions, some of which can be applied to Georgian reality.

An important part of my project will be a 1-month internship in one of the GAP field offices, where I can learn new data processing and analysis techniques. One of the short-term results of the study will be recommendations for implementation of the Gap Analysis Program in Georgia. In collaboration with local environmental organizations, notably the Georgian Centre for Conservation of Wildlife and WWF Caucasus, the results of the study and recommendations will be presented and disseminated to relevant regional and national governmental agencies, nongovernmental organizations, and mass media as a workshop. The workshop will introduce and justify the need for conducting GAP for Georgia, as well as obtaining recommendations for producing a project proposal for implementation. The U.S. National GAP Program as well as the Idaho CFWRU are interested in participating in and providing technical assistance to a Gap Analysis project in Georgia.

Hokkaido Gap Analysis

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Background

Hokkaido is the northernmost main island of Japan. The island is 78,037 km^2 in size, is extensively forested, and has cold, snowy winters and cool, humid summers. Hokkaido Island is home to a diverse group of northern fauna and flora, including 71 freshwater fish species, 9 amphibians, 15 reptiles, 403 birds, 60 mammals, and 2,503 vascular plant species. Despite the important roles these species play in terrestrial ecosystems, a lack of conservation efforts and insufficient information on biological vulnerability resulted in listing many species in Hokkaido's Red Data Book (RDB; a list of endangered species). For example, 20 species of mammals such as the least shrew (*Sorex minutissimus*), ermine (*Mustela erminea*), bats (myotis, noctule, and more), and many others have been listed in Hokkaido's RDB. The loss of Hokkaido's biodiversity is directly linked to habitat modification as well as the growing number of invasive alien species.

Hokkaido GAP

With the complex landownership and environmental management system of Japan, it is a challenge to identify priority areas for the protection of biodiversity. Although the Department of Environment produces GIS-based land cover maps at 1:50,000 scale, Japan's vegetation classification system is not at the alliance level of the NVCS scheme. Consequently, only a few attempts of predicting or modeling distribution of vertebrates have been presented by academic research in Japan. Additionally, just as in many other nations, the availability of biological information of Japan varies among local administrations, institutions, and many research organizations. Because of these obstacles to biodiversity conservation and ecological planning, no effort had been planned to show how the Gap Analysis method of identifying gaps in biodiversity protection could be applied in Japan.

The Hokkaido conservation community has jointly recognized the need for species distribution data for key species of concern, including both invertebrates and vertebrates. To meet this need, the Hokkaido Gap Analysis Program (HGAP) was formed in 1999 as a study group of GAP methods and application. The members of HGAP believe that the methodology of GAP can help to coordinate information required for the biodiversity conservation of Hokkaido. Based on members' continuous research and work for the last four years, HGAP has just published a report called "For Effective Conservation of Biodiversity – Applying Gap Analysis in Hokkaido" (HGAP 2002). Contents of this report include: (1) What is Gap Analysis? (2) Learning from the U.S. National GAP, (3) Getting Gap Analysis into conservation practice in Hokkaido, (4) Checklists of fauna and flora, (5) Species distributions and database, (6) Case studies of Gap Analysis on Hokkaido's vertebrates and alpine flora, and (7) Comments for future biodiversity conservation. Cooperators in HGAP include many researchers from universities, national and local institutes, and several private consulting corporations. Tremendous additional support is also provided by a variety of member nongovernmental/nonprofit organizations.

Database and Information Gap

To facilitate cooperative development and use of information among the members, HGAP produced a database containing detailed distribution of vertebrates based on over 500,000 biological records such as published journal articles, printed distribution maps, and museum records. One of the primary goals of HGAP was to engage numerous investigators and researchers at a variety of institutions in creating novel data sets on a described scale. To a certain degree, this has succeeded. Based on this database, relative abundance of vertebrates was mapped by using 5 km^2 block-size in ARC/INFO and ARC/VIEW. This database maintains accuracy and facilitates accumulation of biological information, enabling the project to provide a better understanding of the distribution of species and application of the gap analysis approach.

HGAP is creating new opportunities for research and providing options for solving problems. Throughout the development of the HGAP database, many valuable scientific insights were found. Overcoming information gaps (Skerl 1999) is key to a better understanding of the protection of biodiversity. While coordinating the creation of a database among the HGAP members, a paucity of compiled information on distributions of certain vertebrate species was discovered. Distribution records on these species are available only in a few biological reports. These species include bats (i.e., *Myotis* spp., *Rhinolophus* spp., *Pipistrellus* spp., and *Nyctalus* spp.), Siberian salamander (*Salamandrella keyserlingii*), Ezo salamanders (*Hynobius retardatus*), and some mustelids (*Mustela* spp. and *Martes* spp.) While there may be a lack of adequate information sources to describe these species' habitat, others have received more attention from the Hokkaido conservation community. For instance, over 2,000 biological records are available for describing distribution of black-faced bunting (*Emberiza spodocephala*) in Hokkaido. These information gaps may prohibit the inclusion of certain species in conservation planning. Clearly, further development of information on several species is needed and will depend on increased communication and collaboration among HGAP members and other scientists.

HGAP Case Study

For our case study, efforts to identify gaps in the network of nature reserves have been conducted by using our preliminary database and GIS only if adequate data sources were available for species. These species include mountain hawk eagle (*Spizaetus nipalensis*), brown bear (*Ursus arctos*), sika deer (*Cervus nippon*), and alpine vegetation. This article, however, only briefly reports the results of some examples of GAP assessment.

Aquatic habitats (i.e., streams, lakes, and ponds) for waterfowl were evaluated. We determined that there is insufficient protection for waterfowl habitats, especially in several important hotspots. For instance, we identified some streams and ponds that are home to over 70 waterfowl species (the maximum number of waterfowl species for a single aquatic habitat is 85 in Hokkaido); however, these hotspots are not included in any type of habitat and population protection regime.

Another approach to assessing existing and proposed hotspots of biodiversity is to capture the variation in mountain geography. Alpine vegetation is one of the magnificent natural resources of Hokkaido Island. Members of HGAP used geographical and topographical variables to identify alpine vegetation distributions across 90 mountain ranges. They determined that 55 mountain ranges have gaps in protection.

Summary

Developing a comprehensive spatial database in Japan presented challenges for both spatial and tabular data acquisition. However, it provided opportunities for data sharing and standardizing procedures for assessment and conservation of biodiversity. We have only practiced GAP methodologies on several species groups, but the adaptation and refinement of GAP techniques and procedures will definitely help to identify priority areas for biodiversity protection. Further discussions and examples of case studies can be found on the HGAP Web page at http://www.HGAP.org. Finally, we acknowledge many friends in the GAP projects of the U.S. who guided us by showing their accomplishments for many years.

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FINAL REPORT SUMMARIES

South Carolina Gap Analysis Project

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The SC-GAP Project began in 1996 as an effort of the South Carolina Cooperative Fish and Wildlife Research Unit. Partners in the project from the beginning included the South Carolina Department of Natural Resources and the U.S. Fish and Wildlife Service's Coastal Ecosystems Project. The objectives of the project were to (1) map the vegetation of South Carolina in as much detail as possible with the goal being the production of a land cover map easily cross-walked to the TNC alliance level, which is dominant species, (2) produce a database of vertebrate ranges and habitat affinities for use in predicting vertebrate distributions within the state, (3) produce a database of protected lands within the state including both public and private agencies with associated ownership data and classify them by protection status, (4) analyze the relative protection of the state's biodiversity through a gap analysis, (5) build partners during the development and implementation stages of the SC-GAP Project, and (6) provide scientific data on South Carolina's biodiversity to managers and decision-makers.

The SC-GAP land cover mapped the state's natural and man-made vegetation types to two classifications. A general 27-class habitat map was used in modeling vertebrate distributions. We also produced a more detailed 54-class map in accordance with the National GAP guidelines of mapping to the alliance level where possible. The initial data used in developing the map was remotely sensed satellite data that was preclassified to 28 classes. We used data from detailed soil surveys, National Wetlands Inventory surveys, and elevation maps to improve this classification and develop our 54-class land cover. This was aggregated into the habitat map for use in producing vertebrate distributions. The accuracy of the map was determined through a combination of aerial photography and ground assessment points that were compared with the general land cover. Overall map accuracy of the general land cover, Anderson Level II, and Anderson Level I classifications were 33%, 50%, and 71%, respectively.

The vertebrate database was developed through consultation with current literature, with acknowledged state experts, and with general taxonomic guides. This produced a database with ranges and habitat affinities for a total of 455 vertebrate species that regularly occur in South Carolina. After the database was completed, experts were again consulted to assist in resolving conflicts in the data and quality-checking the database. A total of 65 amphibians, 73 reptiles, 249 birds, and 68 mammals were included in the final database and predictive modeling. Modeling was done by attributing each species to the counties where it is known to occur and to the habitat types it uses within those counties. These occurrence maps were overlaid to produce coverages of overall species richness and richness for each taxonomic group. The accuracy of the predicted vertebrate distributions was assessed by comparing a list of species that SC-GAP predicts would be present at a site to a list of species known to occur at the site. We used species lists from five areas within the state to check our accuracy. The accuracy ranged from 57% to 85% depending on the site. For the largest site with the longest period of study the accuracy was 85%.

The third database component of the project was the production of a database on land ownership within the state. This was accomplished through a partnership with the U.S. Fish and Wildlife Service, who assisted in mapping stewardship lands for the eight coastal counties. If all GAP status lands (1 through 4) are considered, there is a total of 6,580 acres of publicly and privately owned land within the state, comprising about 8.1% of the total. If only the lands of highest protection (GAP status 1 and 2) are counted, this amounts to 1,801 acres or about 2% of South Carolina. Clearly there is a need for more activity in land protection within the state.

The gap analysis phase of the project indicates the need for further action to protect our natural habitats and our rural landscapes. While many of our forests receive at least some level of protection, very little of our scrub/shrub, grassland, or cultivated land is protected according to GAP status. The very large majority of our vertebrate species are protected on less than 10% of their habitat. For some species of concern, we have reached or surpassed our conservation goals, especially for those with specific habitat needs. For species such as bats, however, where habitat requirements are less well defined, more work needs to be done in ensuring their ongoing protection.

The outreach portion of the project has been very successful through partnerships developed during the accomplishment of our goals. These partnerships will continue through activities such as finer-scale mapping of state natural land covers, through scientific studies of invertebrate diversity and better habitat modeling, and through ongoing land cover and change detection projects. There are many committed and excellent land managers, planners, agency personnel and conservation groups who are interested in the SC-GAP data, and it is our hope that they will take it, use it, and make it better.

Kansas Gap Analysis Project

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The Kansas Gap Analysis Project (KS-GAP) began in June 1995. From the beginning GAP has been a partnership effort in production as well as in support. Kansas GAP has been coordinated at the Kansas Cooperative Fish and Wildlife Research Unit. The land cover map was developed from Landsat Thematic Mapper data by the Kansas Applied

Remote Sensing Laboratory at the University of Kansas and the Kansas Biological Survey, also at the University of Kansas. The stewardship layer was developed by the Geographic Information System Spatial Analysis Laboratory (GISSAL) at Kansas State University. GISSAL also developed the initial Geographic Information System to hold the spatial and attribute data, and incorporated the initial vertebrate distribution models into the GIS. Vertebrate distribution models were developed by personnel at the Kansas Cooperative Fish and Wildlife Research Unit and others at the Division of Biology at Kansas State University. Unit personnel developed the final vertebrate distribution models and the final GIS.

The KS-GAP land cover map is the third statewide vegetation cover map developed for Kansas and is the first to map vegetation at the alliance level. The map is based on remote sensing of three dates of imagery for the 16 thematic mapper Landsat scenes that cover the state. Kansas is divided into eleven physiographic regions based on a combination of underlying geology, soils, and vegetation, which were used in conjunction with the satellite data and other data sources to delineate land cover classes. Man-made features and open water were screened using one of the earlier maps. Agricultural cropland was then distinguished from natural vegetation by use of an unsupervised classification. Finally, natural vegetation classes were identified with a supervised classification.

The Kansas land cover map includes 40 natural vegetation classes, 2 semi-natural classes (non-native grassland and CRP), and three man-made classes (urban, cropland, and open water). The 40 natural vegetation classes include 10 forest, 5 woodland, 4 shrubland, 11 upland, and 10 wetland alliances. Forty-eight percent of the land cover of Kansas is cropland, 10% is non-native grassland and CRP, and native grasslands cover an additional 26%. Classification accuracy varied according to the level of the classification. At the Anderson level 1 classification, overall accuracy is 88-89%. At the finer level of the formation, accuracy was between 64 and 66%, and at the finest level (alliance) accuracy was 49-51%. These accuracy figures are based on small samples for some cover classes, so they should be interpreted cautiously.

