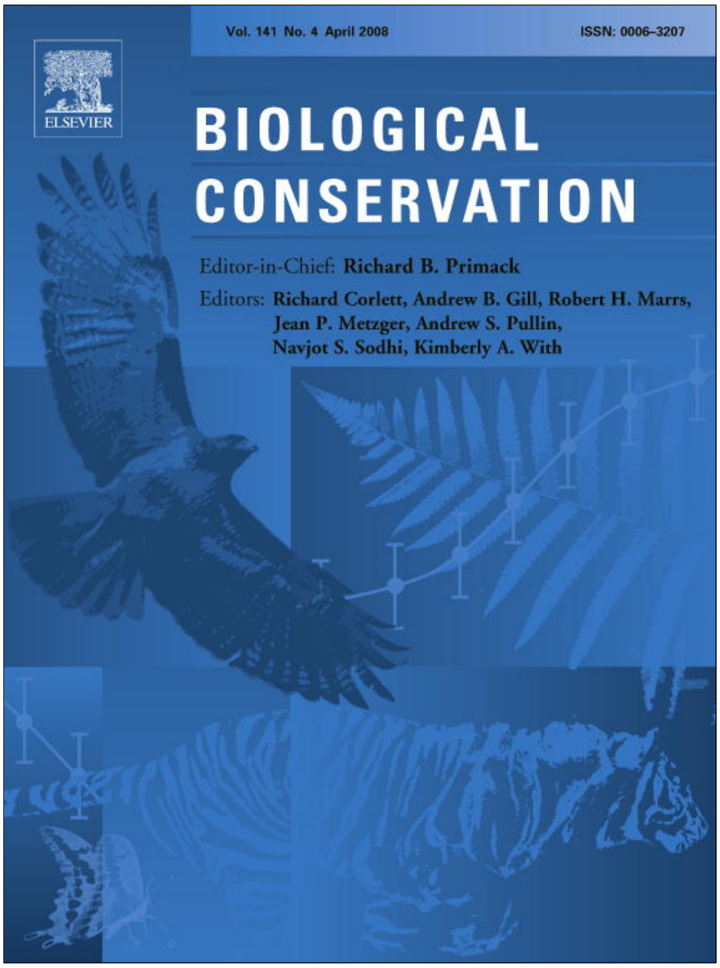
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Prioritizing avian conservation areas for the Yellowstone to Yukon Region of North America

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ABSTRACT

Prioritizing new areas for conservation in the Rocky Mountains of North America is important because the current intensity and scale of human development poses an immediate threat to biodiversity. We identified priority areas for avian biodiversity within a 3200-km corridor from Yellowstone National Park in Wyoming, US to the Yukon in Canada (the Y2Y region). We applied the conservation planning tool, MARXAN, to summarize 21 avian values. MARXAN minimizes the area delineated, while simultaneously incorporating multiple criteria (species richness representation, spatial clustering) and biodiversity targets into a single mappable solution. We prioritized avian biodiversity 'hotspots' at continental and ecoprovincial scales based on: (1) avian species richness; and (2) habitat associations of 20 focal species. At the continental scale, the single best solution represented 19% of the Y2Y region; 29% of this solution overlapped with existing protected areas. In northern Y2Y, large contiguous areas with high avian value were concentrated on the western edge of the continental divide. In southern Y2Y, contiguous areas were smaller and more numerous than in the north. In contrast to the majority of studies prioritizing conservation areas, we explored the effect of varying the extent of the target region by analyzing data at the scale of the entire Y2Y region and for eight ecoprovinces separately. We found that (1) large contiguous patches characterized only three ecoprovinces, while for the remaining ecoprovinces, numerous single scattered habitat patches of varying sizes were required to meet conservation goals; and (2) generally, only a small percentage of sites was already protected within the existing protected areas network. Our results are important for conservation planners and resource managers in the Y2Y region for incorporating areas of high conser-

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vation value for birds at regional and ecoprovincial scales during conservation project design and adaptive planning.

1. Introduction

In many cases, preserving biodiversity will require protecting large, connected areas (Margules and Pressey, 2000; Sarkar et al., 2002). In response to this need, efforts to establish networks of protected areas have been instigated in several regions in North America, among them the Algonquin to Adirondack Initiative (A2A; Algonquin to Adirondack, 2004), Baja to Bering Sea (B2B), Southern Rockies Ecosystem Project (Southern Rockies Ecosystem Project, 2007), and Yellowstone to Yukon (Y2Y; Yellowstone to Yukon Conservation Initiative, 2006) – (see Willcox et al., 1998; Noss et al., 2002; Vásárhelyi and Thomas, 2006; Mahr, 2007). The Y2Y Conservation Initiative is the largest of these broad-scale North American conservation efforts, and aims to maintain and restore biodiversity over extensive spatial scales and across international boundaries.

Several methods have been developed to aid in designing a network of biodiversity conservation areas and corridors. For example, site selection algorithms have been widely used to identify areas of high conservation value, allowing both managers and scientists to make "explicit, effective and accountable decisions about the allocation of scarce conservation resources" (Pressey and Cowling, 2001, p. 275). Since the early work of Kirkpatrick (1983), these algorithms have been deployed to identify efficient and representative protected area networks for a variety of taxa in both marine (e.g., Beck and Odaya, 2001; Cook and Auster, 2005; Richardson et al., 2006) and terrestrial (e.g., Cowling et al., 2003; Kerley et al., 2003; Warman et al., 2004; Shriner et al., 2006) ecosystems, and a suite of planning tool software is now available (e.g., C-plan, MARXAN, SITES).

In this study, our goal was to synthesize distributional data on bird species and their habitats to identify important areas for avian conservation. We chose the Y2Y region to conduct this research because of the large size of this conservation initiative and because of the importance of this landscape as breeding and migration habitat for birds. Approximately 1.2 million km^2 in extent, the region follows the spine of the Rocky and Mackenzie Mountains in the US and Canada. As well as being an important continental flyway for various birds (Drewien and Shea, 2003; Hoffman and Smith, 2003; Sherrington, 2004), the Y2Y region also encompasses extensive breeding habitat for diverse assemblages of landbirds, including many resident and Neotropical migrant passerines (Hutto and Young, 1999; Kelly and Hutto, 2005). A wide variety of habitats for birds is provided by the rough, mountainous terrain, and more than 275 breeding species are represented. These include a substantial portion of the breeding range of several Partners in Flight (PIF) Watch List species (dusky grouse *Dendragapus obscurus*, rufous hummingbird *Selasphorus rufus*, Calliope hummingbird *Stellula calliope*, black rosy finch *Leucosticte nigra*), Species of Regional Concern (American dipper *Cinclus mexicanus*, Cassin's finch *Carpodacus cassinii*, MacGillvray's warbler *Oporornis tolmiei*), significant breeding populations of common loon *Gavia immer* and American wigeon *Anas americanus* (wetlands), and the imperiled long-billed curlew *Numenius americanus* (grasslands).

One advantage in identifying important areas for bird conservation in the Y2Y region is that an established network of partners already exists in the region and is thus well-positioned to implement regional conservation planning. For example, the North American Bird Conservation Initiative (NABCI) endeavors to integrate bird conservation across broad continental scales (NABCI 2007). Under the NABCI vision, the Canadian Intermountain Joint Ventures (CIJV) and Intermountain West Joint Ventures (IWJV) have prepared all bird implementation plans that include the identification of geographically explicit Focal Areas (CIJV) or Bird Habitat Conservation Areas (IWJV); a subset of these areas falls within the Y2Y region.

Similar to other efforts, we chose to use site selection algorithms to identify areas of high conservation value or 'avian conservation value'. Areas with high avian conservation value are those that meet specific conservation targets. However, few attempts have been made to model areas of high conservation value using site selection algorithms for any taxa over such an extensive cross-border area within the Rocky Mountain region, although several smaller-scale studies have taken place (e.g., Warman et al., 2004; Freemark et al., 2006). However, two studies focusing on mammals have been conducted in the region. Carroll et al. (2003) used site selection algorithms to investigate reserve networks for charismatic carnivores in the Y2Y region and Wiersma and Urban (2005) prioritized important areas for disturbance-sensitive mammals in the Yukon territory. Although both of these studies were relatively large in scale, they focused on mammals, whereas in our study we used birds as the taxonomic focus.

