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Comparing the potential effectiveness of conservation planning approaches in central North Carolina, USA

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ABSTRACT

We compared four approaches to conservation site selection to protect forest biodiversity in the Triangle Region of North Carolina, USA. Using biological inventory data and an inventory-based conservation plan as benchmarks, we evaluated the potential effectiveness of a focal species plan and three "simple" plans (large forested patches, close to wetlands and riparian areas, diverse forest types). Effectiveness was measured in three ways: the number of inventory elements captured at least once by the plan (representation), the total number of inventory elements captured (completeness), and the proportion of land in the inventory-based plan included (overlap). We further examined the potential effectiveness of the simple plans by calculating their overlap with land identified by the focal species approach. The simple and focal species plans did not differ markedly in terms of representation, but diverged when completeness and overlap were considered. Although representation rates for all four plans were relatively high, lower rates for completeness and overlap raise concerns about long-term viability. The simple plans did not identify the same lands as the focal species plan, and are thus unlikely to provide appropriate habitat for the focal species. Each approach we tested failed to capture some subset of species and communities, highlighting the importance of explicit conservation targets and consideration of ecological processes. Forced to act quickly and with little data, our findings suggest using initially a set of complementary simple plans, each focused on a different habitat type. This should be considered a stopgap measure, however, while more sophisticated plans are constructed, defining explicit conservation targets and considering ecological processes.

1. Introduction

Ideally, conservation plans – maps identifying land to be protected – would be based on detailed surveys, including a thorough knowledge of each species' life history and demographic characteristics, its interaction with other species and the physical environment, and where it occurs in a planning region. Such comprehensive information is rarely available,

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cannot be obtained quickly, and is costly to accumulate. In response, conservation biologists have developed ways to simplify the process of identifying land for protection (i.e., management for conservation purposes), including surrogate species approaches (e.g., focal and umbrella species) and general conservation principles (e.g., selecting larger habitat patches, or patches from diverse land cover types).

Surrogate species approaches – flagship, focal, indicator, landscape, and umbrella species – identify land for protection based on the needs of a small number of species (e.g., Noss et al., 1996; Simberloff, 1998; Caro and O'Doherty, 1999). The central concept is that land protected for surrogate species will support many other species that also live within the area. Habitat requirements must be determined, but only for a handful of species, thereby reducing the amount of time, money, and data required during planning. The application of surrogate species approaches has engendered controversy among conservation biologists. Proponents argue that surrogate species approaches are effective, efficient, and often the best way to proceed in regions for which few data are available and time is of the essence (e.g., Brooker, 2002; Poinani et al., 2001; Lambeck, 1997, 2002; Sanderson et al., 2002), particularly at broad spatial scales (Caro, 2003; Caro et al., 2004). Critics argue that the approaches are untested and that ample evidence demonstrates that the presence of one species or taxon rarely correlates with the presence of many other species or taxa (e.g., Andelman and Fagan, 2000; Lindenmayer et al., 2002; Roberge and Angelstam, 2004; Brooks et al., 2004).

Tests of the potential effectiveness of surrogate species plans have focused on measures of co-occurrence, representation, and comprehensiveness from studies conducted with large databases (e.g., Andelman and Fagan, 2000; Pearson and Carroll, 1999; Reyers et al., 2000; Ferrier, 2002; Lund and Rahbek, 2002). These tests have been conducted in areas of the globe that are relatively rich in biological inventory data: Australia, Great Britain, North America, and Southern Africa. After selecting potential conservation land using a subset of species in the inventory as surrogates, the potential effectiveness of the proposed reserve system is tested against the full dataset. When the habitat required for the selected surrogate species has a high degree of overlap with the location of other species, or is more effective than random selection of land or species, surrogate species are declared to be effective.

Roberge and Angelstam (2004) commented that although comparison of surrogate species schemes to random selection is reasonable statistically, comparison to schemes based on other conservation principles would be more useful from a management perspective. Such conservation principles include: larger patches of habitat are better than small ones; patches close together are better than patches far apart; well-connected patches are better than poorly connected ones (e.g., Noss and Cooperrider, 1994; Lindenmayer and Franklin, 2002). We found only one example of such a direct comparison. Poinani et al. (2001) found that an umbrella species approach was marginally more effective in overlapping biologically important lands identified by the Minnesota Natural Heritage Program than selecting the largest patches of native habitat (59% vs. 56% of biologically important land overlapped).

1.1. *Objective and approach*

We evaluated and compared the potential effectiveness of four approaches to identifying lands needed to protect forest biodiversity in the Triangle Region, North Carolina, USA: a focal species plan and three "simple plans" based on conservation principles.