Vertebrate distribution models were developed for 359 species, including 190 species of breeding birds, 72 species of mammals, 71 reptiles, and 26 species of amphibians. Lists of species to be modeled were generated and reviewed by scientific review committees of experts identified for each taxonomic group. Development of vertebrate models involved three steps: First, species distributions were identified from combinations of museum specimens, literature searches, and on-line databases. Second, habitat associations for each species were identified by in-depth literature searches. Third, habitat associations identified from the literature were linked to the land cover map cover classes with the help of a database decision-support system developed by Unit personnel. Each phase of model development was reviewed by our Scientific Review Committees for accuracy and completeness.

Bird species richness is highest in the Arkansas River Lowlands, Smoky Hills, and High Plains physiographic regions in Kansas, and mammals had their highest diversity in the same areas, but in reverse order. The pattern at the hexagon scale may be biased, reflecting highest diversity in areas experiencing the most intense research in the vicinity of the state's major universities, where there is a higher probability of detection. Reptile diversity patterns are similar between the hexagon scale and the physiographic region. Reptile species are most abundant in the Arkansas River Lowlands, followed by the Flint Hills, and Osage Cuestas. Amphibian diversity is highest in the Osage Cuestas (23 species), and Glaciated Region (20 species). The Ozark Plateau, Flint Hills, and Cherokee Lowlands each had 19 species. An interesting feature of the richness patterns is that each of the four vertebrate classes has a unique distribution independent of the other three classes in Kansas.

Land stewardship in Kansas is dominated by private ownership, probably to a greater degree than for any other state. There are 312,284 ha of public land or land managed for long-term management of biodiversity (1.7% of the surface area of Kansas). There are only 122 ha under status 1 management, 38,684 ha in status 2, and 222,729 ha identified in management status 3. The remainder of the state is managed as status 4.

One of the primary goals of Gap Analysis projects is to identify "gaps in the protection of biodiversity" in individual states, identified as species or communities that have inadequate protection of habitats under public management for the long-term protection of biodiversity. By this definition, the entire state is a gap. Clearly this is not an adequate view for conservation where land-ownership is almost entirely private, and other approaches to conservation are required. Kansas is unique in having the smallest proportion of its lands in public ownership, but the remaining states in the Great Plains are similarly dominated by private land ownership. Private ownership does not necessarily imply a lack of conservation. At this time, although several Great Plains plant and animal species have greatly reduced distributions compared to former times, none are known to be extinct.

A different conservation approach that focuses on working with private landowners is needed in this region. Possibilities include conservation incentives in the Farm Bill, state and federal agency conservation programs such as the Fish and Wildlife Service Partners for Wildlife Program and the NRCS Wetland Reserve Program. The most powerful long-term tool for conservation in states like Kansas is education of children who will become the private land stewards in the future. Gap analysis can be incorporated into science curricula at both the primary and secondary school levels to instill conservation values at an early age.

STATE PROJECT REPORTS

(Status as of December 2002)

All completed products and reports will be available through the GAP Web site at http://www.gap.uidaho.edu/Projects/Data.asp. Drafts and other products may be obtained from the state project PI as noted.

Alabama

Project under way
Anticipated completion date: December 2005

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Land cover: Land cover mapping is currently in progress. All Landsat scenes for the state have been acquired through the Multi-Resolution Land Characteristics Consortium (MRLC) with the exception of one scene in the Gulf coastal plain. An image analyst/remote sensing technician was hired in June 2002 to facilitate image interpretation. Initial classification was focused on portions of the Piedmont and Southeastern Plains to encompass the Tallapoosa and Coosa watersheds, which will aid both terrestrial and aquatic GAP projects. The four scenes spanning this region have been classified to Anderson Level II (8 classes) using digital ortho-quarter quads (DOQQ) and leaf-off scenes for interpretation. A set of decision rules utilizing ancillary data will be drafted in early 2003 to further refine the Anderson Level II classes to finer GAP-level mapping units. Efforts to classify remaining scenes will continue through 2003 as will field verification work, which was initiated in fall 2002.

Animal modeling: Animal modeling began mid-year 2002 for 372 terrestrial vertebrate species including 65 amphibians, 161 breeding birds, 59 mammals, and 87 reptiles. A steering committee was established to provide expert reviews throughout each modeling phase, and a GIS technician was hired in July 2002 to develop vertebrate models. Hexagon range extents for nearly 90% of species to be modeled have been drafted and are being updated with current location data. Completion of the remaining draft ranges and expert reviews are scheduled for February 2003. The wildlife habitat relationship database has been constructed, and literature reviews have commenced for both amphibian and avian species. We expect to expand literature reviews to all taxa and begin model development in 2003.

Land stewardship mapping: Stewardship mapping is under way. Digital boundary files and ownership data have been compiled from various public and private agencies through cooperative arrangements. Building of this layer will continue through the duration of the project and will be finalized in the last year (early 2005) to provide the most up-to-date data for our gap analysis.

Reporting and data distribution: Report writing will be ongoing through the duration of the project. Project updates and current information can be found on our Web site at http://www.auburn.edu/gap.

Other accomplishments and innovations: AL-GAP has partnered with Alabama Department of Conservation and Natural Resources Division of Wildlife and Freshwater Fishes, Alabama Agricultural Experiment Station, and the School of Forestry and Wildlife Sciences at Auburn University to build species distribution maps for the forthcoming publication of Imperiled Vertebrate Wildlife and Freshwater Mollusks of Alabama. AL-GAP personnel presented at the Alabama State GIS Symposium in August 2002 and participated in National GIS Day events held at Auburn University with a GAP presentation and poster display.

Alaska
Not started

Arizona
Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.
Remapping under way (see Southwest Regional GAP).

Arkansas
Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

California
Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Colorado
Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.
Remapping under way (see Southwest Regional GAP).

Connecticut

(see Massachusetts, Connecticut, and Rhode Island)

Delaware

(see Maryland, Delaware, and New Jersey)

Florida

Draft data available from state (http://www.wec.ufl.edu/coop/gap/). Review under way.

Georgia

Project under way (http://narsal.ecology.uga.edu/gap.html)
Anticipated completion date: July 2003

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Land cover: A 44-class land cover map has been created. A ground-based accuracy assessment is complete for the mountain regions, and an aerial videography assessment is under way for the Piedmont and Coastal Plain.

Animal modeling: Final models have been created for about 50 species. We anticipate completing the remainder by April 2003.

Land stewardship mapping: The stewardship layer was completed in 1999. We will include recent land purchases by the State of Georgia, an updated Forest Service boundary, and several land trust acquisitions by March 2003.

Analysis: We expect to complete analysis of Georgia's land cover and wildlife habitat distributions by June 2003.

Reporting and data distribution: The final report for Georgia GAP should be completed by July 2003.

Other accomplishments and innovations: The initial 18-class general land cover map created as the first stage of GAP mapping provided the base layer for the Georgia Land Use Trends (GLUT) project, which examines changes over the period 1974-1998. We have also completed land cover maps for 1974, 1985, and 1992, and are beginning accuracy assessment and data analysis.

Hawaii

Project under way
Anticipated completion date: June 2005

Contact: Dan Dorfman
Research and Training, University of Hawaii, Honolulu
Dorfman@hawaii.edu, (808) 956-6616

Land cover: HI-GAP is using a spectral decision-tree approach to vegetation classification. HI-GAP's land cover work is based on using spectral properties evident in Landsat TMe 7 images, which have been processed to "at satellite" reflectance values. Classification decisions are based on spectral properties revealed by "raw" bands, vegetation/soil indices, principal component analysis, and the tasseled-cap treatment. Initial efforts are focused on the island of Oahu.

Terrestrial Ecological Systems (corresponding to the Group level of the NVC) are being developed first to represent the physiognomic level of distinction. This effort will be followed by an Alliance level classification representing floristic variations within vegetation systems.

Animal modeling: We have been collaborating with the Hawaii Forest Bird Interagency Database Project to develop bird distributions. The distribution of the only land mammal native to Hawaii, the Hoary Bat, as well as some invertebrates will also be mapped. Species distribution modeling has been initiated for native and nonnative freshwater aquatic species of vertebrates and selected macroinvertebrates. We have been experimenting with various GIS methods for capturing the necessary physical attributes of each stream segment. Our results have been positive, and we now have a set of physical attributes we will capture for all streams in Hawaii and a solid methodology for modeling physical attributes needed to predict species distributions. We are now in the process of implementing the methodology we have developed for Hawaii and expect to have results to test by the end of spring 2003 (see also the report on Hawaii Aquatic GAP on page 79).

Land stewardship mapping: Stewardship mapping has been completed both for the terrestrial and marine environment. GIS data sets are available for dissemination through the Hawaii Natural Heritage Program's FTP site, the National Gap Analysis Program Office, and the Pacific Basin Information Node (PBIN) of the National Biological Information Infrastructure (NBII).

Analysis: Analysis is currently scheduled for FY05. We plan to employ a simulated annealing approach to optimizing biological viability goals while minimizing exposure to degradation of ecological integrity and socioeconomic factors. The gap analysis for our project is anticipated to employ the use of SITES/Marxan for design of a comprehensive ecosystem conservation approach.

Reporting and data distribution: Data are available for both aquatic species survey information mapping and stewardship mapping. Contact HINHP or the National GAP Office for details.

Other accomplishments and innovations: HI-GAP is working in concert with NBII's Pacific Basin Information Node to compile data on and map the distribution of the top incipient invasive species on each island. Each island's Invasive Species Committee (ISC) has provided location data and status information for key invasive species, which will be consolidated into one database over the next few months. HI-GAP is currently working with members of Hawaii's Coordinating Group on Alien Pest Species (CGAPS) to define those alien species that are considered threats to the biodiversity of the Hawaiian Islands. Once the species have been chosen, relevant information will be compiled and mapped, creating an alien species layer that will be used in determining degree of threat to existing native flora and fauna.

Idaho

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Illinois

Project under way (http://www.inhs.uiuc.edu/cwe/gap/gapintro.html)
Anticipated completion date: March 2003

Contacts: Pat Brown, PI
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pbrown@mail.inhs.uiuc.edu, (217) 244-4289

Tari Weicherding, Coordinator
Illinois Natural History Survey, Champaign
tweicher@uiuc.edu, (217) 265-0583

Land cover: The land cover layer and accuracy assessment are complete. The land cover layer can be viewed and downloaded at http://www.agr.state.il.us/gis/index.html.

Animal modeling: The wildlife habitat relationship database has been completed for 472 species. Predicted distribution models are currently being created for all species. We anticipate having all models reviewed and finalized by March 2003. None of the vertebrate maps have been validated.

Land stewardship mapping: The land stewardship layer is complete and will be updated as needed.

Analysis: Analysis will begin in early 2003.

Reporting and data distribution: We expect to complete reporting and data distribution within the next four months. The Illinois Gap Analysis Project Web page can be reached at www.inhs.uiuc.edu/cwe/gap/gapintro.html.

Indiana

Project under way
Anticipated completion date: June 2003

Contact: Forest Clark
U.S. Fish and Wildlife Service, Bloomington
forest_clark@fws.gov, (812) 334-4261 x206

All of the primary data layers are complete, and analysis is near completion. Preliminary products will be delivered to the national GAP office for review in early 2003. We anticipate completion within six months.

Land cover: The Indiana land cover data are complete. We are incorporating these data into our gap analysis of Indiana. The data have also been used by various Indiana GAP partners for diverse projects and provided to numerous organizations upon request.

Animal modeling: The Indiana project completed the modeling of 300 vertebrate species. Pangaea Information Technologies, Ltd. was contracted to run the final models in the autumn of 2002. We are incorporating the models into our gap analysis of Indiana.

Land stewardship mapping: The land stewardship map of Indiana, developed primarily under the aegis of the Indiana Department of Natural Resources, Division of Fish and Wildlife, is complete. We are incorporating these data into our gap analysis of Indiana.

Analysis: A preliminary gap analysis of Indiana has been run in cooperation with Pangaea Information Technologies, Ltd. The initial results have been forwarded to the national GAP office for review. We will continue to evaluate the data in the coming months in preparation for the Indiana Gap Analysis Project final report.

Reporting and data distribution: We are continuing the analysis phase of the project and have initiated writing of the final report. We propose to continue that process through the winter/spring of 2003 and, in cooperation with the national GAP office, make products available in the summer of 2003.

Other accomplishments and innovations: The Indiana Biodiversity Initiative (IBI), which uses Indiana Gap Analysis products extensively to identify landscape level conservation sites, received a generous grant from the Efroymson Fund of the Central Indiana Community Foundation. Working with our partner D.J. Case & Associates, the grant will support completion and pilot implementation of the IBI Regional Assessments in the spring of 2003.

Iowa

Draft data available from state (http://www.ag.iastate.edu/centers/cfwru/iowagap/.
Review under way.
Anticipated completion date: December 2002

Contact: Kevin Kane
Director, GIS Support and Research Facility
Iowa State University, Ames
kkane@iastate.edu, (515) 294-0526

The Iowa Gap Analysis Project (IA-GAP) finished its fourth and final year of funding in 2001. All that remains to be done is submitting the final report. The IA-GAP home page is accessible at http://www.iowagap.iastate.edu/.

Land cover: Land cover mapping is 100% complete. Final maps will be published in the final report and on the IA-GAP Web site. Data can also be viewed on the Iowa Geographic Image Map server at http://ortho.gis.iastate.edu/gaplandcover/gap_lc.html.