Further, because conservation planning and implementation generally occur at a regional level, rather than at the scale of the entire Y2Y region, we wanted to explore how robust the results were to changing spatial extent a data grain concurrently. Spatial scale can determine the distribution and number of sites that are considered priority for conservation within an area, and thus determine efficiency. Efficiency refers to the capacity of a reserve design process to represent regional diversity in the smallest number of available sites (Stewart et al. 2007). For example, Warman et al. (2004) examined the influence of data grain by comparing the spatial similarity (% overlap) of selected sets of conservation sites for 29 threatened vertebrate species between different sizes of planning units and found that they overlapped by $\leqslant$40%. Wiersma (2007) also examined the influence of carrying study area extent, and found that a larger regional extent required fewer protected areas to meet conservation targets than was required to meet the same targets within several smaller extents.

To achieve the goals of identifying areas of avian conservation value, and to apply site selection algorithms over a large area and at two scales, three research projects were completed. Two of the projects involved statistical modeling to locate areas that (1) contained high bird species richness, and (2) contained high-quality bird habitat (defined as areas with a high probability of occurrence for 20 focal species). The third research project utilized the results of these two studies to identify those portions of the Y2Y landscape that harbored high avian conservation value (based on both species richness and habitat), and in an efficient manner when aggregated.

It is important to prioritize efforts for conserving bird biodiversity and focus limited resources. One way to improve the effectiveness of conservation efforts in terms of both species persistence and management cost is to ensure that reserves consist of several large contiguous areas, rather than many small areas scattered across the landscape. Species' dispersal between different sites is enhanced by the connectivity of patches – the more contiguous patches are, the more viable individual populations are within those patches (Hanski, 1998; Beier and Noss, 1998; Briers, 2002). Not only are large contiguous areas more likely to maintain viable populations, but scarce human resources such as labor, research and funding can be applied more efficiently within them. Therefore, when identifying areas of high avian value to be included in a summary map of priority bird areas, preference should be given to areas of high avian value that are aggregated rather than those isolated in the landscape.

Our study provides a unique contribution to the burgeoning literature on the use of site selection algorithms to identify priority biodiversity areas, and previous work in the Y2Y region specifically, for four reasons. First, we investigate the effect of varying the scale of the target region on the location of priority areas, which has rarely been done (see Wiersma 2007 for another recent example). Second, unlike previous studies in Y2Y where the focus has been on mammalian carnivores, we consider the conservation of birds. Third, few unified attempts have been made to model areas of high conservation value using site selection algorithms for any taxa over such an extensive cross-border area within the Rocky Mountain region, although several smaller-scale studies have taken place (e.g., Warman et al., 2004; Freemark et al., 2006). Finally, our approach differs from that taken by Partners in Flight, which is based on identifying habitats *a priori* within Bird conservation regions (BCRs) and developing conservation plans for the priority bird species that use these habitats (Casey 2000).

2. Methods

2.1. Study area

The Yellowstone to Yukon Region straddles the Rocky Mountains and adjacent lowlands, and extends from the Greater Yellowstone Ecosystem north along the Canadian Rockies to the Alaska–Yukon border (Fig. 1; see Willcox et al., 1998 for a detailed description of the Y2Y region). To facilitate comparisons of avian conservation values between geographic areas within the Y2Y region, we examined avian conservation values separately within eight ecological provinces (see Haufler and Mehl, 2002), as well as within the entire Y2Y extent. These ecoprovinces were chosen to represent ecologically distinct zones. This allowed us to generate results that described avian conservation value in ecologically-relevant sub-regions of the Y2Y area, and at an extent and grain that would be useful in informing and integrating the efforts of local conservation groups within the Y2Y region. Examining avian conservation values at this scale also allowed us to explore the influence of the data-rich and species diverse southern regions on the identification of conservation areas within the entire Y2Y region.

2.2. Defining avian values

Our primary objective was to efficiently identify areas of high avian conservation value (defined in the introduction) within the Y2Y landscape in order to guide conservation planning in relation to bird species richness and habitat quality. We derived areas of high avian value using analyses conducted by the authors, one set of analyses from the University of Alberta, Edmonton, AB (Muir, Hannon; University of Alberta); and one set of analyses from Montana State University, Bozeman, MT (Hansen, Jones, Montana State University). These studies employed a large, pre-existing bird distribution dataset (from the BBS), and provided Y2Y with a summary of important avian conservation areas across the region from two different perspectives. The Montana State University team identified hotspots of bird species richness (Hansen and Jones, unpublished data), whereas the University of Alberta team identified high-quality bird habitats for focal species (Muir, 2004). We describe the objectives and general methods used below, as conducted by different teams of co-authors.

2.2.1. Approach 1: Bird species richness

We developed a model of bird species richness for northwestern North America, centered on the Y2Y region, using count data from the BBS (Droege, 1990; Sauer et al., 2005). The BBS is a continent-wide (Canada, United States, and recently, parts of Mexico) bird-monitoring program that uses roadside counts (39.4 km in length) to sample bird populations with a standard protocol that has been in place since the mid-1960s. Unlike data deployed in many large-scale biodiversity studies, BBS analyses are based on standardized, spatially explicit field survey data. Further details of BBS methods are provided by Sauer et al. (2005).

We included only routes meeting BBS standards for compatibility, which had been surveyed for a minimum of four years. Of the 721 BBS routes that met those criteria, only 131 were located north of 55° latitude (northern British Columbia, the Yukon and Northwest Territories). To avoid unbalanced sampling densities between northern and southern regions (biasing estimated model parameters toward southern systems), we randomly selected 200 of the 590 southern routes. This gave us a total of 331 routes (200 in the south and 131 in the north), and offered a more even sampling intensity across the study area. Removing the 390 southern routes from model development provided the added benefit of supplying data that could be withheld for cross-validation.

Although all bird species seen and heard during the BBS surveys were recorded, we limited the analysis to native