Using biological inventory data and an inventory-based plan for the region as benchmarks, we evaluated the potential effectiveness of the focal species and simple plans in three ways: (1) the proportion of inventoried forest species and communities captured at least once by the plan (representation); (2) the proportion of inventoried forest species and communities captured in the land identified by the plan (completeness); and (3) the proportion of land in the inventory-based plan that was included (overlap). These measures can be considered a gradient of protection from minimum (representation) to maximum (complete, with full overlap). An ideal planning approach would capture all species and communities of concern in the inventory database, and all of the land in the inventory-based plan.

We further examined the potential effectiveness of the simple plans by calculating their overlap with land identified as important for conservation by the focal species approach. Simple plans that do not overlap substantially the land identified by the focal species plan are unlikely to provide appropriate habitat for the focal species.

Specifically, we asked:

(1) How effective is the focal species plan?
(2) Are the simple plans as effective as the focal species plan?
(3) To what degree do the simple plans include land identified as important for conservation by the focal species approach?
(4) How do these planning approaches compare to random selection of forested land?

2. Methods

To carry out our evaluation, we

(1) selected forest species and communities of conservation concern from the Natural Heritage Program database for use in quantifying the effectiveness of each plan,
(2) selected areas designed to protect forest species and communities from the inventory-based Significant Natural Heritage Areas plan for use in quantifying the effectiveness of each plan,
(3) compiled the forest focal species plan using habitat maps developed for each focal species,
(4) created a set of simple plans that included the same amount of forest land as the focal species plan,
(5) created a neutral model based on random selection of forest patches,
(6) calculated the effectiveness measures for each plan and the neutral model, and the overlap in land area between the various plans.

We used ArcGIS 8.3 (ESRI, 1999-2002a) and ArcView 3.3 (ESRI, 1992-2002b) for all of our map analyses.

2.1. Study area: North Carolina's triangle region

Centered on the cities of Raleigh, Durham, and Chapel Hill, in North Carolina, USA, the 8600 km^2 Triangle Region lies within the larger physiographic region of the Central Appalachian Piedmont. The western portion of the region is characterized by the greater topographic relief and steeper slopes associated with the Piedmont, whereas the broad, flat, alluvial landscapes of the Coastal Plain dominate the east. The current landscape has been shaped by a history of human land use (Oosting, 1942; Trimble, 1974). Agricultural development and subsequent deforestation began in the mid-18th century and increased steadily until the early 20th century. Abandonment of cultivated lands allowed secondary forest cover to increase during the first half of the 20th century. During the past five decades, and especially since 1980, increasing human population within the region has spurred suburban growth. Housing developments, shopping centers, business parks, and the roads and infrastructure that support them are replacing fields and forests (Hess et al., 2000).

2.2. Natural heritage element occurrence data

North Carolina's Natural Heritage Program is part of a nationwide effort to collect and manage biological information important to conservation planning (Amoroso and Finnegan, 2002; LeGrand et al., 2001; NC Natural Heritage Program, 2004; NatureServe, 2004). The Natural Heritage Element Occurrences database, available in a geographic information system format, contains point locations of species and natural communities of conservation concern. An element occurrence in the database is a point that represents an area in which a species or community is present, with some potential for persistence (NatureServe, 2002). For species, an element occurrence often corresponds to a local population of the species; for communities, it represents a patch of a natural community (NatureServe, 2002). These data have been assembled over decades from a variety of sources including museum records, systematic inventories, and data gathered by academic researchers and private and agency biologists with varied expertise.

The Natural Heritage Program provided a copy of the database that was current through February 2003. We considered only forest species and communities in our analyses, and we eliminated database entries for species and communities that have not been observed recently or have imprecise location information (Table 1). We selected 378 occurrences of 69 different forest species and communities to use in our evaluations (Appendix 1).

Table 1 – We extracted the most reliable information about forest species and communities from the Natural Heritage Element Occurrences database for our effectiveness calculations

Type of species and communities	Number
All species and communities	165
Species and communities we did not consider	
Non-forested	78
Destroyed/extinct	3
Historic (no recent field information but no evidence of destruction)	12
Last observed before 1980	2
Location or date obscure or unknown	1
Poor precision (>152 m (500 ft) from mapped location)	0
Forest species and communities	69

We show only the number of different species and natural communities in the region.

We used the element occurrence data for two measures of effectiveness: (1) the proportion of the 378 occurrences of forest species and communities included in the land identified by the plan (completeness) and (2) the proportion of the 69 species and communities included at least once in the plan (representation). To match the geographic precision of the inventory data we used for testing, we counted as "captured" all species and communities within 152 m (500 ft) of the plan boundary. An ideal plan would capture all of the element occurrences.