Animal modeling: Models have been completed for all species. Iowa has been a cooperator in the upper Midwest vertebrate modeling initiative along with North and South Dakota. Final distribution maps will be published in the final report and on the IA-GAP Web site.

Land stewardship mapping: Stewardship mapping and attribution is complete. Final maps will be published in the final report and on the IA-GAP Web site. The IA-GAP stewardship image map server can be accessed at http://maps.gis.iastate.edu/iagap.

Analysis: Analysis is complete.

Reporting and data distribution: Final maps, report, and data will be published on CDs, the GAP home page, and the IA-GAP Web site.

Other accomplishments and innovations:
<u>Land cover accuracy assessment</u> - The final report submitted to EPA Region VII can be viewed on the IA-GAP home page (http://www.iowagap.iastate.edu/) or on the National GAP site (http://www.gap.uidaho.edu/Bulletins/10/methodological_study.htm).

NatureMapping - In 1999, Iowa State University Extension (ISUE) Wildlife Programs began offering the Iowa NatureMapping Program to a wide-ranging audience. NatureMapping is a citizen-based wildlife monitoring program, which is an education and outreach component of IA-GAP. Reliable, accurate, and up-to-date information about Iowa's wildlife collected by Iowans will give those making decisions in wildlife management and research, urban development, or conservation and preservation a valuable layer of data not otherwise available in traditional land use planning. NatureMapping is a way to collect large data sets while reconnecting people to their local resources.

Iowa Geographic Information Image Server - The server is serving aerial photography (orthophotos), topographic maps, and other Iowa grid data from http://ortho.gis.iastate.edu. This service is heavily used by IA-GAP and our cooperators as well as many other Iowa users for a variety of applications. The goal for 2003 is to update storage to provide data at higher resolution and serve more data, including integrating vector data and new Iowa color infrared photography coordinated by the Iowa DNR.

Kansas

Draft data available from state (http://www.ksu.edu/kansasgap/). Review under way. Anticipated completion date: January 2003

Contact: Jack Cully
USGS, Manhattan
bcully@ksu.edu, (785) 532-6534

Land cover: Complete

Animal modeling: Complete

Land stewardship mapping: Complete

Analysis: Complete

Reporting and data distribution: Finishing final edits on final report.

Other accomplishments and innovations: Developing a set of Great Plains regional animal distribution models using our database decision support system. States included are: Colorado, Kansas, Nebraska, Wyoming, South Dakota, Iowa, Montana, North Dakota, and Minnesota.

The Kansas Gap Analysis Program (KS-GAP) Education Project (contact: Glennis A. Kaufman, PI, Kansas State University, Manhattan, gkaufman@ksu.edu) has been developing seven modules for use in the elementary classroom. These modules use land cover data, stewardship data, and predicted distribution and habitat associations for terrestrial vertebrates in Kansas as the prototype. An oral presentation was given at the12th Annual National Gap Analysis Program Meeting at Shepherdstown, WV, about fostering the partnerships with trial schools and the initiation of module development. At the same meeting, a poster also was presented that showed our progress on the State Project Resource Manual. The manual will illustrate the methods used in developing the modules as well as equipment needed to develop these resources for elementary schools. We anticipate that the pilot project with the ten trial classrooms will be completed by mid-February 2003. The educational modules are served from the Web site, www.ksu.edu/kansasgap/. This project is supported by grants from USGS/BRD and the Kansas Department of Wildlife and Parks.

The KS-GAP Tools Project (contact: Glennis A. Kaufman, PI, Kansas State University, Manhattan, gkaufman@ksu.edu) is developing tools for use in management decisions for the Kansas Department of Wildlife and Parks. These decision tools are based on the land cover, stewardship, and vertebrate data layers developed in the KS-GAP state project. In 2003, the individuals involved in this project will provide presentations and hands-on training in the use of these tools. This project is supported by a renewable grant from the Kansas Department of Wildlife and Parks.

Kentucky

Draft data available from state (http://www.kfwis.state.ky.us/KYGAPWeb/index.htm).
Review under way.
Anticipated completion date: March 2003

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Tom Kind, Co-PI
Murray State University, Murray
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Land cover: Complete.

Animal modeling: Complete.

Land stewardship mapping: Complete.

Analysis: Complete.

Reporting and data distribution: The KY-GAP team is now in the process of compiling the final report. We anticipate acceptance from National GAP by late winter or early spring 2003.

Other accomplishments and innovations: Several ancillary projects have been developed from these data. Three workshops have been conducted in conjunction with Murray State University, University of Louisville, University of Kentucky, and the KY Dept. of Fish and Wildlife Resources to train middle and high school teachers to use ArcView and the land cover and animal modeling data sets. These workshops were funded by a grant from the USGS. The KY Dept. of Fish and Wildlife Resources has also used these data to examine priority areas for the Comprehensive Plan portion of the State Wildlife Grants Program.

Louisiana

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Maine

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Maryland, Delaware, and New Jersey

Draft data available from state (http://fwie.fw.vt.edu/MDGAP/). Review under way. Anticipated completion date: January 2003

Contact: D. Ann Rasberry
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darasberry@mail.umes.edu, (410) 651-6069

Land cover: Land cover mapping for the three-state area was completed during 2001. An additional transformation on the data set was performed in 2002 to improve spatial accuracy and increase the nominal scale to 1:24,000. An accuracy assessment was conducted with nearly 2,500 points randomly selected from the project video. The final fuzzy accuracy assessment calculations have been completed; a report was presented at the annual GAP meeting in West Virginia and can be viewed from the GAP Web pages. The draft data sets were delivered to the Operations Office in January 2003.

Land stewardship mapping: The land stewardship mapping for the project was completed in 2002. Intense editing was conducted to resolve property boundary conflicts. The data sets were delivered to the Operations Office in January 2003.

Analysis: The tables for the land cover analyses have been created. The results of the gap analysis for the project will be completed and presented in the final report in January 2003.

Reporting and data distribution: The final report development was nearly completed in 2002. The report will be delivered to the Operations Office in January 2003.

Massachusetts, Connecticut, and Rhode Island

Project under way
Anticipated completion date: May 2003

Contacts: Curtice Griffin
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Land cover: Although the land cover map was completed in 1997, preliminary field assessment by cooperators indicated that there were significant classification errors, especially in the Cape Cod region. We corrected these misclassification errors and other rectification problems. The land cover map is corrected and completed for the study region.

Animal modeling: Habitat models were revised and completed for birds, reptiles, amphibians, and mammals. Additional expert reviews and revisions were made for all coarse range maps. Predicted habitat distributions for all 273 vertebrates modeled in the Southern New England region are complete. We are currently investigating the use of ancillary data sets for species whose breeding requirements make them difficult to map (e.g., bald eagles and shorebirds).

Land stewardship mapping: We updated and analyzed stewardship and management data for conservation lands throughout Southern New England. Ownership and management of these conservation lands included federal, state, private, nonprofit, municipal, and town-owned properties. Nearly 24% of the total land area of Southern New England is in conservation. However, only 4% is classified as GAP management categories 1 and 2 (the highest levels of biodiversity conservation). Of conservation lands, the major owners include state agencies (59.8%), private owners (17.4%, including private conservation easements, nonprofit organizations, and unrestricted management), and local governments (19.0%, including locally owned parks, recreation areas, and wildlife areas). In Southern New England, federal agencies own only 4% of the conservation land.

Analysis: Accuracy assessment for the land cover map was initially completed in 1996 (Slaymaker et al. 1996). However, considering the recent corrections of misclassification and rectification errors, we hope to redo the land cover map accuracy assessment. We are currently collecting species list and survey data to complete accuracy assessment for the predicted species distribution maps.

Reporting and data distribution: Once the databases and analyses are updated, all data layers will be made available on the National Gap Analysis home page. Until then, there will be only limited access to the data. The final report and data will also be distributed via CD-ROM. Availability of the data and final report is planned for May 2003.

Literature cited:

Slaymaker, D.M., K.M.L. Jones, C.R. Griffin and J.T. Finn. 1996. Mapping deciduous forests in Southern New England using aerial videography and hyperclustered multi-temporal Landsat TM imagery. Pages 87-101 in J.M. Scott, T.H. Tear, and F.W. Davis, editors. Gap Analysis: A landscape approach to biodiversity planning. American Society of Photogrammetry and Remote Sensing, Bethesda, Maryland.

Michigan

Project under way
Anticipated completion date: September 2003

Contact: Mike Donovan
Michigan Department of Natural Resources
Wildlife Division, Lansing
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Land cover: Land cover mapping followed the Upper Midwest GAP protocol (ftp://ftp.umesc.usgs.gov/pub/misc/umgap/98-g001.pdf). Mapping of the existing natural and seminatural land cover of Michigan continues in cooperation with the DNR's Integrated Forest Monitoring Assessment and Prescription (IFMAP) project, utilizing new Landsat 7 imagery. The entire state should be completed in 2003. The existing land cover classification for the state (from original MRLC imagery) has been cross-walked to the NVCS.

Animal modeling: Wildlife Division research faculty at Michigan State University (MSU), in cooperation with the Michigan Natural Features Inventory (MNFI) and other Wildlife Division staff, will be completing work on a species distribution modeling project and gap analysis.

Land stewardship mapping: The stewardship data layer has been delivered to UMESC and is being reviewed.

Reporting and data distribution: Draft land-cover data and stewardship data are available from the USGS Upper Midwest Environmental Sciences Center. Contact Daniel Fitzpatrick at (608) 783-7550 x12 or Daniel_Fitzpatrick@usgs.gov.

Minnesota

Project under way
Anticipated completion date: September 2003

Contact: Gary Drotts

Minnesota Department of Natural Resources, Brainerd
gary.drotts@dnr.state.mn.us, (218) 828-2314

Land cover: Land cover mapping followed the Upper Midwest GAP protocol (ftp://ftp.umesc.usgs.gov/pub/misc/umgap/98-g001.pdf). The state Department of Natural Resources (DNR) has completed classification of the entire state and, with the assistance of NatureServe, the classification has been cross-walked to the NVCS.

Animal modeling: Hexagon species range maps have been developed for Minnesota and delivered to the USGS Upper Midwest Environmental Sciences Center (UMESC). Species expert review teams are helping to develop habitat suitability. The animal modeling coordinator for the Minnesota DNR is Jodie Provost (Jodie.provost@dnr.state.mn.us). Vertebrate distribution mapping and gap analysis will be completed in 2003.

Land stewardship mapping: Stewardship mapping is completed, and a draft version is available from UMESC.

Reporting and data distribution: Draft land-cover data and stewardship coverages are available from UMESC. Additional land cover data are expected to become available in 2003. Contact Daniel Fitzpatrick at (608) 783-7550 x12 or Daniel_Fitzpatrick@usgs.gov.

Mississippi

Project under way
Anticipated completion date: December 2003

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Land cover: The MS-GAP land cover map was completed in 1999 and has been continually used by numerous state, federal, and local resource agencies since its completion. Requests for data remain high. Land cover data is available for download from the MS-GAP home page (http://www.cfr.msstate.edu/gap/gap.htm).

Animal modeling: Modeling for animal ranges and distribution has been completed. Distributions were developed for 402 species including 58 mammals, 216 birds, and 128 reptiles and amphibians.

Land stewardship mapping: Land stewardship mapping was completed in cooperation with the Mississippi Department of Wildlife, Fisheries, and Parks and the US Forest Service. As with many other eastern states, Mississippi is mostly comprised of status 4 lands. Less than 1% of the state is in level 1 status, while level 2 status lands comprise 7% of the state.

Analysis: Analysis is complete and is being used to finalize the MS-GAP final report. A draft final report will be submitted to the National GAP office during 2003.

Reporting and data distribution: Our current efforts are centered on finalizing the MS-GAP final report. Data are being distributed as requested from cooperators and other agencies.

Missouri

Draft data available from state. Review under way.
Anticipated completion date: March 2003

Contact: Timothy L. Haithcoat
Geographic Resources Center
University of Missouri-Columbia
HaithcoatT@missouri.edu, (573) 882-2324

Land cover: Phase I land cover was completed by the Missouri Resource Assessment Partnership. Metadata has been compiled for the base land cover map as well as all derivative databases created from this base such as ecotones, interiors, etc. Ancillary land cover databases (sink holes, wetlands, glades, etc.) compiled for this project were also documented.

Animal modeling: Three hundred forty-eight vertebrates were modeled (66 mammals, 164 birds, 74 reptiles, and 44 amphibians). Ninety-meter grids representing the species' predicted distributions were created for final GAP reporting. Metadata has been compiled for these predictive species maps with the exception of the avian grids.

Land stewardship mapping: Stewardship was created by the Missouri Resource Assessment Partnership. Public lands comprise only 6.7% of Missouri with 4.7% under federal and 2% under state jurisdiction. All areas greater than 16 hectares were analyzed for biodiversity components. Metadata has been compiled for these stewardship maps.

Analysis: All analyses have been completed, and the peer-reviewed final report has been submitted to the National GAP office.

Reporting and data distribution: A draft report has been submitted. GIS data have been submitted for review.