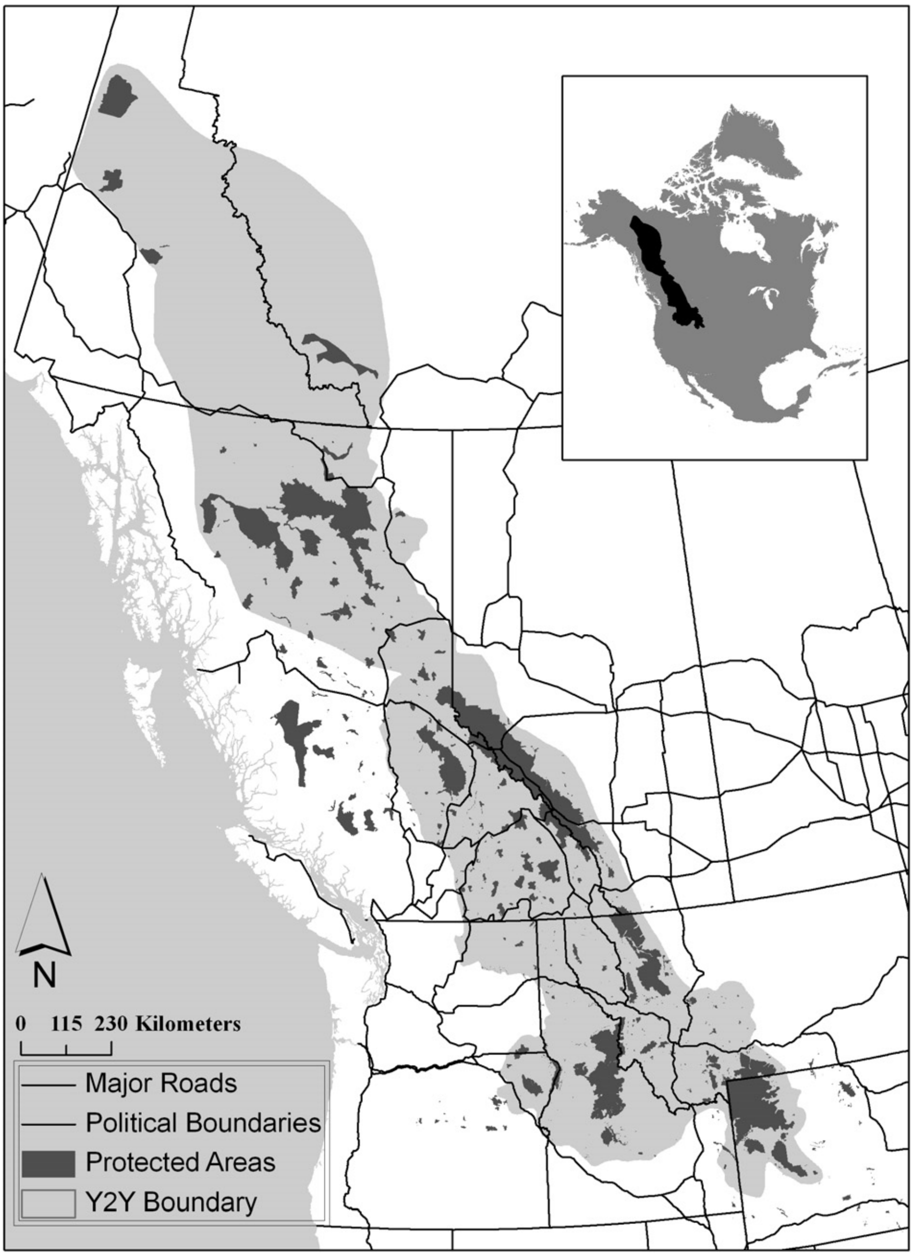

Fig. 1 – Boundaries of the Y2Y region showing locations of protected areas.

landbirds and groups poorly surveyed by point counts. We developed an index of avian conservation value based on native landbird species richness weighted by PIF Species Assessment breeding scores (see Panjabi et al. 2005). The latter are based on seven criteria, among them vulnerability, conservation concern, and regional responsibility (Carter et al., 2000; Panjabi et al., 2005). We used this PIF-weighted richness measure as our primary avian surrogate of species diversity based on its effectiveness as a surrogate for conservation value (Nuttle et al., 2003). To calculate PIF-weighted species richness for each route, we summed the PIF Species Assessment breeding scores for all species recorded on a BBS route in a given year. For each route, we then calculated the average PIF-weighted species richness value across years. We assigned this average value to the spatial centroid of the route.

We compiled environmental data-layers from a variety of data sources measuring topography, soil/water, landcover and vegetation productivity. These environmental variables were selected because they were potential correlates of species richness (Currie, 1991; Rosenzweig, 1995; Gaston, 2000; Rahbek and Graves, 2001; Van Rensburg et al., 2002). Each environmental-data layer was used in a grid format with a 1-km^2 spatial resolution. To reconcile the difference in size and shape of the response variable units (BBS routes) and the predictor variable units (1-km^2 raster pixels), we summarized predictor variables within a circular sampling unit of 19.7 km radius (half the length of a BBS route), centered at the BBS route centroid. Within each circular sampling unit, we calculated zonal summary statistics (quantitative variables: mean, standard deviation, coefficient of variation;

qualitative variables: majority, minority, variety) using the Spatial Analyst extension of ArcGIS™ 8.3 (ESRI, 2003).

We first inspected Pearson correlation matrices of all variables and discarded predictors with no significant bivariate relationships with the response variable. Where predictors showed strong collinearity ($r > 0.75$), we retained the one most strongly correlated with the response. To detect non-linear relationships, we examined scatter-plot matrices with loess smoothers; where the relationship with the response variable was quadratic, we added a polynomial term. We created Generalised Linear Models using avian species richness as the response variable and environmental layers as predictors. We then used stepwise forward selection to discriminate among variables, using Bayesian Information Criterion (BIC), to identify a subset of models with similar descriptive ability. We based final selection on the ability of models to accurately predict avian diversity indices at BBS routes not deployed in model development. Using iterative resampling and fitting cross-validation routines; we discarded models that overfit the data (i.e., model R-squared values were inflated relative to actual predictive ability) and tested more parsimonious models until predictive ability stabilized. We ran 1000 iterations of the cross-validation, producing a mean value of the squared correlation between predicted and observed values, as well as an associated standard error. We performed statistical analyses using R statistical computing environment versions 1.9.1 and 2.0.0 (R Core Development Team, 2004).

We used the resulting statistical models to extrapolate bird species richness across the study area. We did this by entering the linear model equation into a Geographic Information System (ESRI, 2003) containing continuous 1 km^2 resolution maps of the predictors from the best models. Because we used a radius of 19.7 km around BBS centroids to derive the predictor variables, the extrapolation process deployed a moving circular window with a radius of 19.7 km in which summary statistics were calculated and used to make predictions for each square kilometer. We then analyzed the resulting diversity maps to determine the spatial distribution of species richness hotspots.

2.2.2. *Approach 2: Predicting the distribution of focal species*

We used a focal species approach to describe the distribution of bird species within 19 broad habitat types. We assumed that areas with a high probability of occurrence for the focal species would indicate important areas for many other species that used similar habitat types. To select focal species, we grouped the 109 Y2Y priority species according to their habitat associations within 19 habitat classes using expert opinion and a review of the literature. We then used cluster analysis and filtering approaches to select a subset of 20 umbrella focal species (listed in Table 1). All analyses were conducted using S-Plus v6.1 (Insightful Corporation, 2002). These focal species were selected on the basis of their having: (1) a large part of their geographic range within the study area and (2) primary habitat that represented at least one of the existing 19 habitat types. They were assumed to act as umbrellas (see Andelman and Fagan, 2000; Roberge and Angelstam, 2004) for other birds using the same habitat types. Five of these species were listed as Watch List or Stewardship

Table 1 – The proportion of each conservation target met in each ecological province-scale analysis and the entire Y2Y region

	Full Y2Y	Yukon plateau	Mackenzie–Selwyn Mountains	Boreal and Northern Rocky	Central Interior Rocky	Okanogan	Southern Interior Rockies	Middle Rockies	Utah–Wyoming
Focal species (PIF-weighted diversity)	1.00	1.07	2.40	1.00	1.00	1.00	1.00	1.00	1.00
American dipper	1.09	–	–	–	1.01	–	1.20	1.00	2.68
American tree sparrow	1.00	1.00	1.00	1.00	–	–	–	–	–
American wigeon	1.00	1.00	1.00	1.00	1.02	–	1.00	1.00	1.00
Blackpoll warbler	1.00	1.00	1.00	1.00	1.00	–	1.00	–	–
Brewer's sparrow	1.00	–	–	–	–	1.76	1.00	1.00	1.16
Brown creeper	1.00	–	–	–	1.20	1.40	1.00	1.00	–
Cassin's vireo	1.00	–	–	–	1.19	1.04	1.00	–	–
Clark's nutcracker	1.00	–	–	–	–	–	–	1.00	1.00
Common loon	1.01	–	–	1.69	1.00	1.00	1.01	–	–
Golden eagle	1.18	1.00	1.75	1.37	–	1.00	1.26	1.03	2.18
Grasshopper sparrow	1.02	–	–	–	–	1.03	1.00	1.02	–
Gray-crowned rosy finch s	2.42	–	–	2.12	1.00	–	1.54	–	–
Lewis' woodpecker	1.00	–	–	–	–	1.00	1.00	1.00	1.00
Long-billed curlew	1.00	–	–	–	–	1.01	1.00	1.00	1.13
Ruffed grouse	1.00	1.13	–	1.23	1.00	–	–	–	–
Spotted sandpiper	1.37	2.26	2.10	1.33	–	–	–	1.00	1.00
Veery	1.04	–	–	–	1.00	1.46	1.00	1.00	–
White-crowned sparrow	1.38	1.56	1.68	1.14	1.00	–	–	–	2.54
Wilson's warbler	1.02	–	2.25	1.14	1.00	–	–	–	–
Yellow warbler	1.00	1.48	1.12	1.00	1.03	–	–	–	–

Values greater than 1 indicate that an area greater than the target area was represented in the best solution. Avian values which were not considered to occur within an ecoprovince are marked with a dash (–).

species by PIF (American tree sparrow, *Spizella arborea*; Brewer's sparrow, *Spizella breweri*; Clark's nutcracker, *Nucifraga comumbiana*; grasshopper sparrow, *Ammodramus savannarum*; and Lewis's woodpecker, *Melanerpes lewsi*), one was a waterfowl species of continental concern (American wigeon), and one was a highly imperiled grassland-nesting shorebird (long-billed curlew).