Although they are the best available biological inventory data for the region, the Natural Heritage data have limitations common to species databases (Margules and Austin, 1994) that constrain our ability to test planning approaches. The data are uneven in terms of taxonomic and geographic coverage. Not all lands are surveyed, and data collection tends to be concentrated on lands with public access (e.g., already protected areas) and areas well known to biologists. The database does not contain any record of where species or communities were looked for and not found (recorded absences). Nevertheless, an effective conservation plan should capture the species and communities that have been recorded.

2.3. The inventory-based significant Natural Heritage Areas plan

Using the Natural Heritage inventory data, Natural Heritage Program personnel have created a map of Significant Natural Heritage Areas that constitute core conservation lands in the state. The boundaries of these conservation lands were established for long-term persistence by considering the habitat needs of each species, the habitat available where the species were found, and the extent of natural communities (Figure 1; NC Natural Heritage Program, 2004; Linda Pearsal, personal communication). We obtained the Significant Natural Heritage Areas plan in a geographic information system format (polygons) from the North Carolina Natural Heritage Program and extracted the 236 km^2 of Significant Natural Heritage Areas in the Triangle Region that contained forest species and communities. We used this map for our third measure of effectiveness: the proportion of land in Significant Natural Heritage Areas included in our focal species and simple plans.

2.4. Focal species plan

Focal species planning (Lambeck, 1997) is a surrogate approach in which conservationists: (1) identify threatening processes responsible for the declining size of species populations, (2) select a suite of focal species, each of which is considered most sensitive to each of the threatening processes, and (3) identify and protect the habitat that each focal species needs. Habitat requirements for the focal species are used to create explicit guidelines for the compositional, spatial, and

Table 2 – Summary of forest focal species selected for use in the Triangle Region, North Carolina (Hess and King, 2002), including the landscape type represented and the criteria used to map each species' habitat (Rubino and Hess, 2003; Bode, 2002; King, 2001; Hess, unpublished data)

Landscape type	Focal species (threat category[1], sensu Lambeck, 1997) *Rationale*	Criteria for mapping habitat
Extensive undisturbed habitat	Bobcat (Area, Dispersal). Requires large area of habitat with relatively low levels of human activity. Movement threatened by roads.	(1) Define high (upland herbaceous, shrub, hardwood except oak/gum/cypress), medium (low intensity developed, cultivated, managed herbaceous, Southern Yellow Pine, mixed hardwood/conifer), and low (high intensity developed, riverine/estuarine herbaceous, oak/gum/cypress, water, unconsolidated sediment, and any habitat within 100 m of a road) quality habitat.(2) Identify all high quality patches >1.76 km^2 as potential habitat. (3) Add to potential habitat any other high quality patches separated from the potential habitat by $\leqslant$700 m of medium quality habitat, and the connecting medium quality habitat. Low quality habitat is never to be crossed or included. (4) Eliminate any of the resulting patches <20 km^2. (Bode, 2002)
	Eastern box turtle (Area, Dispersal, Resource). Connectivity between breeding habitat and other resources threatened by roads, but at a smaller scale than for the bobcat.	(1) Identify all land within 300 m of open water. (2) Eliminate cultivated and developed land, and land within 50 m of railroads and roads. (3) Eliminate patches <400ha. (4) Eliminate patches with <75% forest cover. (Hess, unpublished data)
Riparian and bottomland forest	Barred owl (Area, Resource). Nests in mature, large trees; rarely forages far from bottomland.	(1) Identify all bottomland forest as potential habitat. Although no data were available to establish the age of forests, bottomland forests in this region tend to be mature because regulations and difficulty accessing them have prevented their harvest. (2) Eliminate any potential habitat within 100 m of a road or 60 m of crop, pasture, or herbaceous land cover. (3) Eliminate patches <86ha. (Rubino and Hess, 2003)
Upland forest	Ovenbird (Area, Process). Prefers large areas of mature upland forest with well-developed under story. Tree harvested before becoming mature enough (disruption of succession process).	(1) Identify all upland forest as potential habitat. (2) For each forest pixel (30 m), classify it based on conditions within 1.37 km as being $\geqslant$70% forest or <70% forest. (3) Eliminate forest edge: 60 m in $\geqslant$70% forest areas; 120 m in <70% regions. (4) Eliminate potential habitat within 100 m of roads. (5) Eliminate potential habitat less than minimum patch size: 100ha for $\geqslant$70 forested regions; 500ha for <70% forested regions. Note: No data were available to establish forest age. We included all upland forest meeting the criteria above, because it all has the potential to be ovenbird habitat with time. (King, 2001)
	Broad-winged hawk (Area). Requires extensive forested uplands.	(1) Identify potential nest habitat as deciduous and mixed deciduous forests with 11–33% slope. (2) For foraging, nest habitat must be within 200 m of water and 140 m of non-forest vegetation. (3) Eliminate potential nest habitat within 100 m of interstates, 4-lane roads, and urban 2-lane roads. (4) Eliminate potential sites with <50% forest within 100 m. (5) Create 3.5 km^2 circular territories from all remaining potential nesting sites. (Hess, unpublished data)
Mature forest	Pileated woodpecker (Area, Resource, Process). Requires large area of mature forest and large dead trees for breeding. Trees harvested before becoming mature enough (disruption of succession process).	(1) Identify all forestland as potential habitat. (2) Eliminate from consideration any potential habitat within 100 m of a road. (3) Eliminate any patches <130 ha. Note: No data were available to establish forest age. We included all forest meeting the criteria above, because it all has the potential to be pileated woodpecker habitat with time. (Hess, unpublished data)