Montana

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Nebraska

Project under way
Anticipated completion date: March 2003

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James W. Merchant, PI
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Land cover: The land cover map has been completed.

Animal modeling: We are in the midst of expert reviews, accuracy assessments, and metadata preparation. Plans for the next three months include completing expert reviews, accuracy assessments, and metadata for models and maps.

Land stewardship mapping: Land stewardship mapping has been completed.

Analysis: Draft maps of species richness by taxon are complete. Initial expert reviews are encouraging. Final analysis is pending completion of expert review and revision of animal models.

Reporting and data distribution: Metadata assembly, data lineage, and methods documentation are nearing completion.

Nevada

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.
Remapping under way (see Southwest Regional GAP).

New Hampshire

(see Vermont and New Hampshire)

New Jersey
(see Maryland, Delaware, and New Jersey)

New Mexico
Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.
Remapping under way (see Southwest Regional GAP).

New York
Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

North Carolina
Draft data available from state (http://www.ncgap.ncsu.edu/). Review under way.
Anticipated completion date: March 2003

Contact: Alexa J. McKerrow
North Carolina State University, Raleigh
mckerrow@unity.ncsu.edu, (919) 513-2853

Land cover: The statewide land cover is complete (Figure 1). The land cover map contains over 60 cover types across the state, ranging from spruce-fir forests to ocean beaches. The final assessment of the statewide mosaic is under way.

Figure 1. North Carolina land cover.

Animal modeling: Our vertebrate species database contains biological, range, and distribution models for 416 terrestrial vertebrate species that breed in North Carolina. Review of the species occurring throughout the Roanoke-Tar-Neuse-Cape Fear (RTNCF) ecosystem has been ongoing as a part of the use and distribution of the GAP Ecosystem Data Explorer Tool.

Land stewardship mapping: The stewardship map contains over 2000 polygons with information on ownership, management, and the level of protection for long-term biodiversity (Figure 2).

Figure 2. Land management status as a proportion of all land in North Carolina. Large water bodies (e.g., bays and reservoirs) were excluded from the area calculations.

Analysis: Analyses have been completed for the RTNCF ecosystem and are under way for the statewide data layers.

Reporting and data distribution: The statewide report is near completion; internal review of the land cover and stewardship chapters is ongoing. Completion of the vertebrate species and analysis chapters is expected by mid-February.

Other accomplishments and innovations: A GAP Ecosystem Data Explorer workshop for wildlife and conservation biologists was held January 27, 2003. While the core audience was Fish and Wildlife biologists, this workshop included individuals from Natural Resources Conservation Service, North Carolina Wildlife Resources, and North Carolina Natural Heritage Program.

North Dakota

Project under way
Anticipated completion date: September 2003

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Land cover: Activities in 2002 included: (1) refinement of regression tree models predicting the relative abundance (% biomass) of common grass species in North Dakota (ND), (2) analysis of multitemporal Thematic Mapper (TM) imagery using classification tree and supervised clustering and maximum likelihood methods, (3) integration of grassland plant community map (from cluster analysis of grass species relative abundance maps) and land cover maps from TM imagery, and (4) design and data collection for an accuracy assessment of the land cover map. Land cover data for the accuracy assessment were collected using aerial photography and ground surveys in a two-phase, unequal-probability, stratified random sampling design. Primary activities in 2003 will be completion of a vegetation and land cover map for ND in winter of 2002-03 and the construction and analysis of data sets for accuracy assessment of the map.

Animal modeling: Wildlife habitat relationship models have been reviewed and updated as necessary. Some comments are still being received. Environmental data grids for modeling species distributions were evaluated and prepared. Efforts for 2003 include running species models when the land cover map is completed, reviewing model outputs, and assessing the accuracy of species distribution maps by comparisons with species lists available for national wildlife refuges and parks.

Land stewardship mapping: Cooperators continued to provide significant in-kind resources. The U.S. Fish and Wildlife Service (FWS), the North Dakota Game and Fish Department, and the Bureau of Land Management continued work on their land unit vectors. Information on the land cover composition of FWS fee-title lands was received. Vector and management data for the final U.S. Forest Service Dakota Prairie Grasslands Management Plan were received. Additional land stewardship data for Bureau of Reclamation and national and state park lands were acquired or constructed. A procedure addressing coincident lines and polygon sliver problems was developed for assembling the individual agency land ownership vectors into a single public land stewardship vector for ND. Where necessary, land ownership vectors are snapped to U.S. Public Land Survey System section and quarter section vectors derived from 1:24,000 scale maps or to land ownership vectors developed using GPS. We will complete the acquisition of vectors for public lands and assemble and attribute a single public land stewardship vector for ND in winter of 2002-03.

Analysis: Gap analysis, creation of final digital map products for delivery to the National Gap Analysis Program, and report writing will be major activities in the spring and summer of 2003.

Reporting and data distribution: The final report and CDs for distribution of products to the National Gap Analysis Program will be completed by September 30, 2003. The report and data will also be made available to North Dakota GIS Technical Committee for distribution on the ND GIS Hub.

Other accomplishments and innovations: Two posters on the land cover objective were presented in 2002:

Strong, L.L. 2002. Integration of GIS and remote sensing for mapping rangeland plant communities of the Northern Great Plains. 55th Annual Meeting of Society for Range Management, 13-19 February 2002, Kansas City, Missouri.

Strong, L.L. 2002. Integrating GIS and remote sensing to create a vegetation and land cover database for North Dakota. 9th Annual Conference of The Wildlife Society, 24-28 September 2002, Bismarck, North Dakota.

Ohio

Project under way
Anticipated completion date: September 2005

Contact: Donna N. Myers, Coordinator
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dnmyers@usgs.gov, (614) 430-7715

The Ohio Gap Analysis Project consists of terrestrial and aquatic components. Both component projects are working together to enhance the wetland habitat classification in the Lake Erie Basin in Ohio. The Ohio Department of Natural Resources (Ohio DNR), the Ohio Lake Erie Commission (OLEC), and the Ohio Environmental Protection Agency (Ohio EPA) continue to play active roles in the project. About 75% of the aquatic GAP project and about 40% of the terrestrial GAP project were completed by the end of 2002.

Land cover: Progress was made toward the goal of completing, in draft form, 66% of the land-cover map by June 2003. A complete draft land-cover map is planned for production by June 2004. Accelerated mapping activities began with the hiring of a second vegetation classification specialist and several graduate students to assist with image processing and other activities in October 2002.

The acquisition of aerial digital images began in 2002 after completion of a pilot study in the fall of 2001. A total of 32,346 digital images were taken during 30 days of flying in the growing season of 2002. These images represent about 60% of the state, completing the goal for calendar year 2002. About 20 additional days are needed in 2003 to complete flights in remaining areas and will result in about 60,000 photos covering most of Ohio, including overlap with adjacent states. The resolution of these images is 0.30 meters. To date, all the digital photographic images have been stored on two identical sets of DVDs. A highly automated solution for georeferencing these images is under development and will replace a manual method currently being used. In 2002, approximately one-third of the state's land cover was completed using an unsupervised classification of leaf-on and leaf-off LANDSAT 7 images taken in 1999 and 2000.

The National Vegetation Classification System is being used to develop terrestrial and wetland vegetation alliances in Ohio. Preliminary ground-truth data were collected from most of the areas that were photographed in 2001-02. Initial vegetation classification was begun in 2002 using the ground-truth data and aerial imagery to train photo interpreters on canopy color, shape, and texture of forested, wetland, and other natural areas. Field verification of 39 wetland sites was conducted in 2001-02. When completed in 2003, about 18,000 data samples representing all plant community alliances in Ohio will have been collected for field verification. These samples will serve as the basis for the final alliance classification, planned for completion by December 2003. In 2004, the wetlands alliances will be further classified with hydrology-related information to indicate wetland type, such as coastal, riverine, or isolated, to help model and predict species occurrence.

Animal modeling: The hexagon range maps were released for review in spring of 2001, and the expert review of these maps was completed in the summer and fall of 2001 for all amphibians, birds, and mammals. The expert review of Ohio reptiles is still under way, and further comments are expected from two herpetologists in Ohio for reptile range information. The reptile range maps will be 75% completed in June 2002 and fully completed in 2003.

The literature review of habitat affinity information for each terrestrial vertebrate species is being developed and is connected to an Access database. The literature review of Ohio terrestrial vertebrates is complete for 50% of the species list. The Vertebrate Modeling Database developed by the Kansas GAP was used as a guide, and this work has been ongoing since 2000. The habitat affinity database and literature review are planned for completion in 2003.

Land stewardship mapping: The land stewardship map is 85% complete. In 2002, available data and maps of Army Corps of Engineers land, county and local parks, and privately-owned preserves were added. Upcoming work on the land-stewardship map entails attributing and verifying the GAP status for some of the newer acquisitions. Completion is planned for May 2003.

Reporting and data distribution: Hexagon range maps for birds, amphibians, and mammals are planned for release and review on the Ohio-GAP Web page (http://oh.water.usgs.gov/ohgap/ohgap.html) in early 2003. Stakeholder meetings were held on June 6 and December 4, 2002. Two stakeholder meetings are planned for 2003.

Other accomplishments and innovations: One of the largest stressors to animal and plant communities in Ohio is the transportation network and related urban sprawl that develops around new and improved roadways. Ohio-GAP, in cooperation with OLEC, Cuyahoga River Community Planning Organization, U.S. Environmental Protection Agency (EPA), Ohio Department of Transportation, Federal Highway Administration, and Northeast Ohio Areawide Coordinating Agency, will begin to develop a Decision Support System to aid in the early integration of environmental and transportation planning at the watershed scale. Early integration of biodiversity information into transportation planning can help to avoid, reduce, or mitigate the cumulative effects of urban development on Ohio's natural landscapes. The project was funded cooperatively through grants from the USGS Gap Analysis Program and Cooperative Water Program, OLEC, and EPA-Region 5.

Oklahoma

Draft data available from state. Review under way.

Oregon

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Pennsylvania

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Puerto Rico

Project under way
Anticipated completion date: October 2005

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Land cover: The International Institute of Tropical Forestry has recently mapped land cover for Puerto Rico at the formation level using 1991-92 Landsat TM data (Helmer et al. 2002). The land cover map has 27 vegetation and 4 nonvegetation classes. In the last year we have compiled more detailed information on the associations and dominant communities from field studies and the literature, including information on eight of the major forest types on the island (Carrero et al. in prep.). These include two coastal flooded forest types (black mangrove and *Pterocarpus*), mature dry forests, lowland moist forests, submontane tabonuco forests, montane palo colorado, palm and elfin forests. These span a range of important habitat types in Puerto Rico. We have also compiled a cloudfree mosaic from more recent (1999-2001) Landsat TM data. Our goals for next year are to improve the mosaic with atmospheric and radiometric correction, classify the image using the methods and land cover classes of Helmer et al. (2002) and expand on the habitat information within the mapped formations. A particular gap in vegetation description exists in understanding the younger lowland and submontane moist and dry forest types that have emerged on abandoned agricultural land in the last 20 - 50 years. These forests are dominated by exotic tree species but have significant numbers of native species. Little has been written about their species composition, habitat characteristics, and extent.

Animal modeling: We have compiled a list of 437 vertebrate taxa in a Microsoft Access database and are beginning to compile information on an initial set of 16 taxa with a range of habitat distributions (very restricted to wide ranging). We have also created a hexagon coverage that includes 7 hexagons nested within the EMAP hexagons typically used in the GAP program. This is to accommodate the finer scale of biotic and landscape heterogeneity found on the island. In the coming year we will produce habitat models for our initial species, produce range maps, and have vertebrate experts review the habitat models and range maps. We will use this process to refine our modeling efforts for all species and continue to compile information on the habitat characteristics of the remaining species.

Land stewardship mapping: We have a GIS coverage of all managed lands for Puerto Rico, and in the coming year we will classify these into the four management strategies used in the GAP program.

Analysis: Gap analyses will begin as we complete our vertebrate models and database in 2004.

Reporting and data distribution: Two posters were presented at the National GAP meeting (Reyes et al. 2002 and Carrero et al. 2002), a poster was presented at the Luquillo LTER meeting in January 2003 (Carrero et al. 2003), two talks were given in late 2001 (Gould 2001a, b) and two in 2002 (Gould and Carrero 2002, Gould et al. 2002), and a paper on our vegetation description is in preparation for *Conservation Biology* (Carrero et al. in prep.).

Other accomplishments and innovations: We have established a collaboration with the Department of Natural and Environmental Resources in Puerto Rico that will aid us in compiling information on vertebrate species habitat preferences. We have acquired the volunteer services of an Argentinean landscape ecologist to visit our Institute for 2003 to work on the PR GAP project. He will focus on refining our cloudfree imagery and updating our vegetation map. We are working closely with the North Carolina GAP project in order to gain from their expertise and experience.

Literature cited:

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Carrero, G., W. Gould, G. González, and J. Ramírez. 2003. Endemic, non-native, and critical plants in eight forest types along an elevational gradient. Poster presented at the Luquillo LTER Annual Meeting, January 2003, San Juan, Puerto Rico.