We used backwards stepwise logistic regression to develop models for 19 species using presence/absence data. Because little sagebrush steppe habitat within Y2Y was identified by our habitat classification, insufficient 'unused' samples for Brewer's sparrow could be derived. Consequently, we used presence/available data for this species. BBS data was the primary source of bird presence or presence/absence data, but was supplemented by additional point count data collated from a range of government and non-governmental sources in areas where BBS coverage was poor. We filtered the data so that only one point count survey was included in a square kilometer sample unit. Models were then developed for each umbrella bird species to predict probabilities of occurrence for each square kilometer within habitat types used by the species in the Y2Y region. Non-linear transformations of predictor variables were used where appropriate. K-fold cross-validation (using Huberty's rule of thumb to identify the number of partitions, Fielding and Bell 1997) was used to assess model performance. Model goodness of model fit was examined using the percentage of deviance explained and the area under the receiver operator characteristic (ROC) curve was used to assess model discrimination ability (Fielding and Bell 1997; Pearce and Ferrier 2000).

Because of the scarcity of BBS routes and other point count data in northern and high elevation areas, we expected model predictions to be less reliable in those areas than in southern and low elevation areas. We converted these model predictions to maps of relative habitat quality by ranking predicted probability values and categorizing them into (1) least suitable; (2) poor; (3) fair; (4) good; and (5) most suitable. Where species' ranges overlapped northern (defined as just north of the 55° parallel) and southern parts of Y2Y, we developed separate maps. For each species, the north and south maps were then combined to provide a single map of habitat quality for each species (see Muir 2004 for more details).

2.3. Synthesis: Identifying areas of high conservation value

We used simulated annealing implemented in MARXAN v1.8.2 (Ball and Possingham, 2000; Possingham et al., 2000) with the ArcView Geographical Information System (GIS) interface, CLUZ v1.6 (Smith, 2005) to summarize the spatial patterns of bird diversity and 20 focal species-habitat associations (or 21 avian values), into a single mapped solution. MARXAN was developed to assist in the design of reserve networks; it employs a range of heuristic and iterative improvement algorithms as well as simulated annealing, to select a reserve system that meets specified conservation goals (Ball and Possingham, 2000; Leslie et al., 2003). With CLUZ interface, researchers can enter data and map results using the GIS, ArcView 3 (ESRI 2003).

MARXAN operates by selecting a group of sites that meet set conservation targets, while at the same time minimizing total cost of the reserve network. It achieves this by scoring different combinations of areas called planning units (or the smallest grain resolution identified in our study), which are potential candidates for the reserve network. To produce a range of near optimal conservation solutions, the program is run iteratively, which increases the chances of finding the best solution.

In simulated annealing, the algorithm seeks to minimize the value of a single objective function. Within the function many different criteria can be incorporated – in MARXAN these are conservation targets, spatial clustering and a generalized cost.

Two main features are considered in simulated annealing: (1) the cost of planning units required to optimize conservation goals, and (2) the spatial arrangement of those planning units. Simulated annealing generally performs better than simple heuristic algorithms but it also involves extended computer time (McDonnell et al., 2002; see Vanderkam et al. 2007 for a recent comparison of processing time between different algorithms). Moreover, it produces several solutions rather than a single solution, which allows the irreplaceability of planning units to be examined. Irreplaceability here is defined as the extent to which the avian values found at one planning unit can be equally well-represented by other planning units (McDonnell et al., 2002; Leslie et al., 2003). An irreplaceable planning unit is one which contains unique avian values that cannot be found elsewhere on the landscape. Choosing priority areas based on irreplaceability ensures that planning units with rare conservation values are given priority when selecting a conservation network. Note that the use of the term irreplaceability in MARXAN is different than that used in Pressey et al. (1994). We used MARXAN to identify parts of the Y2Y landscape that met explicit conservation goals regarding the distribution of the 20 focal species and avian species richness. Thus we considered 21 avian value layers in our models.

We considered two spatial scales in our approach: the entire region (Y2Y) scale, and the ecological province-scale at a finer resolution. Eight ecological provinces have been defined for the region (Haufler and Mehl 2002), and these describe major climatic, vegetation and topographic differences. Summarizing the bird values within each ecological province separately provided finer-grained information on bird values. To select a set of sites that prioritised avian conservation goals we: established conservation goals, defined planning units, defined the level of clustering desired, ran simulations, mapped results, and completed a comparison with existing protected areas.

2.3.1. Establish conservation goals

Our ultimate goal was to identify a subset of areas within the Y2Y region with high avian value at regional and ecoprovincial scales in order to prioritize conservation efforts and to focus limited resources. We also wanted to identify where high value areas could be clustered to maximize efficiency in achieving conservation goals.

MARXAN (v1.8.2) allows different values to be set for conservation goals (target values), some of which have been used for conservation planning purposes (see Svancara et al., 2005; also Stewart et al., 2007). They may be based on biological targets (e.g., a population viability analysis for a target species), policy information (e.g., in the US there is a national mandate to protect 20% of coral reefs) or social values (e.g., setting aside a reserve area for recreational or educational purposes – see Leslie et al., 2003). In the absence of any empirically-based targets within the Y2Y region, we chose area targets of 20% and 40% for illustrative purposes only. These values were also similar to those used in other recent studies; for example, Leslie et al. (2003) used 10%, 20% and 30% of all habitat types as targets, and Leroux et al. (2007) used targets of 25%, 50% and 70% for planning units with suitable habitat for woodland caribou (*Rangifer tarandus caribou*). Recent reviews indicate that evidence-based targets range from 33% to 99% (Svancara et al., 2005; Wiersma and Nudds, 2006). Thus, in our case, if a target of 40% is selected, then MARXAN will attempt to include 40% of the available planning units representing that avian value into the reserve system. Our targets within the MARXAN reserve system were to obtain:

- 40% of the planning units with species richness values within the top 10 percentile;
- 40% of the 'most suitable' planning units for species with restricted range and scattered distribution within this range: American tree sparrow, grasshopper sparrow, blackpoll warbler *(Dendroica striata)*, Clark's nutcracker, long-billed curlew;
- 40% of the 'most suitable' planning units for wetland species: American wigeon, common loon;
- 40% of the 'good' or 'most suitable' planning units for species with restricted range and very little identified suitable habitat: Brewer's sparrow, Lewis's woodpecker;
- 20% of the 'most suitable' planning units for widespread species: American dipper, brown creeper (*Certhia americana*), Cassin's vireo (*Vireo cassinii*), golden eagle (*Aquila chrysaetos*), gray-crowned rosy finch (*Leucosticte tephrocotis*), ruffed grouse (*Bonasa umbellus*), spotted sandpiper (*Actitis macularius*), veery (*Catharus fuscescens*), white-crowned sparrow (*Zonotrichia leucophrys*), Wilson's warbler (*Wilsonia pusilla*), yellow warbler (*Dendroica petechia*).

2.3.2. *Define planning units in the Y2Y region*

Although the study area could be mapped at a resolution of 1 km grid cells, the total area exceeded our modeling capacity at this resolution. Therefore, we used a planning unit size of 10 km^2 for the analysis of the whole Y2Y region, and a unit size of 4 km^2 for the sub-regional analysis (ecological province scale).

2.3.3. *Define the level of clustering desired*

Preliminary analysis suggested that aggregating planning units resulted in less than a 5% increase in area required to meet the planning targets. In MARXAN, we can encourage the clustering of selected planning units by using a boundary length modifier of 1 in the objective function (Ball and Possingham, 2000). The boundary length modifier is a constant defined by the user which varies the importance of generating clumped unfragmented reserve systems (Richardson et al., 2006). We used a boundary length modifier of 1 in all analyses.

2.3.4. *Run simulations*

We ran the MARXAN simulations with 10 iterations. This value was chosen as a compromise between computer-processing time and reduced prediction variability, and was found to provide an adequate range of solutions for the study area. We recorded the number of times (out of 10) that each planning unit was included in a MARXAN identified conservation network. This measure, or percentage of runs, describes the 'irreplaceability' of planning units (see earlier definition). In designing a MARXAN conservation network, the most irreplaceable locations (i.e., those showing up in the majority of simulations) should be given highest priority. We also recorded which of the 10 MARXAN runs selected the network that minimized the objective function the most, and thus met our conservation goals by identifying the least area. This simulation result was defined as the 'single best solution'.