1 *Area* limited species are threatened because there is an insufficient amount of suitable habitat. *Dispersal* limited species are threatened because movement among habitat patches is restricted. *Resource* limited species are threatened by a shortage of critical resources. *Process* limited species are affected negatively by disruption of critical ecological processes.

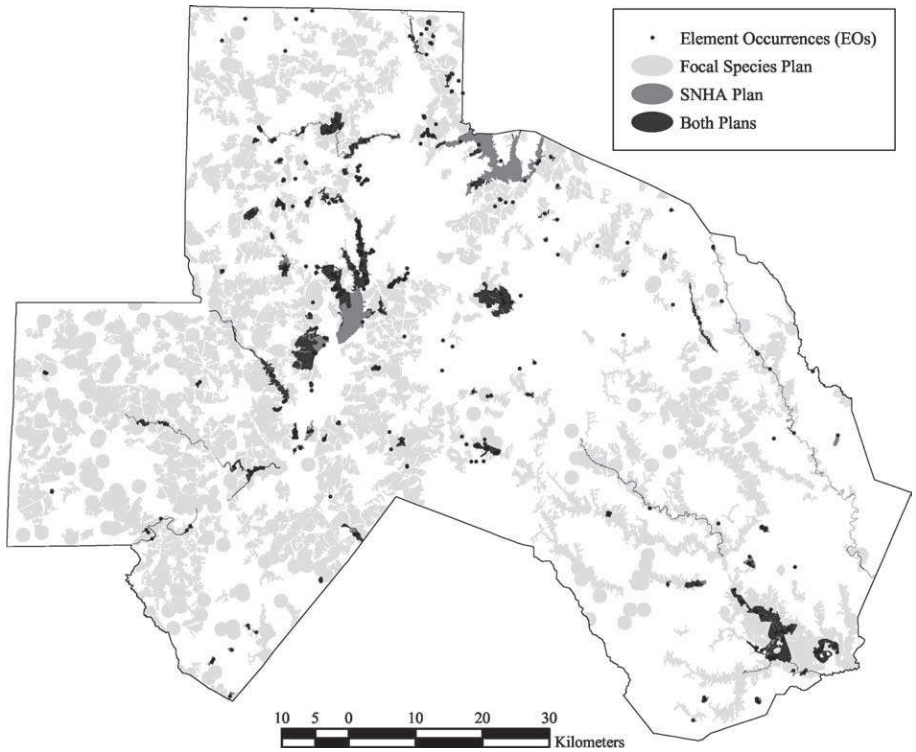

Fig. 1 – The Triangle Region of North Carolina, USA, showing overlap among: (1) forest species and communities recorded in the Natural Heritage database (element occurrences), (2) a focal species plan for the region, and (3) the inventory-based Significant Natural Heritage Areas plan for the region.

functional attributes that landscapes must possess to support them.

Hess and King (2002) surveyed local experts to create a list of focal species that could provide a basis for wildlife conservation within the Triangle Region. They identified nine focal species to be used for planning to protect biodiversity in a variety of landscapes, including six species for forested landscapes (Table 2). Rubino and Hess (2003) outlined a methodology for identifying potential habitat for focal species by synthesizing habitat needs for survival and reproduction through a literature review and consultation with local experts, linking those needs to readily available geographic information system data, and using the data to identify suitable habitat. Using their approach, King (2001), Bode (2002), Rubino and Hess (2003), and Hess (unpublished data) produced a map of potential habitat for each focal species (Table 2). We combined the maps for the six forest focal species to create our focal species plan: a map of 2446 km^2 of land important to wildlife under varying degrees of threat and with differing landscape requirements (Fig. 1).