Carrero, G., W. Gould, G. González, and J. Ramírez. In prep. Native, endemic, non-native, and critical plants in eight forest types in Puerto Rico: Implications for conservation. *Conservation Biology*.

Gould, W.A. 2001a. Puerto Rico Gap Analysis Project. Presented at Departmento Recursos Naturales Ambiental (DNRA) meeting, December 2001, San Juan, Puerto Rico.

Gould, W.A. 2001b. Puerto Rico Gap Analysis Project. Presented at North Carolina State University GAP workshop, December 2001, Durham, North Carolina.

Gould, W.A., G. Carrero, and B. Reyes. 2002. Puerto Rico Gap Analysis Project. Presented at the February 2002 Southeast Regional GAP meeting, Chattanooga, Tennessee.

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Helmer, E.H., O. Ramos, T. del Mar Lopez, M. Quiñones, and W. Diaz. 2002. Mapping forest type and land cover of Puerto Rico, an island within the Caribbean biodiversity hotspot. *Caribbean Journal of Science* 38:165-183.

Reyes, B., G. Carrero, and W. Gould. 2002. Puerto Rico Gap Analysis Project. Poster presented at the 12th National GAP Meeting, Shepherdstown, West Virginia.

Rhode Island

(see Massachusetts, Connecticut, & Rhode Island)

South Carolina

Draft data available from state. Review under way.

South Dakota

Draft data available from state (http://wfs.sdstate.edu/sdgap/sdgap.htm). Review under way.

Anticipated completion date: March 2003

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Land cover: Completed.

Animal modeling: Completed.

Land stewardship mapping: Completed.

Analysis: Completed.

Reporting and data distribution: The final report and data are in review.

Southwest Regional GAP (SWReGAP)

Remapping under way for the five-state region encompassing Arizona, Colorado, Nevada, New Mexico, and Utah. State coordination for all aspects of the project is facilitated through the SWReGAP Web site (http://leopold.nmsu.edu/fwscoop/swregap/default.htm).

Anticipated completion date: December 2004

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Land cover: The RS/GIS Lab at Utah State University is the regional land cover mapping lab for the five-state southwest region. Coordination with the other four states is facilitated through a Web page that allows access to spatial data, procedural documents, and an Internet Map Server (http://www.gis.usu.edu/docs/projects/swgap). During 2002 the five-state region completed the following tasks:

Coordination with USGS National Mapping Division at EROS Data Center – One of the most significant developments related to land cover was the initiation of a more formal relationship with the EROS Data Center (EDC). Based on this relationship, SWReGAP will participate in a more coordinated fashion with the USGS National Mapping Division's National Land Cover Database (NLCD) program. The objective of this relationship is to ensure the resulting SWReGAP land cover map is complementary to the NLCD. Increased interaction between SWReGAP and EDC has already improved information, training, and data transfer between the two mapping programs and is expected to increase technical transfer through the remainder of the land cover mapping effort.

Development of regional target legend for Ecological Systems – An equally significant development has been NatureServe's development of a target legend comprised of 100+ Ecological Systems for the five-state region. Ecological Systems are groups of National Vegetation Classification System (NVCS) Associations. As part of this effort, NatureServe developed Ecological System descriptions that include lists of NVCS Associations for each system. NatureServe also developed dichotomous keys to aid in labeling field training sites for a large portion of the five-state region. The target Ecological System legend is considered nearly inclusive of all land cover classes that the project anticipates mapping. Additional classes include some NVCS alliances and aggregations of Ecological Systems.

Land cover mapping methods – SWReGAP uses mapping zones to provide a gross biophysical stratification of the five-state area, and as a programmatic means to segment the work among participating states. Landsat 7+ imagery for three dates (spring, summer, and fall) as well as DEM-derived ancillary data layers are being used as the spatial data source for land cover description. The land cover mapping protocol follows approaches employed by EROS Data Center for the National Land Cover Database effort. Classification and Regression Trees (CART) are being employed to create a coarse-level map. Subsequent classification at the level of Ecological Systems and NVCS Alliances are accomplished via CART as well as traditional supervised and unsupervised image classification methodologies.

Field data collection – Presently approximately 50% of field data collection has been completed (approximately 32,000 training sites for the region), and the remaining 50% is anticipated to be completed during the 2003 field season. In addition to training sites collected by project personnel, SWReGAP has obtained existing field data through cooperation with government agencies, military installations, and Natural Heritage Programs.

Land cover regional coordination – In December 2002, Utah State University (USU) hosted a land cover workshop for the five states in the SWReGAP region. A key function of the workshop was to bring together scientists and technical experts from EROS Data Center, NatureServe, and USU to refine land cover mapping protocols for the region, as well as develop standard procedures for vegetation classification at the Ecological System level. As a result of the workshop, land cover mapping protocols were identified that are standardized and consistent with land cover mapping protocols currently used by other projects in the USGS. These protocols will be compiled in a land cover mapping protocol document that will be available on the Web.

Goals for the coming year – We are in the process of establishing milestones for the coming year. The timeline for the SWReGAP project requires the completion of the land cover map by December 31, 2003. With this target in mind, 50% of the region should be mapped by June 2003.

Animal modeling: The New Mexico project serves as the regional animal habitat modeling lab for the five-state southwest region. The regional lab has focused on the following objectives: (1) identifying the list of taxa to be modeled, including decision rules and orchestrating review of this list among the five projects; (2) allocating taxa modeling responsibilities among the projects with project review of allocation; (3) identifying multiple modeling techniques that may be of use for the project; and (4) creating a database to facilitate association compilation, expert review and modification, and potential end-user application. In addition, the New Mexico project conducted a regional animal habitat modeling workshop in Las Cruces, New Mexico, in April 2002.

Decision rules and modeling allocation – Taxa inclusion into the modeling process was determined by a series of decision rules. Currently 839 species-level taxa are to be modeled in the SWReGAP effort. At the species level, the following taxa were excluded:

- Taxa with only incidental, accidental, or vagrant occurrence.
- Taxa for which authoritative taxonomic sources have eliminated species standing.
- Taxa that have been extirpated from the area to be modeled for 20 years or >5 demographic generations, whichever is a greater time span. (Retain ecologically or demographically recent extirpations). Note that taxa that are extirpated within one or several state project areas but have occurred anywhere in the region within this time limit will be modeled across the region. Also, wide-ranging taxa that have been extirpated but are considered for reestablishment may not be excluded if projects and regional lab agree to retain them for modeling.
- Taxa representing unsuccessful introduction or reestablishment in the area subject to distribution modeling.
- Exotic (nonnative), primarily urban-dwelling taxa.
- Exotic taxa with restricted occurrence associated with specialized or ephemeral landscapes or only under human manipulation such that the taxon cannot be modeled effectively using GIS layers available for SWReGAP.

A taxa allocation decision rule was created to distribute initial taxa modeling responsibilities among all projects in a manner that capitalizes on previous modeling experience, is localized to the distribution of taxa experts, and is sensitive to local conditions applicable to more restricted taxa. All projects will have opportunity for input on modeling approach and results for all taxa, regardless of the lead assignment.

Potential modeling techniques – We are continuing to review modeling techniques that can be applied to Gap Analysis habitat association information. We have included, within our present modeling endeavor, the option of applying a weighted index overlay procedure in addition to the standard Boolean AND overlay procedure. This pilot project will determine feasibility of applying this particular procedure at larger scales or including other more rigorous procedures in the future. Index overlay offers a subjective consideration of the relative value of habitat variables, and fuzzy sets allow for the inclusion of ambiguity at the habitat boundaries. If applicable, two products will be produced: nonbinary representations incorporating uncertainty and the traditional GAP binary representations.

Habitat modeling database – The New Mexico project is in the process of creating a modifiable database to be used to compile taxa-specific information for modeling purposes. The intent is to create a data set that manages information and is used to construct each taxon's wildlife habitat relationship model. The database is being created to address several concerns of the regional group regarding expert participation and end-user functionality. It should be noted that the process of populating the regional database for wildlife habitat relationship models and defining range limits runs simultaneously. Included within the database is a user-friendly method to define range limits using the 8-digit hydrologic unit code (HUC). Incorporating regional suggestions we have defined a 3-character coding system based on historic/recent distribution as either known (K), potential (P), or extirpated (X). Following the example from Colorado we developed a coding system based on reproductive use (breeding, nonbreeding, both) and seasonal use (migratory, wintering, summering, wintering and summering).

The region has agreed to a set of core data layers that will be minimally addressed in each wildlife habitat relationship model. These core data layers are land cover, elevation (minimum and maximum), slope, aspect, soils, hydrology (distance to and association with permanent water), and patch size. Other layers specifically addressed in the database are mountain ranges, temperature (minimum and maximum), and precipitation. In addition, the database is being created in such a way that further data layers can be incorporated into the model-building process. This will allow each project to address subregional modeling needs.

Although the database is not currently ready to be populated, states are beginning the phase of gathering information on taxa to facilitate database population by compiling data. The protocol for database population has been submitted to each state project with a hard copy form to be used for data collection. Initial data collection received thus far at the regional lab includes complete or partial habitat models for 256 taxa of the 839 total to be modeled in the region. Completion of land cover mapping is projected for December 31, 2003, and will impact when models will be run and predicted animal habitat distributions will be mapped.

Land stewardship mapping: Land stewardship mapping activities will begin regionwide during 2003. Collaboration with BLM to obtain regionwide stewardship information and methods to consistently map stewardship across the five states will be discussed early in 2003.

Regional cooperation: Regional cooperation continues to be critical to the proper functioning of SWReGAP. Individual states contributed to the regional project during 2002 by participating in (1) two land cover mapping workshops in January and December; (2) regional breakout sessions held at the National Gap Analysis Meeting to coordinate animal habitat modeling and land cover mapping activities; (3) an animal habitat modeling workshop in April to facilitate collection of animal habitat modeling data; and (4) preparation of a regional brochure for outreach and education.

Regional poster and presentations – The SWReGAP poster was presented at various regional and national conferences across the U.S. In addition, the SWReGAP states and Regional Coordinator gave presentations throughout the year. For example, the Utah Project provided an overview of the GIS tools used in SWReGAP at the 23rd Annual ESRI Conference in San Diego and participated in the "Workshop on Remote Sensing for Sagebrush" hosted by the USGS Forest and Rangeland Ecosystem Science Center in Boise, Idaho. An article entitled "Preclassification: An Ecologically Predictive Landform Model," authored by Gerald Manis, John Lowry, and Doug Ramsey, was published in the 2001 GAP Bulletin.

Regional Web site and listserv – The New Mexico Project continues to maintain the main Web page and listserv communications for the entire region. The Utah Project maintains a Web page allowing access to spatial data and an Internet Map Server.

Analysis: Analysis for SWReGAP will take place when the mapping tasks are completed.

Reporting and data distribution: All products derived from the Southwest Regional Gap Analysis Project are scheduled to be complete by 2004 with some possibility of timeline revisions to be considered by the group in 2003.

Other accomplishments and innovations:

AZ-GAP – Arizona has documented many previously undescribed alliances in the NVCS for Arizona and submitted these alliances to NatureServe for inclusion in the land cover classification system for the region.

CO-GAP – The Colorado Project Coordinator continued development of an ArcView tool to collect and review vertebrate range distribution information. For animal habitat modeling, work has begun through the Natural Resource Ecology Lab at Colorado State University to depict uncertainty in habitat modeling outputs.

NV-GAP – Nevada staff established an interagency agreement engaging U.S. EPA-Las Vegas, the BLM Field Office in Ely, and the Eastern Nevada Landscape Coalition. This unique agreement allowed the state to achieve field data collection goals for the 2002 field season and established a strong relationship with BLM for future work to benefit both SWReGAP and BLM. In addition, discussions were held to establish a collaborative relationship with the USGS SageMap project in 2003.

UT-GAP – One key innovation developed in 2002 is an Internet-based tool for image standardization. Image standardization is the process of normalizing image pixel values for differences in sun illumination geometry, atmospheric effects, and instrument calibration. Standardizing imagery improves the ability to mosaic adjacent imagery and compare imagery over time (e.g., change detection). The image standardization Web site can be reached at http://www.gis.usu.edu/docs/projects/swgap/ImageStandardization.htm and provides three tools that create ERDAS Imagine™ spatial models (.gmd format).

Another innovation is an ArcView extension to facilitate interaction between the SPLUS statistical software and ArcView GIS. The StatMod ArcView extension was developed by Christine Garrard as part of an MS degree in biology at Utah State University. StatMod is a tool designed to provide a GUI interface between the spatial modeling capabilities of ArcView GIS with two statistical software packages (SAS and SPLUS) to facilitate ecological predictive modeling. The extension is available for free and can be downloaded, with user guide, from http://bioweb.usu.edu/gistools/statmod or from the ESRI ArcScripts Web page.

Tennessee

Draft data available from state. Review under way.

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Land cover: Completed. The final map contains 30 land cover classes with 18 forest alliance groups.

Animal modeling: Predicted species distributions and species richness data have been completed for Tennessee's 364 terrestrial vertebrate species.