2.3.5. *Present results*

We evaluated the results using three measures: (1) the target proportion met; (2) the irreplaceability of sites (Leslie et al., 2003); and (3) the single best solution showing areas with high conservation value. The target proportion met is a measure of how well the derived MARXAN conservation network meets the specified conservation goals (i.e., 40% and 20% in our study). If each conservation goal is met precisely within the MARXAN conservation network, then the proportion of the target met will equal 1. If the identified MARXAN conservation network exceeds a conservation goal, then the proportion of the target met may exceed 1; conversely if the conservation goal cannot be met, then the proportion of the target met may be less than 1. Irreplaceability and the single best solution were mapped in ArcView 3 (ESRI, 2003).

2.3.6. *Complete a comparison with existing protected areas network*

We examined how well existing protected areas represented avian values by calculating the proportion of the single best solution contained within the existing protected areas network.

3. Results

3.1. *Synthesizing avian values at the Y2Y scale*

The single best solution comprised 19% of the entire Y2Y region, and 29% of the solution overlapped with the existing protected areas system (Table 2). Large contiguous areas representing the targeted avian values were frequently concentrated on the western edge of the continental divide along the Rocky and Mackenzie Mountains (Fig. 2). In the northern Y2Y area, targeted avian values were identified in the vicinity of (1) the Ogilvie Mountains; (2) to the east and south of Fishing Branch Ecological Reserve in the Yukon; (3) in the western Rocky Mountains; and (4) south of Whitehorse, down into

Table 2 – Summary statistics describing the extent of representation of the area identified within the best MARXAN solution (the reserve set) within existing protected areas

Location	% area selected in MARXAN reserve set[a]	% ecological province area currently protected[b]	% reserve set conserved[c]
Entire Y2Y region	19	27	29
Yukon Plateau Ecoprovince	23	19	41
Mackenzie-Selwyn Mountains Ecoprovince	23	2	3
Boreal and Northern Rockies Ecoprovince	20	17	20
Central Interior Rockies Ecoprovince	18	13	14
Okanogan Ecoprovince	18	12	11
Southern Interior Rockies Ecoprovince	19	33	35
Middle Rockies Ecoprovince	15	23	28
Utah–Wyoming Ecoprovince	21	57	57

a The percentage of each ecoprovince contained within the single best solution.
b The percentage of each ecoprovince that is designated an existing protected area.
c The percentage of the single best solution that overlaps with an existing protected area (s).

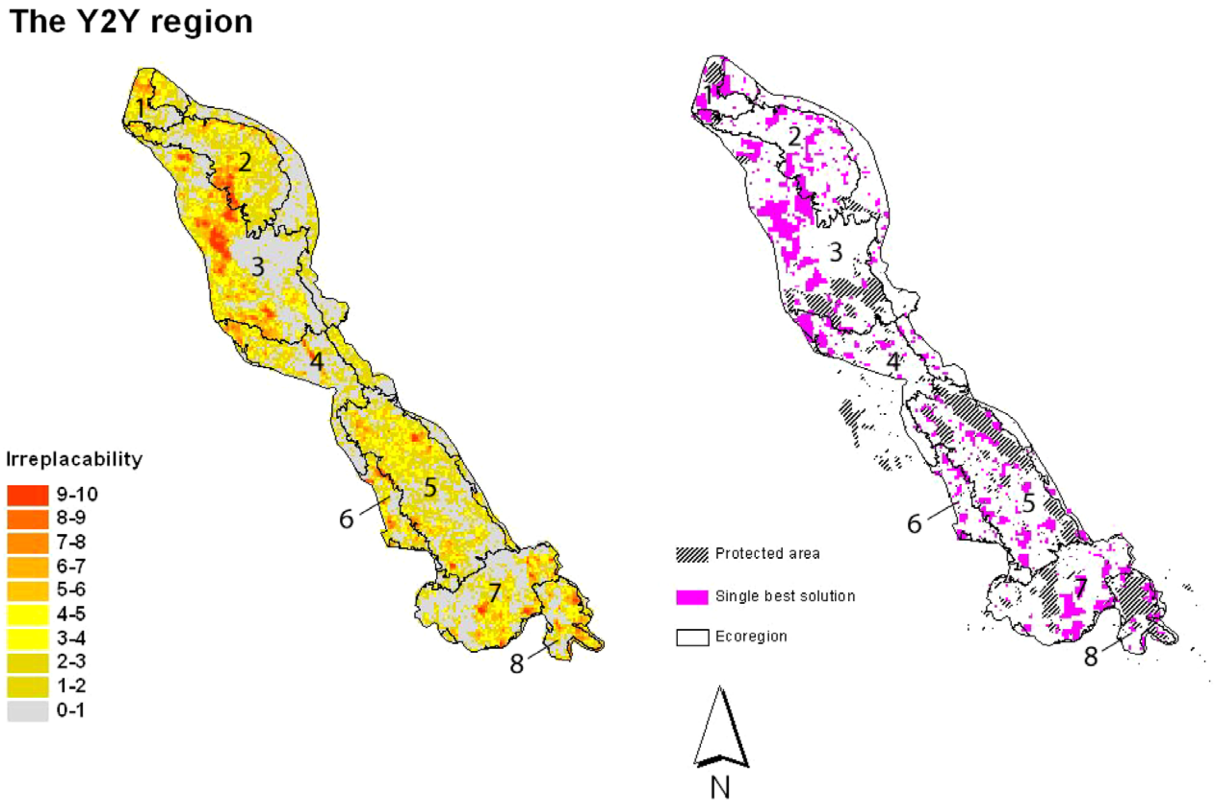

Fig. 2 – Results of the Y2Y MARXAN analysis. The numbers refer to the ecological provinces (1. Yukon Plateau, 2. Mackenzie–Selwyn Mountains, 3. Boreal and Northern Rockies, 4. Central Interior Rockies, 5. Southern Interior Rockies, 6. Okanogan, 7. Middle Rockies, 8. Utah–Wyoming). The first map shows the irreplaceability of planning units, and the second map shows the single best solution. Irreplaceability values indicate the number of times out of 10 that a unit was located in a MARXAN conservation network.

British Columbia to approximately the 56th parallel (near Bear Lake). These areas were identified as the most irreplaceable within the Y2Y region (Fig. 2).

In the southern half of the Y2Y region, contiguous areas identified within the reserve set were generally smaller in size and more numerous, possibly reflecting the greater avian diversity, number of avian values considered, and higher quantity of data available. Habitat fragmentation in the more human-populated areas of this region may also play a role. Areas identified coincided with Banff and Jasper National Parks, Wells Gray Provincial Park, and scattered areas along the western edge of the Okanagan Valley in Canada. In the United States, areas representing targeted avian values corresponded with the eastern and northern edge of Yellowstone National Park, and areas on the western edge of the Rocky Mountains to the Salmon–Selway Ecosystem in central Idaho (Fig. 2).

3.2. *Synthesizing avian values at the ecological province scale*

From 15% to 23% of each ecological province was identified in the best reserve set by MARXAN (Table 2). In three ecological provinces (Okanagan, Utah–Wyoming, Yukon Plateau), these areas were defined by a few large contiguous patches. Within most ecological provinces, many individual, scattered patches of habitat were required to meet the conservation goals (Fig. 3). Although these areas frequently coincided with existing protected areas (Fig. 3), on average 26% of each reserve set (ranging from 3% to 57%) overlapped