2.5. *Creating simple plans using conservation principles*

2.5.1. *Largest forested patches in the region*

This method corresponds to the conservation principle that large patches of habitat are better than small ones for conservation (Murphy and Wilcox, 1986; Rosenzweig, 1995; Dramstad et al., 1996). We used a land cover map derived from the US Environmental Protection Agency's National Land Cover Dataset (US EPA, 2001). These data were generated using satellite imagery from 1991 to 1993 and are available nationwide. We extracted pine, hardwood, mixed forest and woody wetland cover from the data, for a total of 5872 km^2 of forested land. From this total, we removed all forest within 100 m of a road and grouped the remaining forested land into unique patches. We eliminated all patches smaller than 4500 m^2, because patches this small are likely to be misclassified (Smith et al., 2002). The remaining 3874 km^2 of forested patches were considered for inclusion as protected land. We selected forest patches beginning with the largest, regardless of forest type, until the total area was as close as possible to that of the focal species plan (2446 km^2).

2.5.2. *Diverse forest types*

This approach ensured that a diversity of forest types was included in the conservation network and corresponds to approaches based on landscape representation and biophysical surrogates (e.g., Hunter et al., 1988; Kintsch and Urban, 2002; Lombard et al., 2003). Starting with the National Land Cover Dataset, we considered each of the forest types (evergreen, deciduous, mixed forest or wetland forest) separately, grouped them into patches by forest type, and eliminated all patches smaller than 4500 m^2. We ranked the forest types by total area in the region from lowest to highest: 419 km^2 of wetland forest, 501 km^2 of mixed forest, 1596 km^2 of evergreen forest, and 2384 km^2 of deciduous forest. Starting with the forest type that occupied the smallest area (wetland forest), we selected the largest patch from each forest type. We repeatedly selected the largest remaining patch from each forest type until the total area was as close as possible to that of the focal species plan (2446 km^2).

2.5.3. Close to wetlands and riparian areas

This method corresponds to the view that wetlands and riparian areas are critical for conserving biodiversity (Naiman et al., 1993; Mensing et al., 1998). We began with a map of bottomland forests created by Rubino and Hess (2003) for a barred owl GIS habitat model. This map included all forests within 100 m of a stream, on hydric soils, classified as woody wetlands in the National Land Cover Dataset, or classified as palustrine forested wetlands by the National Wetlands Inventory (Cowardin et al., 1979). We eliminated patches less than 4500 m^2 in area from this map, leaving 2523 km^2 of bottomland forest eligible for selection. We selected the remaining eligible forest patches, largest to smallest, until the total area was as close as possible to that of the focal species plan (2446 km^2). Although this is a large portion of the eligible area of bottomland forest, the data contained many small patches and only 4167 (32%) of 12,865 eligible patches were selected.

2.6. Random selection of forest patches

Neutral (or null) models are frequently used in landscape ecology and conservation biology as a benchmark against which to compare more complex models (With and King, 1997; With, 1997; Turner et al., 2001). In the context of our study, if identifying land for protection by randomly selecting forested land is as effective as a deliberate planning approach, one must examine carefully the value of the planning approach. We selected forested patches at random until the target area was reached, with no consideration of the location of species and communities or their habitat requirements. We selected from the same 3874 km^2 of forest used to create the largest forested patch plan. All forested patches had an equal probability of being chosen, regardless of size. For each measure of effectiveness, we calculated a mean for 50 replicates, and a 95% confidence interval based on a normal distribution.

3. Results

How effective is the focal species plan? The focal species plan called for the protection of 2446 km^2 of forested land (42% of the 5872 km^2 of forested land in the region). It captured 87% of species and communities at least once (representation), captured 68% of element occurrences (completeness), and included 58% of the land mapped as Significant Natural Heritage Areas (overlap) (Table 3).

Are the simple plans as effective as the focal-species plan? The simple plans captured as many or more element occurrences (completeness) and species and communities (representation) as the focal species plan in two cases: diverse forest types, and wetland and riparian areas. In the remaining case – largest forested patches – the focal species plan captured only slightly more element occurrences than the simple plans (Table 3). However, the focal species plan overlapped more of the Significant Natural Heritage Areas land than all simple plans (Table 3).

To what degree do the simple plans include land identified as important for conservation by the focal species approach? Overlap between plans ranged from 44% to 73% (Table 4). When the focal species and all three simple plans are overlaid, a common area of only 531 km^2 is identified.

How do these planning approaches compare to random selection of forested land? When compared to the focal species plan, random selection, on average and within 95% confidence intervals, was almost as complete and had the same level of representation (Table 3). Two of the simple plans were more complete and had higher representation than random selection. All plans overlapped more Significant Natural Heritage Areas land than random selection (Table 3).