Land stewardship mapping: Completed.

Analysis: Gap analysis has been completed.

Reporting and data distribution: Revisions to the final report are in progress.

Texas

Project under way
Anticipated completion date: April 2003

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Land cover: Complete.

Animal modeling: Complete.

Land stewardship mapping: Complete.

Analysis: Accuracy assessment for predicted vertebrate distribution under way.

Reporting and data distribution: Final report is 90% complete.

Other accomplishments and innovations: Data are being used as part of a 150-year analysis of change in land use and land cover in Texas. Data are also being used to develop models for vertebrate distribution by guilds based on elevation, precipitation, temperature, and soils, but not vegetation. This model developed for Texas will then be modified and applied to the entire Chihuahuan Desert, where the vegetation data layer is nonexistent.

Utah

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.
Remapping under way (see Southwest Regional GAP).

Vermont and New Hampshire

Draft data available from state. Review under way.
Anticipated completion date: June 2003

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Land cover: Complete.

Animal modeling: Complete.

Land stewardship mapping: Complete.

Analysis: Nearly complete.

Reporting and data distribution: Digital coverages were submitted in mid-2001. The final report will be distributed for peer review in early 2003.

Virginia

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Washington

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

West Virginia

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

Wisconsin

Project under way
Anticipated completion date: September 2003

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Land cover: Land cover mapping followed the Upper Midwest GAP protocol (ftp://ftp.umesc.usgs.gov/pub/misc/umgap/98-g001.pdf). Land cover mapping is completed, and a draft version is available from the USGS Upper Midwest Environmental Sciences Center (UMESC). With the assistance of NatureServe, the classification has been cross-walked to the NVCS.

Animal modeling: Wisconsin vertebrate mapping is being undertaken by UMESC. A regional vertebrate mapping approach, coordinated by UMESC and including participation by Minnesota and Michigan, was initiated in the fall of 2000. Regional species lists, range maps based on EPA hexagons, and habitat suitability matrices stratified by Bailey's Ecoregion Provinces are a few of the strategies being employed to minimize cross-state edge-matching and to reduce duplication of effort.

Land stewardship mapping: The Wisconsin DNR has finished compiling data for state, county, and U.S. Forest Service lands. UMESC has acquired coverages of DOI lands and has compiled the complete stewardship coverage. Stewardship attributing is being reviewed.

Reporting and data distribution: Land-cover data are available from UMESC. Contact Daniel Fitzpatrick at (608) 783-7550 x12 or Daniel_Fitzpatrick@usgs.gov.

Wyoming

Data on GAP Web site (http://www.gap.uidaho.edu/Projects/Data.asp) or CD.

AQUATIC GAP PROJECT REPORTS

Great Lakes Regional Aquatic GAP

Anticipated completion date: September 2007
Web site URL: http://www.glsc.usgs.gov/GLGAP.htm

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The Great Lakes states began a regional Aquatic GAP project in 2001 to be completed in 2007 in three states. The Ohio Aquatic GAP pilot project has been in progress since early 2000 (see separate status report for Ohio Aquatic GAP in this section). The objectives of the regional project are to develop a riverine aquatic gap analysis for all eight states in the Great Lakes Region. Projects are planned sequentially with new projects starting up when existing projects are nearing completion. Active partners in the new projects are the Michigan Department of Natural Resources (MDNR), Wisconsin Department of Natural Resources (WDNR), New York State Department of Environmental Conservation (NY DEC), and U.S. Fish and Wildlife Service (USFWS)-Region 5.

Stream classification: In mid-2002, new statewide projects started in Michigan, New York, and Wisconsin. The statewide projects are adopting many of the protocols from the Aquatic GAP pilot studies in Missouri, Ohio, and South Dakota. These methods include classifying streams using the Valley-Segment Type (VST) classification based upon channel, riparian zone, total catchment area, and other hydrogeomorphic features.

Before classifying streams, thematic data layers must be acquired and processed. In 2002, map layers including surficial geology, elevation (30 m National Hydrography Dataset [NHD]), and hydrography (1:100,000) were obtained for Michigan, New York, and Wisconsin. In Wisconsin, various automated machine language (AML) programs were acquired and tested in 2002 for processing data to determine stream order, sinuosity, gradient, and other geomorphic features across the basin. Corrections were made to the NHD in Michigan and Wisconsin to address flow direction coding errors, disconnected reaches, and primary/secondary flow codes.

The USGS Office of Ground Water reviewed the Darcy model, a groundwater-flow model used to help predict stream temperature for the VST classification. Modifications and improvements were recommended. The revised Darcy model will be used in 2003 in Michigan, New York, and Wisconsin to predict the relative importance of groundwater in streams and categorize streams as being cold, cool, or warm water.

Animal modeling: There are over 300 species of fish in the Great Lakes (GL) Basin as well as many species of freshwater mussels, crayfish, and aquatic insects. An Oracle™ database (Central Database) is in development and is planned to serve available aquatic species occurrence and abundance data for the regional project (which covers riverine ecosystems but not the actual Great Lakes). A prototype for serving data was developed in 2002 and is running successfully. The Integrated Taxonomic Information System (ITIS) codification and naming system for fish species is being used for standardization across the region. Currently, over 150,000 sampling sites in four states are being quality-assured before being entered into the Central Database.

In Michigan, the project is being coordinated with ongoing work at MDNR's Institute for Fisheries Research. Fish-sampling data have been acquired, including 79,961 records at 8,620 sites for presence/absence of species. Fish abundance data are available for an additional 2,000 sites. These data have been loaded into the Central Database, and a significant number (1,100) of additional records were added by hand. Sources of habitat affinity data to be entered into a database for GL Aquatic GAP have been identified.

The New York project has acquired a very extensive database of fish occurrence and distribution for the entire state from the NY DEC. The database includes more than 15,000 georeferenced samples (each an assemblage at a particular site) from 1988 through the present, most of which are verified by experts. The historic database (1900-87) consists of more than 100,000 samples and includes extensive data from the Biological Surveys of the 1920s and '30s, conducted by watershed throughout the state. Those data are also georeferenced but must be processed through the quality-control program. Additional acquisitions from the DECs extensive aquatic invertebrate and water-quality databases dating back to the mid-1970s are planned.

In Wisconsin, the WDNR biology database, which includes fish-species occurrence data, is being developed as part of another ongoing project with contributions from the Gap

Analysis project. Updated locations for fish-species data were obtained from WDNR and loaded into the WDNR Biology Database in 2002. This Oracle™ database includes over 16,000 different site visits where fish records have been collected. The database includes data for approximately 130 fish species that were collected as far back as 1880, with over 82% of the samples collected between 1970 and 2002. Additional information from WDNR was obtained to improve the location information for more than 18,000 site visits for fish-species sampling from 1945 to 1995.

Coastal GAP Pilot Project: A pilot project to develop a coastal gap analysis for the Great Lakes also began in 2002. Two areas are being proposed for pilot work in 2003-04 in western Lake Erie and eastern Lake Ontario. The initial development process includes acquiring and reviewing the local and regional data availability for habitat within the coastal zone. Assessment of data quality and extent indicates that available databases are sufficient to develop methods for successful completion of the GL Coastal Gap Analysis Pilot Project. The near-shore region of large water bodies like the Great Lakes can be difficult to sample, particularly in high-energy areas. The limited data collected from those areas are being gathered and assessed in Year One. We are also making progress on development of an effective habitat classification system. Research components including examination of methods to characterize and model coastal habitats and their relationships to the fish and other inhabitants began in Year One and will continue in subsequent years. Environmental databases containing information on Great Lakes coastlines, bathymetry, coastal geology and geomorphic units, and some coastal aquatic substrata have been collected. Data and information about circulation systems, exposure, and other habitat features are being acquired with the assistance and cooperation of many agencies and individuals. Data ownership and distribution issues must be resolved to complete database acquisition and application. Through meetings and conversations with biologists at the NY DEC, the project has acquired much of the available fish occurrence data for nearshore areas of Lake Ontario's eastern basin.

Reporting and data distribution: A Fact Sheet was started in 2002 and is planned for completion in the first half of 2003 and for publication later in the year. A Web site for the project was established at http://www.glsc.usgs.gov/GLGAP.htm with links to the home pages for the Ohio and Wisconsin Aquatic GAP projects and to the National GAP Web page.

Outreach and meetings: In October 2002, the regional team attended an Aquatic GAP training meeting in Missouri, hosted at the USGS Columbia Environmental Research Center by the Missouri Resource Assessment Partnership. In November 2002, the Wisconsin Aquatic GAP project was presented and discussed with stakeholders and cooperators at the WDNR Fish and Habitat Annual Section Meeting. In December 2002, the Wisconsin project personnel attended the Midwest Fisheries meeting in Iowa and provided an overview of the Aquatic Gap Analysis project. Stakeholder meetings are planned in 2003 in all states with active projects. The Coastal Pilot study team also participated in a USFWS workshop in December 2002.

A daylong session entitled "Biodiversity Conservation in the Great Lakes Region" is being planned for the annual meeting of the International Association for Great Lakes Research to be held in Chicago from June 22-26, 2003. Planned presentations will include an overview of the National Gap Analysis Program by Mike Jennings, presentations from the New York and Upper Midwest terrestrial GAP projects, and five presentations from the Great Lakes Regional Aquatic GAP describing projects in Wisconsin, Michigan, Ohio, and the coastal pilot study. Other invited abstracts came from The Nature Conservancy, the U.S. Environmental Protection Agency, the Ontario Ministry of Natural Resources, Ohio Sea Grant, and The Nature Conservancy Canada.

Hawaii Aquatic GAP

Anticipated completion date: May 2004

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HI-GAP has initiated an Aquatic Gap Analysis project and is working with local, state, and federal agencies to complete a statewide aquatic species distribution data set. Our approach to modeling vertebrate and macroinvertebrate distributions is based on a multivariate analysis of geomorphology and environmental variables. A meeting with representatives from local freshwater agencies was held in March 2002, where strong support for the project and proposed mapping methodology was expressed. The dramatic topography of Hawaii required a revision of standard methods for capturing a stream's physical attributes so that an increased level of detail could be captured. These adjustments enabled us to capture changes in habitats throughout the stream network. In order to achieve our modeling goals and objectives, several new tools are in the process of being developed for the project.

The first geomorphologic attribute the advisory group identified as a critical component to species modeling was the classification of waterfalls. Most aquatic biologists believe waterfalls are one of the major physical attributes defining a species' range in the stream continuum. To identify waterfalls, the Hawaii Gap Analysis Project has combined methods created by The Nature Conservancy's (TNC) Freshwater Initiative and new methods developed at the Hawaii Natural Heritage Program. In combination, these methods or tools identify the location of waterfalls and rate each in comparison with other waterfalls in a single watershed and amongst other waterfalls on a single island. Waterfalls are identified based on user-defined parameters. Height information is derived from the USGS 10-meter Digital Elevation Model (DEM). The results are then used to identify the maximum, minimum, and average height of each waterfall within each watershed and for each individual island. This information is added to a geodatabase containing all physical attributes for each island.

The second major morphological variable identified as significant for modeling species distribution was change in slope. The State of Hawaii has a unique topography with dramatic elevation changes over short distances, making slope indices implemented in other states inapplicable. For example, in Hawaii, a single stream can go from the headwaters at 3,000 feet to the mouth of the stream at sea level in less than four miles. After rigorous experimentation with several approaches to slope modeling, the advisory committee chose TNC's Freshwater Initiative slope tool as most applicable to Hawaii's needs. The tool was then used to identify slope changes in the stream continuum based on parameters defined by a group of aquatic biologists. So far, the slope tool has been applied to half of the islands in the Hawaiian Island chain. When combined, the slope and waterfall identification tools have successfully defined the analysis units for this project. The geomorphologic information contained in the analysis units along with the habitat affinity database will be used to produce a species distribution mapping model.

All data collected for this project is being stored in a customized geodatabase designed specifically for the Hawaii Aquatic Gap Analysis Project. The geodatabase contains all of the physical attributes derived for each analysis unit as well as all habitat affinity data provided by the State of Hawaii Division of Aquatic Resources. The common data structure and spatial aspect of the geodatabase will allow us to use an iterative approach to the modeling effort, giving us the chance to fine-tune the model.

Over the next year the Hawaii Aquatic Gap Analysis Project will continue to collect all necessary physical attributes for the main Hawaiian Islands. In the upcoming months we will be experimenting with species distribution modeling on Kauai. Extensive field surveys will be conducted following the initial species distribution modeling results to determine the accuracy of the model. Based on our results, changes will be made to the structure of the model to increase the accuracy of predicting species distributions.

Lower Missouri River Basin Aquatic GAP

a. Iowa

Anticipated completion date: December 2003

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The statewide coverage of reaches, including an area in NW Iowa where additional stream segments were added to match the density of surrounding quad sheets, has been completed. Unique segment IDs were added to each reach, based on a combination of the reach code and internal ID. An ArcInfo AML from MoRAP was run on the coverage to append some separate NHD table information to the linework. Each of the 57 hydrologic unit codes (HUCs) will have to be subset from this main coverage to be further processed to code primary or secondary (braid or loop) channels. Disconnected stream segments will also be attached if they are judged to be incorrect. Topographic maps will be used to analyze the disconnected segments. Currently, 5 HUCs (watersheds) have been subset, but the reach processing has not begun. The stream reaches (NHD) for four watersheds were made available through IRIS (http://madagascar.gis.iastate.edu/iris).