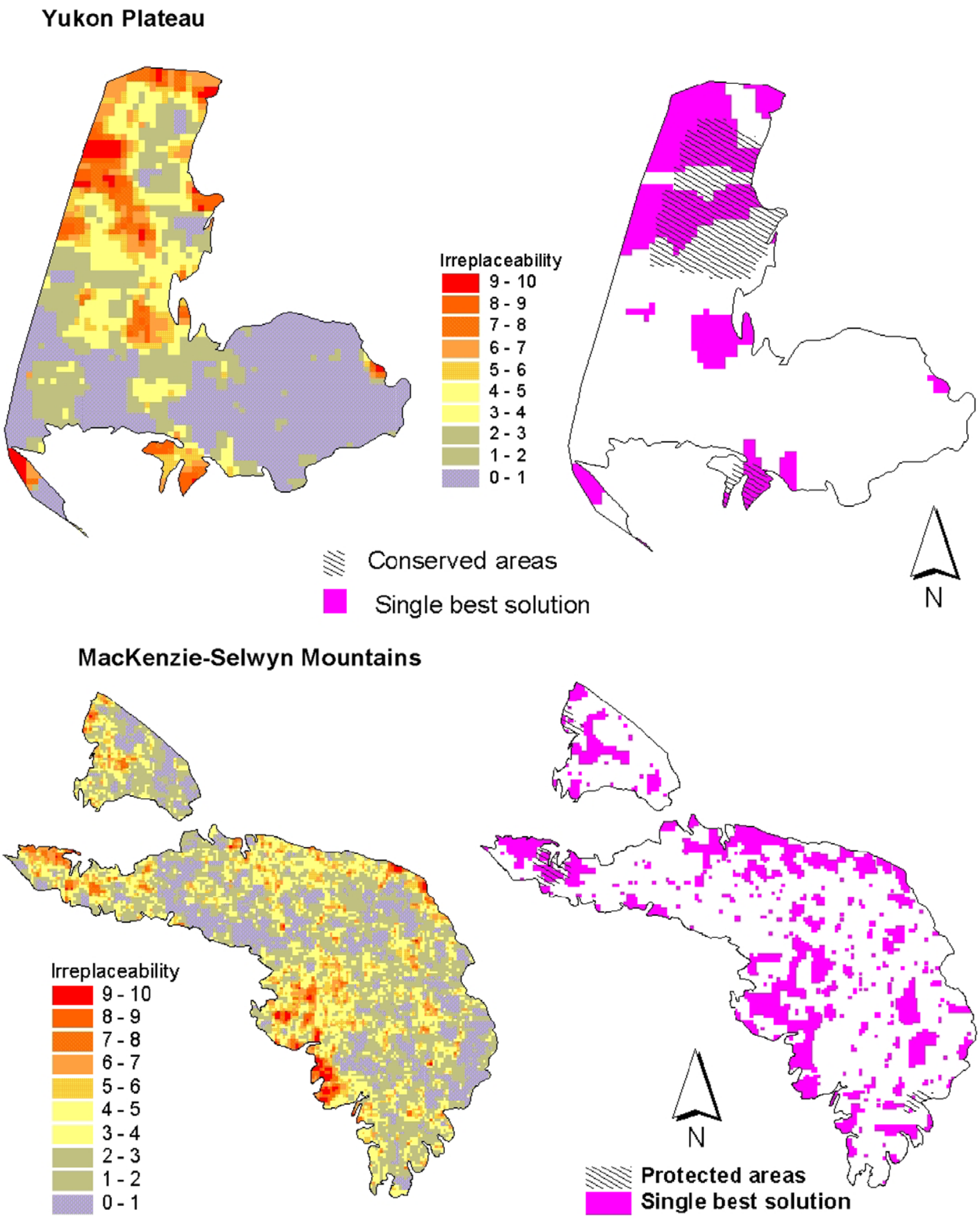

Fig. 3 – For each ecoprovince, the irreplaceability of each planning unit is shown in the first map, and the second map shows the single best solution.

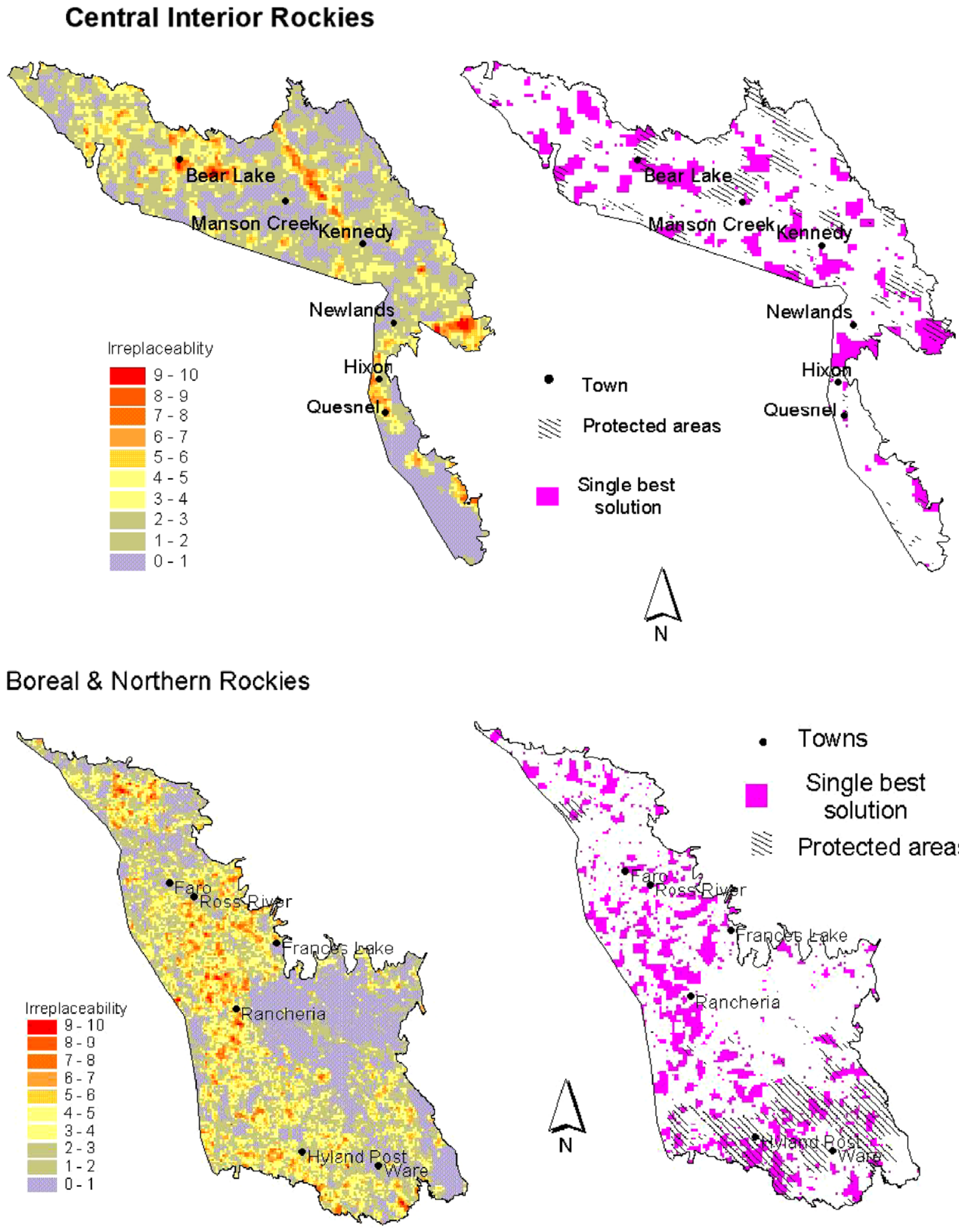

Fig. 3 – *continued*

the existing protected areas system (Table 2). The MacKenzie–Selwyn Mountains contained the lowest level of representation (3%), although this ecological province contained a low overall percentage (2%, Table 2) of protected areas. The greatest overlap in area between the existing protected area network and the identified best reserve set was found within the Utah–Wyoming and the Yukon Plateau ecological provinces.