4. Discussion

Whether or not one considers the focal species and simple plans to be effective depends on the measure of effectiveness used. In our tests, effectiveness decreased markedly as conditions for effectiveness were made increasingly stringent. When measured by the proportion of species and communities represented, effectiveness ranged from 84% to 94%; when measured against the number of element occurrences captured (completeness), effectiveness ranged from 64% to 86%; and when measured by the amount of overlap with the inventory-based Significant Natural Heritage Areas plan, the range was 49–58% (Table 3). Each measure leads to a different answer to the question "How effective is this planning approach?" Although the representation rates for all four plans were relatively high, the lower rates for completeness and overlap raise concerns about the long-term viability of the species and communities under those plans.

Most previous tests of the effectiveness of surrogate species approaches have used representation as a benchmark.

Table 3 – Three measures of effectiveness for each plan: the proportion of species and communities of conservation concern captured at least once (representation), the proportion of element occurrences captured (completeness), and the proportion of land in the inventory-based plan included (overlap)

Plan (area)	Representation: species and communities captured (%)	Completeness: element occurrences captured (%)	Overlap: area of inventory-based plan captured (%)
Focal species	87	68	58
Close to wetlands and riparian areas	90	81	49
Diverse forest types	94	86	52
Largest forested patches	84	64	50
Random (95% confidence interval)	87 ± 1.2	66 ± 1.3	40 ± 1.4

Each plan includes 2446 ± 2 km^2 of forested land.

Table 4 – Overlap among focal species and simple plans

	Close to wetlands (%)	Diverse forest types (%)	Large forested patches (%)
Focal species plan	44	51	73
Close to wetlands		43	45
Diverse forest types			54

Shows the proportion (%) of overlap in land area between pairs of plans. All plans are 2446 ± 2 km^2 and the proportion was calculated as [area of overlap]/2446 × 100%.

Using this benchmark, Andelman and Fagan (2000) examined the effectiveness of various surrogate schemes. They found that selection of surrogate species based on ecological rationales faired no better than random selection of surrogate species in most cases. Our equivalent test concurs with their findings – random selection of forested land provided levels of representation similar to the focal species and simple plans (Table 3). However, we found that random selection of forested land was outperformed by some simple plans when evaluated by the number of element occurrences captured, and by all plans when evaluated by the portion of Significant Natural Heritage Areas land included. Several researchers have found that land protected for surrogate species would represent a relatively high proportion of other species (DeNormandie, 2000; Fleishman et al., 2000; Noss et al., 2002; Rubino and Hess, 2003). Again, our results concur with these only when representation is used as a benchmark. The focal species plan appears far less effective when completeness and overlap are considered.

To the extent possible, plans should go beyond representation to consider the ecological process required for long-term persistence (e.g., Ferrier, 2002; Carroll et al., 2003; Pressey et al., 2003). None of the plans we evaluated included explicit estimations of population viability (e.g., Soulé, 1987; Beissinger and McCullough, 2002; Morris and Doak, 2003). The low levels of overlap with Significant Natural Heritage Areas land suggests that neither the focal species or simple plans identify the right land to support viable populations of the cataloged species and communities for the long term. The focal species plan did include consideration of the reproductive needs of the focal species and, to some degree, necessary ecological process and disturbance regimes (Hess and King, 2002; Rubino and Hess, 2003). The simple plans did not identify the same land for protection as the focal species plan (Table 4; Fig. 1), and focal species might not be able to persist in the lands identified by the simple plans. The highest degree of overlap between the focal species and simple plans was 73% between the focal species and large forested patches plans. The relatively high degree of overlap in this one case is not surprising, because many of the focal species require large patches of forested habitat.

A complementary combination of simple plans might prove effective, but one would have to be very clear about the target species and their habitat needs. The simple plans tested here selected very different land from one another. Overlap between simple plans ranged from 43% to 54%. The simple plans are complementary to some degree, because of the very different rationales behind each. In fact, if one combines all three simple plans, the resulting 4483 km^2 of forested land provides 100% representation, 98% completeness, and includes 74% of the land identified by the inventory-based plan – but requires 76% of the forested land in the region. Patterns in which species went unrepresented in particular plans further highlight differences in the land identified for protection by each plan (Appendix 1). For example, the diverse forest types plan captured species and forest communities unrepresented in the other plans. The focus on diversity led to the selection of patches too small to be selected by the largest patches approach and more diverse than those selected using the close to wetlands approach. Similarly, the close to wetlands and riparian areas plan captured rare bottomland species and communities that the other plans did not.