Much of the existing fish sampling data have been obtained from numerous state and federal agencies and academic institutions as well as from published literature. The data have been entered into a relational database designed by the Missouri Aquatic GAP Project but customized for Iowa Aquatic GAP. The fish database currently contains 4,160 community fish samples dating from 1926-2002, with a total of 40,196 species occurrence records.

Future plans: We will continue to subset the HUCs and begin to process the reaches within each HUC. As a HUC is completed, it will be sent to MoRAP for further processing. They will generate values for 10 variables, and the unique combination of those variables will create the valley-segment type variable. Those 11 variables will be attached to the reaches, and the HUC will be sent back to us. The reach information will be used, along with the biological sampling data, to generate predictive models for fish species.

Upon completion of the valley-segment characterization by MoRAP, work will continue on attributing the NHD reaches with stewardship information and physical and biological characteristics. Completion of this phase and the completion of species habitat descriptions will allow species prediction to commence. As data layers and species habitat descriptions are developed, they could be made accessible through IRIS.

The remaining sampling data will be collected and entered into the fish database. Stream reach locations will be determined for each sample collected. These data will then be used to generate statewide distribution maps for each species on a watershed-by-watershed basis, using 10-digit hydrologic units for widely distributed species and 12-digit hydrologic units for narrowly distributed species. Once maps for all fish species are completed, they will be sent out for professional review.

Development and Use of the Iowa Rivers Information System (IRIS)

The database created within ArcView 3.2 containing variables describing certain physical features of stream reaches in Iowa is complete, with very few exceptions. The database is represented as shapefiles of streams for each of the 57 HUC 8-level watersheds for the state. During 2002 we added four new variables to the previous list: gradient, public land, tier/range/section (T/R/S), and 24K topographic quad name. The public land information indicates whether or not the reach flows through public land designated by the Iowa GAP stewardship data. T/R/S and 24K quad name information was obtained from Iowa DNR NRGIS coverages. Gradient was calculated within ArcView using an extension from the ESRI ArcScripts page and a digital elevation model grid. We also added a new table to the collection, similar to the percentage of GAP land cover within 90 meters of a particular reach segment. It shows land cover percentage using the National Land Cover Dataset (NLCD) available from USGS; we added this information because we have reaches that fall outside the Iowa border. The exceptions mentioned previously include two watersheds for which gradient has not yet been calculated, one watershed for which GAP land cover percentage has not been calculated, and ten watersheds for which stream order has not been completed due to missing reaches. The IRIS ArcIMS data protocol has changed, so that reach information is no longer provided through an Access database table. The reach information for all watersheds is supplied directly as shapefiles.

We are continuing work on the Web interface for IRIS (http://madagascar.gis.iastate.edu/iris) using ESRI's ArcIMS technology. Currently users are able to view, query, and interact with IRIS data through a limited set of traditional GIS tools. Tools include the ability to zoom in and out, find specific reaches, and classify reaches according to IRIS attributes. Additional data layers have been added as they become available, and links to metadata or information about the different data layers now exist. An additional layer allowing users to view USGS real-time stream gauge information has been added. These data are currently being stored in an ArcSDE data layer. Scripts were written to extract real-time gauge data from the USGS Web site every three hours, then update the layer in the database.

Future plans: We are investigating providing the reach data through an Arc Spatial Database Engine interface directly to the IMS page. When GAP provides land cover data for the states surrounding Iowa, we will add that information to our database. The gradient and land cover variables missing for certain watersheds will be calculated. Stream ordering for the 10 watersheds will be done as time permits, but will have to be done by hand. Assistance will be given to the improvement of the IMS interface process and the point creation for biological sample sites as requested.

A variety of display and reporting features is planned. Mapping tools will be developed to select adjoining reaches up- or downstream from a point selected by the user and to download data for use in a GIS. Advanced reporting options will also be developed. A user will be able to perform a spatial or attribute query, generate a map of the selected features, and output a report that includes the map and attributes of the selected records.

b. Kansas

Anticipated completion date: May 2005

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The Kansas Aquatic GAP Project has made substantial progress in the past year and a half. This project is part of the regional Aquatic GAP effort in the lower Missouri River basin; however, we are including a portion of the Arkansas River basin because these drainages account for approximately half of the aquatic systems in Kansas. Draining of aquifers and major land use changes have been well documented, even before the turn of the century (Mead 1986). Because of these changes and the resulting loss of biodiversity in Kansas, we have received enthusiastic support from numerous cooperators in the state.

Two major steps are completed or near completion. The first step of formatting the stream network data layers has been completed. This base layer identifies stream valley segments, which are specific reaches delineated by stream confluences. This data layer will be used for the finest scale of species modeling. Numerous habitat descriptors have been attached to these valley segment habitat units, including stream size, gradient, location in the watershed, and proximity to other waterbodies. The second step of compiling biological data for both fishes and mussels is near completion, and most records are stored in a relational database along with the habitat information. To date we have over 2,000 collection sites in Kansas. These data have been compiled, and species distribution maps have been constructed and are available on our Web page (www.ksu.edu/aquaticgap). Currently, we are adding additional data from a variety of sources (e.g., museums, field notes of local biologist, etc.). Because much of our data included instream habitat measurements, we are also in the process of calibrating our GIS layers by comparing them with on-the-ground measurements.

Mead, J.R. 1986. A dying river. *Transactions of the Kansas Academy of Sciences* 14:111-112.

c. Missouri

Anticipated completion date: October 2003

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Aquatic ecological classification: An 8-level Aquatic Ecological Classification Hierarchy was developed in cooperation with The Nature Conservancy's Freshwater Initiative Program. Statistical methods for using biophysical data to classify aquatic ecological units were developed for levels 4-7 in the hierarchy, and those levels were subsequently mapped with a GIS. Methods for preprocessing the 1:100,000 NHD were also developed to make it suitable for further classifications procedures.

The following products were created:

- ArcView shapefiles and ARC INFO coverages for Aquatic Subregions of Missouri, Ecological Drainage Units (EDU) of Missouri, Aquatic Ecological Systems (AES) of Missouri, and Valley Segment Types of Missouri
- Written descriptions of the preprocessing and classification procedures for each of these levels in the hierarchy
- A suite of Arc Macro Language scripts to automate many steps in the Valley Segment classification process

Predictive distribution modeling: We developed methods of integrating our species occurrence records and attributes from our Valley Segment Coverage into a single database and then performing Classification and Regression Tree analyses to develop predictive models for each species. We also developed statistical methods for identifying undersampled watersheds and for more objectively correcting the geographic range of species. These methods appear superior to the more subjective professional review process, provided enough collection data are actually available to help drive the revision process.

The following products have been generated:

- A relational database of existing collection records for fish, mussels, crayfish, and snails within Missouri, containing nearly 8,000 records dating from 1900 to 1999 and including state, federal, and global rankings of all species. Each record is geographically linked to the 1:100,000 National Hydrography Dataset, allowing users to query and display within a GIS the specific stream reaches in which an individual species has been collected or view all species collected within a single stream reach. Each record is also geographically linked to the Missouri 1:24,000 12-digit Hydrologic Unit (HU) coverage. This allows users to query and display within a GIS the geographic range of each species throughout Missouri by 12-, 10-, or 8-digit HU, based on actual sampling data. It also allows users to query and display all species that have actually been collected within a single HU.
- A species occurrence database by 8- (for mussels) or 10-digit HU, which incorporates revisions made by taxonomic experts to the geographic range maps that were produced using only actual occurrence records. This database is also geographically linked to the Missouri 8- and 10-digit HU coverages and thus allows users to query and display within a GIS the professionally-reviewed geographic range of each species or all species occurring within a given unit based on both actual data and professional judgment.
- Endemism Database which categorizes each species (except for snails) according to levels of endemism corresponding to Aquatic Ecological Unit Classification. These categories reflect how restricted the overall geographic range of a species is and also allows us to identify which species are most distinctive within a given Ecological Unit.
- General habitat-affinity descriptions extracted from existing literature for all fish, mussels, and crayfish with associated citations.
- Region-specific predictive distribution models for all fish, mussels, and crayfish. Models were constructed primarily through the use of Classification and Regression Tree analyses that analyzed the occurrence records of each species with respect to attributes attached to our Valley Segment Coverage. For species with limited occurrence records we had to rely on more subjective model development procedures using the habitat-affinity information extracted from the literature or through the use of contingency tables for individual predictor variables, which were then qualitatively examined to identify species-habitat associations.
- 1:100,000 statewide predictive distribution maps for all fish, mussel, and crayfish species. These maps show, within the geographic range of each species in Missouri, all of the individual NHD stream reaches in which a species would likely be found under natural conditions. Unlike "terrestrial GAP projects" we are unable to predict present-day distributions because of our inability to accurately account for how the numerous and interactive effects of human-induced alterations specifically affect the distribution of riverine biota.

- A 1:100,000 statewide hyperdistribution coverage, allowing users to query and display within a GIS the predicted distribution of any fish, mussel, or crayfish species throughout Missouri. It also allows users to select individual reaches to see all of the fish, mussel, and crayfish species predicted to occur in that reach. Users can generate and display statistics pertaining to richness, endemism, and species of conservation concern across the state or for any region or watershed of interest.
- A suite of SAS programs to integrate and reorganize the species occurrence data and the attributes in the Valley Segment coverage required to generate species-specific databases in a format suitable for Classification and Regression Tree analysis.

Identifying conservation gaps and targets: In addition to the traditional gap analysis process we have developed a method to identify conservation gaps and prioritize conservation opportunities at multiple spatial scales (i.e., Ecological Drainage Unit, Aquatic Ecological System, and Valley Segment Type) by assessing the biophysical distinctiveness and conservation status of our ecologically-defined units at multiple spatial scales.

The following products have been developed:

- Conservation ranks for EDUs based on professionally reviewed biological data (based on richness, endemism, G1-G3 species statistics). These ranks indicate relative importance of each EDU within each Aquatic Subregion with regards to conserving aquatic biodiversity in Missouri.
- We are waiting for the final hyperdistribution database so we can attribute our AESs with the appropriate biological data and then conduct a similar assessment that will also incorporate a stewardship assessment. This assessment will show conservation gaps and also the relative conservation status of AES types within each EDU.
- We calculated over 60 land cover and land use statistics for each individual AES polygon across the state in an effort to condense this list into a meaningful set of statistics that could distinguish the relative environmental quality of each unit. Because of the high degree of correlation among most of these variables we were able to condense this list to just 8 relative uncorrelated variables. These include %Forest, %Wetland, %Urban, Population Change, Density of Mines, Density of Point Source Discharges, Density of Confined Animal Feeding Operations, and the Degree of Fragmentation caused by impoundments. These will be used as the core set of variables for our conservation status/threats assessment. An additional variable used in this analysis will be the number of exotic species.
- The final assessment will reveal conservation gaps of the dominant VSTs for each AES type within each EDU. This assessment is analogous to assessing the relative stewardship of vegetation classes by Landtype Associations within each Ecological Subsection (as defined by Bailey's Ecological Classification System).

d. Nebraska

Anticipated completion date: July 2003

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The Nebraska Aquatic Gap Analysis Project commenced in August 2002 with a training session with the Missouri Aquatic GAP Project team at MoRAP in Columbia, Missouri. All NHD basin coverages relevant to Nebraska have been acquired. An initial test basin has been edited and submitted to MoRAP for review and approval to commence further processing. The braided course of the Platte River poses a challenge for consistent but comprehensive processing of basins and confluences. We are studying alternate strategies for representing the Platte within the MoRAP protocol. We have started to identify sources of specimen records.

Ohio Aquatic GAP

Anticipated completion date: March 2005

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Stream classification: The Ohio Aquatic Gap Analysis Project is using many of the protocols used for the pilot study in Missouri (MoRAP) to classify streams in the state. These methods include classifying streams using the Valley-Segment Type Classification (VST). Ohio Aquatic GAP completed VST classification in 2001. Fish species were linked to occurrence in specific VSTs for data analysis and animal modeling in 2002. Wetlands are being classified separately based on hydrology and vegetation. Inland lakes and the Great Lakes are not included in the project.

Aquatic animal modeling: Sample point maps of 150 fish species were completed and released on the Ohio-GAP Web site for expert review in July 2001. These data include maps of native and introduced fish species that reproduce in Ohio streams. Final corrections based on expert reviews were completed for all 150 fish species in 2002. Fish distribution points associated with specific VSTs were used to model potential species distributions for 150 fish species using the Genetic Algorithm for Rule-set Production (GARP) (Stockwell and Peterson 1999) desk-top version software (Scachetti-Pereira 2002). In 2003, fish-species models will be combined to produce a map of Ohio with a probability-like distribution showing fish-species diversity patterns. In the first half of 2003, analyses to take into account some factors such as land use and dams and how these factors limit the accuracy of predictions of fish-species distributions are planned. Gap analysis of Ohio fish species is planned for completion by the end of September 2003.