The ecological province level analysis identified a greater area of high conservation value than the Y2Y-scale analysis

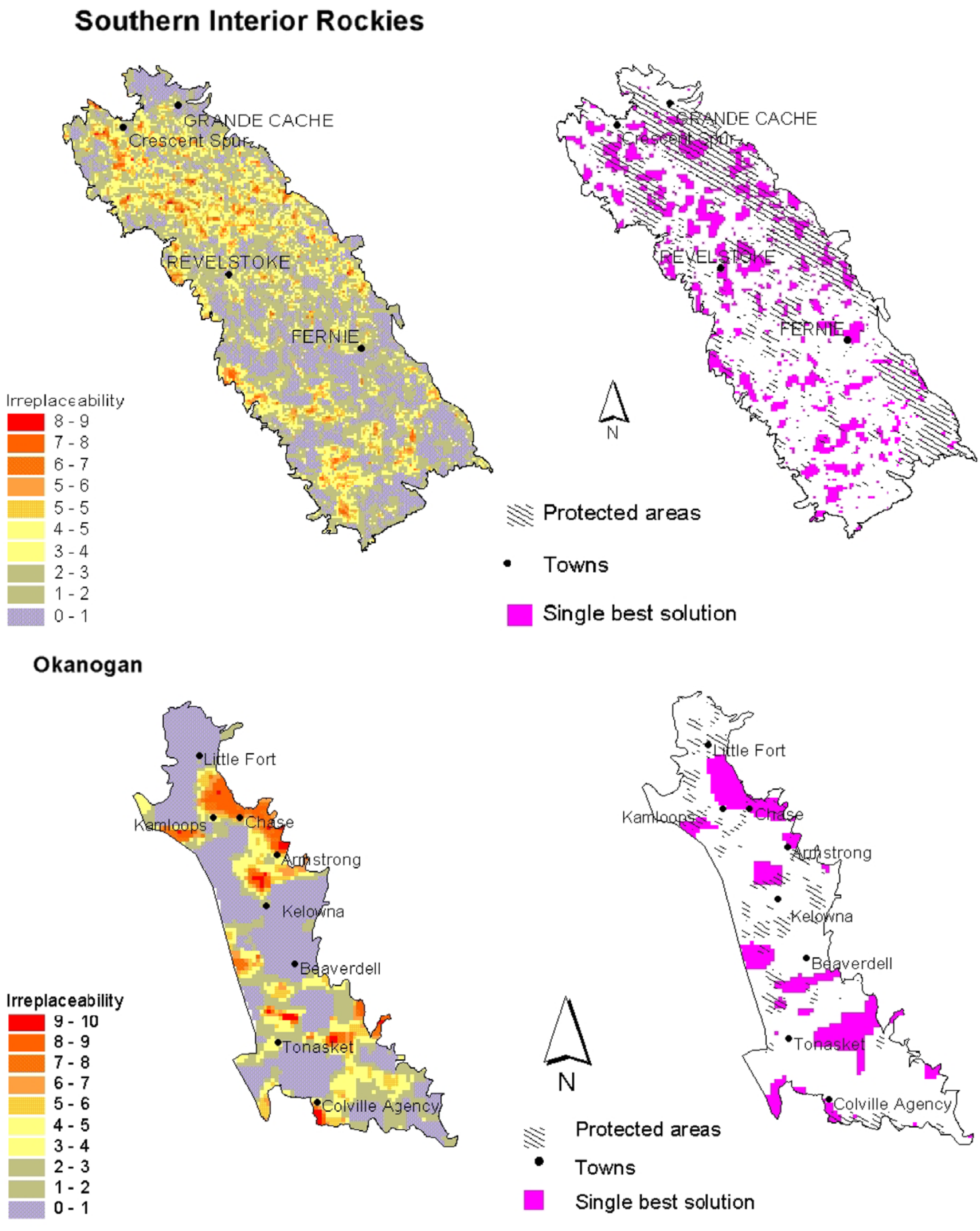

Fig. 3 – *continued*

suggested. This is expected because all conservation goals need to be met in each ecological province, resulting in redundancy. However, both extents of analysis identified similar geographic regions in their respective MARXAN best reserve sets. Exceptions were found in the Yukon Plateau and Central Interior ecological provinces, where qualitatively different areas were identified by each analysis.

4. Discussion

Our results and synthesis demonstrate, for the first time for the entire Y2Y region, how data on bird distribution can be used to prioritize broad-scale conservation planning over very large areas. Our analysis is based on avian species richness hotspots and habitat associations of focal species, and

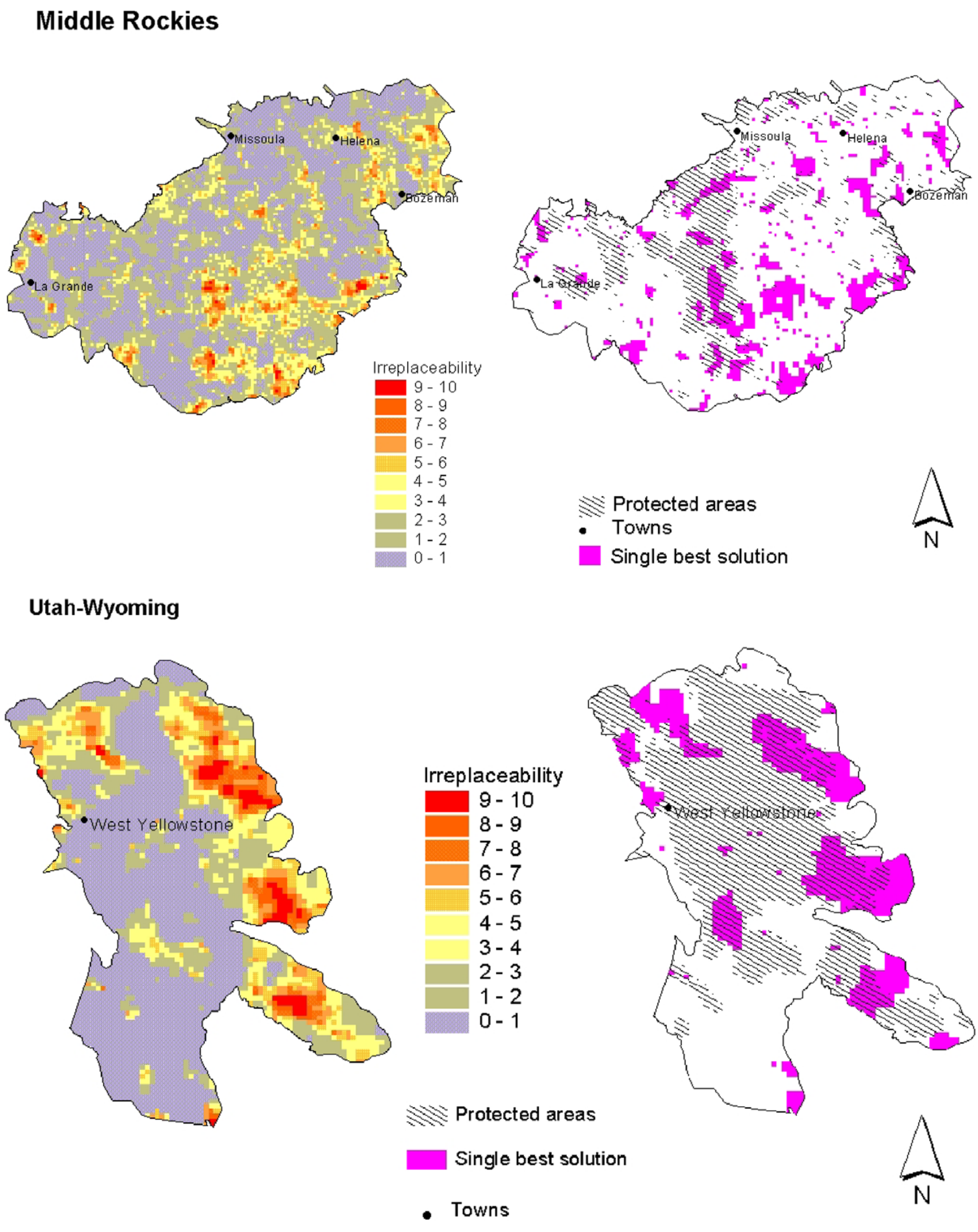

Fig. 3 – *continued*

indicates that Y2Y needs to include taxa other than charismatic large carnivores (e.g., Carroll et al., 2001) in biodiversity assessment. Priority areas identified by Carroll et al. (2001) for more than three carnivore species represent only a subset of the area required to meet avian conservation goals. Our results identified areas of high avian conservation value, and they are also relevant in terms of setting total area objectives for conservation, as well as the size and juxtaposition of patches. In addition, they highlight the importance of conducting analyses at multiple scales. While results were similar for the two scales used, the entire Y2Y region scale would be most appropriate for large-scale planning, whereas the ecological provinces are perhaps more appropriate for sub-regional conservation design and project planning. Lastly, our findings support other studies that show a relatively low percentage of sites important to biodiversity conservation has been protected within the current reserve system (e.g., Freemark et al., 2006; Wiersma, 2006).