Limitations in the data available and the analyses performed temper our results. Any generalization of our findings requires further testing in a wider variety of systems. Although the region in which we conducted our tests has been surveyed well, the Natural Heritage Inventory database is incomplete and imperfect and might lead to over- or under-estimates of effectiveness. Almost all of the species and communities not represented in the plans occurred only once in the database (Appendix 1). It is possible that some of the species and communities our analyses identified as unprotected by a particular plan actually occur within that plan, but have simply not been cataloged by the Natural Heritage Program. We considered a species or community protected by a plan if the point representing it was within 152 m (500 ft) of our plan boundaries. In reality, a plan that includes this point might not protect the full extent of the community, or the habitat needed to support the species. This latter concern is borne out to some degree by consistently lower scores for completeness and overlap than for representation.

5. Conclusions

Whether or not one considers a plan to be effective depends on the measure of effectiveness used. When all three measurements of effectiveness are considered – representation, completeness, and overlap – the focal species and simple plans appear unlikely to provide adequate protection of known species and communities of conservation concern in the Triangle Region. Although the representation rates were relatively high, lower rates for completeness and overlap raise concerns about the long-term viability of the species and communities.

Our findings highlight the importance of matching the planning approach to specific conservation targets (e.g., Pressey et al., 2003), and consideration of the ecological processes required to support the target species (e.g., Ferrier, 2002; Carroll et al., 2003; Pressey et al., 2003). Each planning approach we tested failed to capture a subset of species and communities. In some cases this was because the plan did not include the habitat needed; in other cases the species and communities were in patches too small to be included. The simple plans we tested did not identify the same lands as the focal species plan, and are thus unlikely to provide appropriate habitat for the focal species. The 236 km^2 of Significant Natural Heritage Areas, designed to protect rare, narrow-ranging species, are clearly inadequate to protect the focal species.

Forced to act quickly and with little or no data, the relatively strong performance of the "diverse forests" approach in terms of representation and completeness suggests using initially a set of complementary simple plans, each focused on a different habitat type. We caution that such an approach be considered a stopgap measure while more sophisticated plans are constructed, which define explicit conservation targets and consider ecological processes (e.g., Pressey et al., 2003). The strong performance of the "diverse forests" approach also suggests that biophysical or environmental surrogates are a fruitful arena for further research (e.g., Hunter et al., 1988; Ferrier, 2002; Kintsch and Urban, 2002; Lombard et al., 2003; Pressey et al., 2003; Brooks et al., 2004; Roberge and Angelstam, 2004; but see Araújo et al., 2001 for contradictory evidence). Ferrier (2002) has further proposed integrating environmental and biological surrogates by modeling the relationships between environmental surrogates and patterns of biological diversity.

MacNally et al. (2002, p. 910) noted that there is little expectation among researchers and managers of "...a miracle solution: a 'one scheme fits all' scenario." Although different approaches will be required in different situations, there may be patterns to the circumstances in which certain approaches can and cannot be used. Going forward, we suggest continued work in data-rich areas to evaluate, with carefully chosen targets and measures of effectiveness, a variety of conservation planning approaches in a variety of ecosystems and at a variety of scales (Ferrier, 2002; Garson et al., 2002; Favreau et al., 2005). Where possible, analyses of population viability and ecosystem integrity should be included. By analyzing data systematically in this manner we might be able to determine the conditions under which different approaches can be used.

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Appendix 1

Forest species and natural communities cataloged in the Natural Heritage Program data for the Triangle Region (as of February 2003) that we used to evaluate the effectiveness and efficiency of the conservation plans. We show the frequency of occurrence in the database and the number of each species and community captured by each plan we evaluated.

Species	Plan				
Scientific name (common name)	Database	Focal species	Close to wetland	Diverse forests	Largest patches
Ambystoma tigrinum (Tiger salamander)	4	1	2	1	1
Anemone berlandieri (Southern anemone)	1	**0**	1	**0**	**0**
Aster laevis var concinnus (Narrow-leaf aster)	1	**0**	1	1	**0**
Berberis canadensis (American barberry)	1	1	1	1	1
Cardamine douglassii (Douglass's bittercress)	13	10	13	10	10
Carex jamesii (James's sedge)	2	2	2	2	1
Carya laciniosa (Big shellbark hickory)	1	1	1	1	**0**
Collinsonia tuberosa (Piedmont horsebalm)	2	2	2	2	2
Delphinium exaltatum (Tall larkspur)	1	1	1	1	1
Dendroica cerulea (Cerulean warbler)	1	1	1	1	1
Echinacea laevigata (Smooth coneflower)	3	2	2	3	2
Enemion biternatum (Eastern isopyrum)	5	5	5	5	3
Erynnis martialis (Mottled duskywing)	1	1	1	1	1
Euphyes bimacula (Two-spotted skipper)	4	**0**	1	3	1
Fixsenia favonius ontario (Northern oak hairstreak)	1	**0**	**0**	1	**0**
Fothergilla major (Large witch-alder)	2	1	1	2	1