Completion of 80% of the crayfish database was a priority in 2002. The crayfish database at The Ohio State University Museum of Biodiversity contains a total of 4,251 records (sites), 80% of which are from Ohio. Additional work needs to be done in the first half of 2003 at the Cleveland Museum of Natural History. When completed there will be about 5,000 records from both museums in the database. Distributions of 88 species of freshwater mussels were mapped statewide in 2002. Expert review will be completed in 2003, and modeling is planned for 2004.

Development of a database of fish and amphibian distribution in wetlands was started in 2002 and will continue in 2003. Known distributions of 16 fish species and 13 amphibian species were mapped in 2002. Modeling the potential distributions of fish, amphibians, reptiles, and birds in wetlands is planned for completion in 2004.

Analysis: Fish-species distribution models were developed using GARP modeling software. GARP implements four rule-types to build species prediction models: atomic, logistic regression, bioclimatic envelope, and negated bioclimatic envelope. GARP was used to generate 1,000 models of potential distributions for each fish species. A different set of presence points was used to build and test each model, thus providing good cross-validation of the models. Twenty of the “best” models for each species were chosen, selecting models that minimize omission and commission errors. Omission errors ranged from 0 to 22%, and commission errors ranged from 1 to 66% in selected models of 150 fish species. Error rates for narrowly distributed fish species typically were substantially lower than those for broadly distributed ones.

Reporting and data distribution: In spring 2003, fish distribution maps and valley segment attributes are planned for publication and release on the Ohio-GAP Web site (http://oh.water.usgs.gov/ohgap/ohgap.html) as well as on CD-ROM. A manuscript discussing the Aquatic GAP project will be prepared in the summer of 2003 and published in 2004.

Literature cited:

Scachetti-Pereira, R. 2002. DesktopGarp. Accessed December 16, 2002, at URL http://beta.lifemapper.org/desktopgarp/.

Stockwell, D., and D. Peterson. 1999. The GARP modeling system: Problems and solutions to automated spatial prediction. *International Journal of Geographical Information Science* 13:143-158.

Southeast Aquatic GAP

a. Alabama

Anticipated completion date: February 2004

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We are currently spatially referencing all historical and recent collection data for the Tallapoosa Basin. Efforts to categorize land use/land cover are under way; a Level I Anderson classification has been competed for the basin. We are in the process of delineating watersheds above sampling sites and compiling landscape-level data for each. We will develop faunal models using distribution data and landscape metrics. The first models will be developed for six fishes that are considered "at-risk" by the U.S. Fish and Wildlife Service. Models will be used to make decisions relative to status of the "at-risk" species. Hierarchical models developed by the Georgia Aquatic GAP Project have already shown promise for identification of conservation strategies for aquatic species.

b. Georgia

Anticipated completion date: August 2003

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We have completed spatial referencing of all historical (pre-1995) and current fish, crayfish, and mussel sampling locations using records provided by the Georgia Department of Natural Resources (GADNR), Georgia Museum of Natural History, USGS, Auburn University, and the University of Georgia (UGA). We are in the process of delineating watersheds for each sampling location. We also have developed geomorphic channel classifications for Flint River Basin stream segments in cooperation with GADNR and UGA and are in the process of combining these with hydrologic and fish population response models. These models will be used by GADNR to examine the effect of various river regulation and water use scenarios and develop streamflow management policies.

Upper Missouri River Basin Aquatic GAP

Anticipated completion date: October 2004

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Status: We completed an aquatic gap analysis as part of the terrestrial GAP of South Dakota and have expanded the aquatic analysis to the Upper Missouri River Basin (UMRB). States and provinces included in the study area are Alberta, Saskatchewan, Montana, Wyoming, North Dakota, South Dakota, Minnesota, and Iowa. In coordination with all state, federal, and international agencies the following base layer data sets have been acquired: stream network (NHD or an equivalent for the provinces), geology layer, 80% of the stewardship layer, 80% of the land cover layer, a complete DEM (except for Alberta), hydrologic units (except North Dakota), and fish data for the UMRB. We are attributing stream segments with ten physical habitat affinities (temperature, stream size, flow regime, channel gradient, size discrepancy, floodplain interaction, geology, elevation, stream connectivity, and groundwater input). We have completed attributing physical habitat features to stream reaches with the above habitat affinities. We are currently working on attributing groundwater input (80% complete), floodplain reach

(90% complete), and flow regime for reaches in Canada. The transfer of South Dakota Aquatic GAP data from RF3 to NHD data is about 95% complete. We have produced a 30 m land cover map from Landsat 7 TM data for Canada. We are working with agencies in North Dakota to complete the 10-digit hydrologic units for North Dakota. Fish location data have been attributed to the stream reaches, except for Canada and the Missouri River in North Dakota.

Analysis: Gap analysis of aquatic diversity has been completed for South Dakota. We modeled distributions of 116 fish species across South Dakota and assessed biodiversity of fish species and habitat in relation to land conservation. We found that the fishes of South Dakota have more protection than the terrestrial animals. A few areas proposed for the protection of mammals have the potential to provide additional protection for many aquatic species. Our Web page located at http://wfs.sdstate.edu/sdgap/aquaticgap.htm has links to fish distributions by 10-digit hydrological units, fish habitat affinities, and fish-habitat models by stream reach for South Dakota. Gap analysis of the UMRB valley segments should begin in April of 2003.

Future plans: We plan to complete attributing physical habitat features and fish locations to individual valley segments by the end of March. We will then conduct a quality check and begin fish-habitat modeling. We are working with The Nature Conservancy to delineate ecoregional drainage units based upon ecoregions and major drainages to further classify fish distributions.

Upper Tennessee River Basin Aquatic GAP

Anticipated completion date: June 2003

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In 2001, researchers from the Department of Fisheries and Wildlife Sciences and the Conservation Management Institute of Virginia Tech began an aquatic gap analysis of the upper Tennessee River basin (UTRB), which is shared by Virginia, Tennessee, North Carolina, and Georgia. Most of the efforts so far have been directed at assembling available GIS coverages on biota, land and water use, and physical landscape features. These coverages are nearly complete, and we are beginning to develop models to predict species occurrence. Sophistication and precision of models will vary with data availability. For example, for poorly sampled species we may develop only qualitative models (low precision) from relational databases of natural-history information from the literature. In contrast, for well sampled species we may develop more quantitative models based on logistic regression or discriminant analyses.

A main research focus is to develop more powerful protocols to assess threats to aquatic biota. We anticipate that merely knowing ownership of lands adjacent to aquatic habitats will not be adequate to assess protective status or level of threat. Thus, we intend to develop an integrative protocol for assessing a wide array of threats to stream biota. Threats vary in scope of origin (nonpoint vs. point source), frequency of occurrence (accidental spill vs. permitted effluent), and severity (heavy metal contamination vs. nutrient enrichment). Moreover, most threats to aquatic biota emanate from outside the aquatic environment and traverse aquatic networks at varying rates. Through the use of geographic information systems, site-specific data, and conceptual models, we will evaluate aquatic sites for overall levels of threat. Data layers contributing to this assessment include point-source pollution, transportation corridors, historic spill locations, and areas of rapid development. We are conducting a meta-analysis to evaluate the approaches currently used to assess threats to aquatic biodiversity. This analysis will help us design a small set of trial protocols to apply to the UTRB. Ultimately, we will develop a framework to organize and rank site-specific or watershed-specific threats to biota. As is typical for gap analyses, this threat coverage will be integrated with the biotic coverages to identify priorities for conservation efforts.

NOTES AND ANNOUNCEMENTS

Announcing National GAP Annual Meeting in Colorado

The 13th Annual National Gap Analysis Program Meeting will be held October 7-10, 2003, in Fort Collins, Colorado. The meeting is hosted by the U.S. Geological Survey (USGS), Biological Resources Discipline, and the U.S. Fish and Wildlife Service (FWS), National Wildlife Refuge System. The theme of this year's meeting is "GAP Data and its Application to Planning, Management, and Decision Making in Refuges and Other Conservation Areas."

We invite you to join us to share new information and experiences from Gap Analysis projects and related research, and to celebrate and enhance the National Gap Analysis Program's partnership with the FWS. This year marks the 100th anniversary of the founding of the National Wildlife Refuge System (NWRS). A major way of promoting further successes in conservation is to apply the latest scientific techniques and data, such as those stemming from GAP, to our land protection and management efforts. It is in this spirit that we are focusing this year's meeting on applying biological data to conservation and management issues, with specific examples from FWS, the NWRS, and GAP.

This meeting is an opportunity for anyone interested in large-area biodiversity science to learn about GAP's philosophy, data, information and products and to network with others in the conservation community. Also, this year we are inviting professionals from FWS to participate and discuss their needs for biological data and give examples of the use of scientific information in day-to-day management. A specific focus will be FWS' new initiative on strategic growth of the refuge system, which focuses on how FWS works with partners to manage refuges within a larger landscape. This meeting is also an opportunity for all FWS programs to learn about GAP and identify how GAP can be applied to planning and conducting biodiversity conservation at the landscape scale.

Goals

The goals of the meeting are to highlight current GAP projects and products and to hear from FWS partners about their management issues, specifically with regard to how biological data are used in decision making. This will be an opportunity for FWS professionals to learn more about GAP, and for GAP professionals to understand the actual challenges faced by leaders in FWS. Another goal of this meeting is to define a series of joint initiatives aimed at improving the use of scientific data to enhance conservation management efforts within the FWS.

Location of Meeting

This meeting will take place in Fort Collins, Colorado, at the University Park Holiday Inn. Fort Collins, located 65 miles north of Denver, is home to Colorado State University. Along with its world-class research facilities, the city borders on many natural attractions, including the Cache la Poudre Wild and Scenic River, Roosevelt National Forest, and Pawnee National Grassland.

Who Should Attend

We are bringing together an interdisciplinary group to discuss some of the most challenging issues facing conservation efforts in the United States today. The target audience for this meeting includes:

- Anyone involved in Gap Analysis projects
- Managers and staff from FWS interested in the future of landscape planning of the Refuge System
- Biologists interested in planning efforts such as Comprehensive Conservation Plans (CCPs), Habitat Conservation Plans, or migratory bird protection plans
- Research scientists, biologists, ecologists, data developers
- Professionals from conservation agencies focused on remote sensing, GIS, and the predictive modeling of species

Registration information will be available at http://www.gap.uidaho.edu/meetings/2003/info.htm. For additional information, contact Angela Reichert by e-mail at areichert@usgs.gov or by phone at 208-885-3717.

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[1] See Gap Analysis Bulletin 7 for a review of the initial UW-UDP Gap Analysis pilot project in Spokane County, WA.

[2] See Gap Analysis Bulletin 8 for an in-depth discussion of the identification and mapping of high priority habitat.

[3] The project team consisted of the authors and Doug Pflugh and Wood Turner (UW-UDP) Karen Dvornich (WA-GAP and Nature Mapping), Christian Grue (Washington Cooperative Fish and Wildlife Research Unit, School of Fisheries, UW), Grant Griffin and Karen Trueman (Pierce County), and Michelle Tirhi (Washington Department of Fish and Wildlife). Funding and support for this project were provided by Pierce County, Washington State Department of Fish and Wildlife (WDFW), U.S. Fish and Wildlife Service, the USGS Biological Resources Division (National Gap Analysis Program and Cooperative Research Units), and the Rocky Mountain Elk Foundation.

[4] Descriptions of an 'Urban-Rural Continuum' developed by Christopher Duerksen et al. were key to this process.
[5] Refer to the 2000 Pierce County GAP application project available on the Pierce County Web site www.co.pierce.wa.us/pals/palsnews, or to P. Iolavera's 1999 Master's Thesis for details.
[6] A Handbook for Conducting Gap Analysis, Chapter 2, Mapping and Categorizing Land Stewardship, 23 February 2000. http://www.gap.uidaho.edu/handbook/Stewardship/default.htm (January 5, 2003).
[7] The chief resources available at the outset of this pilot project were Volume 5 of the report produced by WA-GAP that described analysis of land stewardship and the final report for the UW-UDP Spokane County, Washington, pilot project. The Gap Analysis Handbook had not yet published the chapter on stewardship.
[8] Refer to the 2000 Pierce County GAP application project available on the Pierce County Web site www.co.pierce.wa.us/pals/palsnews, or to P. Iolavera's 1999 Master's Thesis for detailed descriptions of this process.
[9] Examples include works by Meffe et al. 1997, Noss et al. 1994, Salmon Habitat Indicator Group 1998, Duerksen et al. 1997.
[10] The Washington State Growth Management Act establishes 'Critical Areas' that local governments are required to plan for and to protect. The units listed are elements of critical areas specified in that law (RCW 36.70A). See www.access.wa.gov/lawsandrules/RCW.
[11] Washington State Law ESSB 6400 can be accessed at www.leg.wa.gov/pub/billinfo/2001-02/Senate, January 10, 2003.