(*continued on next page*)

Appendix 1 – *continued*

Species	Plan				
Scientific name (common name)	Database	Focal species	Close to wetland	Diverse forests	Largest patches
Hemidactylium scutatum (Four-toed salamander)	15	8	11	14	12
Hexalectris spicata (Crested coralroot)	1	1	**0**	1	**0**
Hexastylis lewisii (Lewis's heartleaf)	23	12	21	15	13
Ictinia mississippiensis (Mississippi kite)	2	2	2	2	2
Isoetes piedmontana (Piedmont quillwort)	1	**0**	1	**0**	**0**
Liatris squarrulosa (Earle's blazing star)	4	1	3	3	1
Lindera subcoriacea (Bog spicebush)	3	2	3	2	1
Macbridea caroliniana (Carolina bogmint)	3	3	3	3	3
Magnolia macrophylla (Bigleaf magnolia)	1	**0**	1	**0**	**0**
Monotropsis odorata (Sweet pinesap)	5	3	4	3	3
Necturus lewisi (Neuse river waterdog)	6	4	6	5	4
Picoides borealis (Red-cockaded woodpecker)	4	1	2	3	1
Platanthera peramoena (Purple fringeless orchid)	2	2	2	2	2
Porteranthus stipulatus (Indian physic)	5	1	3	3	1
Ptilimnium nodosum (Harperella)	1	1	1	1	1
Ruellia humilis (Low wild-petunia)	3	1	1	2	2
Ruellia purshiana (Pursh's wild-petunia)	1	1	1	1	**0**
Saxifraga pensylvanica (Swamp saxifrage)	1	1	1	1	1
Sciurus niger (Eastern fox squirrel)	4	3	4	4	3
Scutellaria leonardii (Shale-barren skullcap)	4	3	4	3	3
Trillium pusillum var pusillum (Carolina least trillium)	2	2	2	2	2
Number of species	*37*	*31*	*35*	*34*	*29*
Total number of species occurrences	*134*	*80*	*111*	*105*	*80*
Natural Communities					
Basic mesic forest (piedmont subtype)	13	10	13	12	9
Basic oak-hickory forest	15	11	10	14	11
Coastal plain bottomland hardwoods (brownwater subtype)	8	8	8	7	8
Coastal plain levee forest (brownwater subtype)	3	3	3	3	3
Coastal plain semipermanent impoundment	2	2	2	2	1
Coastal plain small stream swamp (brownwater subtype)	1	**0**	1	1	**0**
Cypress – gum swamp (brownwater subtype)	1	1	1	1	1
Dry oak – hickory forest	14	8	7	13	8
Dry-mesic oak – hickory forest	20	12	11	19	12
Floodplain pool	8	7	8	8	7
Granitic flatrock	4	2	3	2	2
Hillside seepage bog	1	1	**0**	1	1
Low elevation seep	3	2	3	3	2
Mesic mixed hardwood forest (coastal plain subtype)	2	2	2	1	2
Mesic mixed hardwood forest (piedmont subtype)	42	34	41	40	32
Mesic pine flatwoods	2	**0**	**0**	1	**0**
Oxbow lake	3	3	3	3	3
Piedmont longleaf pine forest	2	2	**0**	2	2
Piedmont monadnock forest	7	5	4	7	5
Piedmont/low mountain alluvial forest	18	14	18	18	12
Piedmont/mountain bottomland forest	10	10	10	9	8
Piedmont/mountain levee forest	8	8	8	6	4
Piedmont/mountain semipermanent impoundment	10	7	10	10	7
Piedmont/mountain swamp forest	7	6	7	7	4
Pine/scrub oak sandhill	10	3	4	6	2
Pine – oak/heath	1	**0**	**0**	1	**0**
Streamhead Atlantic white cedar forest	4	3	4	1	2
Streamhead pocosin	4	1	3	3	1

Appendix 1 – *continued*

Species	Plan				
Scientific name (common name)	Database	Focal species	Close to wetland	Diverse forests	Largest patches
Upland depression swamp forest	7	5	3	7	5
Upland pool	2	1	1	2	1
Wet pine flatwoods	2	1	**0**	1	1
Xeric hardpan forest	10	5	6	10	7
Number of communities	*32*	*29*	*27*	*32*	*29*
Total number of community occurrences	*244*	*177*	*194*	*221*	*163*
Total number of species and communities	*69 (100%)*	*60 (87%)*	*62 (90%)*	*66 (94%)*	*58 (84%)*
Total number of occurrences	*378 (100%)*	*257 (68%)*	*305 (81%)*	*326 (86%)*	*243 (64%)*

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