4.1. *Spatial pattern of areas of value*

We found that the spatial pattern of areas of high conservation value for birds varied by ecological province. For most ecological provinces, many individual scattered habitat patches (of various sizes) were required to meet all conservation goals, primarily because high-quality habitat for many species was patchily distributed at the landscape scale, as identified by Muir (2004). This is because the largely mountainous terrain resulted in strong variation in topography and climatic conditions over short distances, and many habitat types (such as lakes, marsh, bog, riparian), naturally occur in patches. The large contiguous patches identified in three ecological provinces occurred primarily because certain habitat types were patchily distributed. In the Yukon and Utah–Wyoming ecological provinces large contiguous patches were obtained because alpine, subalpine and northern shrubfields were located in only a few large patches within the ecological province. In the Okanogan ecological province, several distinct habitat zones were apparent. The northern part of the ecological province tended to be forested habitats, the central part of the province contained a large amount of lake habitat and the southern extremes contained grassland habitat. In each of these provinces, additional avian targets could be met in the vicinity of these areas.

It is important to note here that: (1) determining core areas and connectedness necessitates the incorporation of many other factors in the reserve selection algorithm, including the road network; and (2) it is possible to set targets for minimum reserve size, connectivity or other design criteria once these factors are incorporated. This is a critical next step in this analysis. Some authors have argued that targets for reserve size or other criteria should be considered *a priori* together with representation or other target goals (Rodrigues et al., 2000a, 2000b; Rodrigues and Gaston, 2001; Wiersma and Nudds, 2006). Rodrigues et al. (2000a) found that percentage targets varied depending on the number of target species, the size of conservation planning units, and the level of endemism of the species concerned.

4.2. *How can our results be used to inform bird conservation within Y2Y?*

In contrast to more theoretical conservation assessments, our results are based on real data describing the distribution of bird species, particularly focal species. They are in keeping with more modern and rigorous conservation assessments such as evidence-based conservation (Sutherland et al., 2004) that uses the best available information. Our results have tremendous potential to benefit conservation partners in the Y2Y region because the results and input parameters are spatially explicit. In many cases, assessments of biodiversity are not based on measurable ecological objectives but on anecdotal or qualitative assessment. Furthermore, political agendas and economic gain often confound the setting of such ecological targets and objectives (Svancara et al., 2005; Tear et al., 2005).

Our approach can be used in conjunction with other conservation planning assessments (e.g., the implementation of plans of the Canadian Intermountain Joint Ventures [CIJV] and Intermountain West Joint Ventures [IWJV]), by combining the goals, objectives and priority species of these assessments into a unified set of avian conservation targets, and rerunning the MARXAN analysis. We hope that they can be used to steer adaptive approaches to setting priority conservation objectives, while recognizing that the data and software used have some limitations (see below). The application of our approach using a greater array of conservation targets could contribute to greater cohesion among the multiple approaches to avian (and other) biodiversity conservation in the Y2Y region, where an impressive number of organizations, initiatives and approaches to bird conservation exist. These include State Wildlife Action Plans, the efforts of the CIJV and IWJV, and the ongoing revision of objectives at the BCR level within the four major bird initiatives (Partners in Flight, US Shorebird Conservation Plan, North American Waterbird Conservation Plan, and the North American Waterfowl Management Plan). Although we focused here on landbirds, a comparable technique could be used for all birds and thus represent a more coherent and holistic approach to avian biodiversity conservation in the Y2Y region.

Our approach differed from that taken by Partners in Flight in that we use species distribution and abundance data to determine areas of high value, rather than *a priori* identifying priority habitats and the priority bird species that use them. Our approach also differed from the research of CIJV and IWJV, which used relationships between habitat and priority bird species to identify and map focal areas for coordinated bird conservation. Both groups have committed to refining their research design and we view the tools we used to be of key importance to those processes, particularly from the standpoint of optimization and efficiency in conservation reserve design.

4.3. *Strengths and weaknesses of approaches*

We have identified areas of high conservation value in the Y2Y region with a conservation planning software tool that uses the concepts of irreplaceability (Leslie et al., 2003). The main strengths of such an approach are: (1) it is objective and evidence-based, and uses empirical data (no pre-conceived ideas about the distribution and abundance of species or *a priori* or even *ad hoc* selection of specific habitat types or landscape elements); (2) it is repeatable, using different model parameters or adding more sophisticated and/or new information such as threats or infrastructure layers; (3) it can be conducted over broad areas; (4) it can be re-run at multiple scales depending on the need to examine finer scale issues; (5) it can be used for a patch-centric approach such as designing an optimal conservation area network and identifying networks of core areas, but it can also consider the intervening matrix; and finally, (6) it provides a visual map of areas meeting avian conservation targets, which is transparent and conceptually easy to understand.

Setting conservation targets and identifying priority areas in which to focus scarce conservation resources requires making decisions. First, in MARXAN, when the contributions of species representation, spatial clustering and a generalized cost are summed together, a weighting needs to be applied to reflect the relative importance of each. No objective method exists to assign these weights (S. Sarkar, pers. comm.). An alternative is to use a program that satisfies species richness targets (e.g., MARXAN, C-plan or ResNet; Sarkar et al., 2002) and to run a separate program for multi-criteria analysis at the same time (e.g., MultCSync – Moffett et al., 2004; Moffett and Sarkar, 2006). A second tradeoff is that in order to maximize the aggregation of high value areas, the boundary length modifier incorporates some areas of lower avian value. One solution to this problem may be to use a smoothing distribution and then examine the effectiveness of aggregated units using a decision-theoretic uncertainty analysis (see Moilanen and Wintle, 2006).

Strengths and weaknesses also exist in the avian value data used to populate models. The BBS offers one of the most geographically extensive and long-term datasets on birds in the world, and arguably provides the best biodiversity information in North America (Sauer et al., 2005). However, it suffers from a number of biases, including observer differences (Sauer et al., 1994), the fact that the location of older routes is not truly random (though the start points of newer routes are), as a roadside sample it is a biased sample of habitats, and it offers limited coverage in much of central and northern Canada (Bart et al., 1995; Hanowski and Niemi, 1995; Keller and Scallan, 1999; Cumming et al., 2001).

Mapping species richness is perhaps one of the easiest ways to represent biodiversity over broad areas and has been used many times as a biodiversity surrogate for site selection. It is one among several different methods of representing biodiversity with a single index, and has been used for entire continents (Ricketts et al., 1999), countries (Prendergast et al., 1993), ecoregions (Davis et al., 2003) and individual states (Scott et al., 1993). However, species richness, based on a snapshot of species presence or absence over time, does not consider persistence, which is critically important in identifying areas for bird diversity (van Teeffelen et al., 2006; Wiersma and Nudds, 2006). This could in fact be done using BBS data by incorporating time series data from annual counts of individual species repeated over time in the same location. This would also enable persistence to be incorporated by selecting areas where a species occurs at relatively high abundance (see Rodrigues et al., 2000b), with the caveat that occurrence or abundance does not necessarily reflect habitat quality (Van Horne, 1983).

The focal species approach has also been criticized for various reasons, including the fact that the species chosen may not in fact be representative (Lindenmayer et al., 2002). Watson et al. (2001) found that woodland birds benefited from a focal species approach when ideal guidelines were implemented, but not when less stringent guidelines were adopted to meet local situations.

In the focal species approach originally developed by Lambeck (1997), the species chosen were those which specifically responded to the main threats or processes in the landscape. An advantage of such an approach is that a few species (chosen using standardized selection criteria, including modeling) can represent the ecological requirements of other biota. In this study we used focal species that were actually priority species identified by Partners in Flight (Carter et al., 2000; Rich et al., 2004). To identify high-quality habitat, we then used species distribution data and selected the most representative species from groups identified by cluster analysis. While these are not focal species in the strict sense of the threat-response approach, the advantage of using the PIF priority species is that their importance is not just based on rarity but on other criteria such as jurisdictional responsibility (the continental or global proportion of a species' population or range within a particular region; Dunn et al., 1999), current threats, and whether the species is declining. A disadvantage is that the usefulness of priority bird species as surrogates for biodiversity conservation in the Y2Y region is not proven and needs to be tested empirically.

Another potential shortcoming of using avian diversity and habitat type as drivers to select conservation areas, even as modified with a focal species emphasis, is that our best solutions may still not be adequate to meet population objectives for individual species. For example, patch sizes may not be sufficiently large to maintain viable populations. For those species with continental objectives to maintain current population levels, such as the American tree sparrow (*S. arborea*), protecting 19% of the Y2Y landscape might suffice, but this analysis has not been done. For other species such as the Brewer's sparrow (*S. breweri*) and dusky grouse (*D. obscurus*), which were not in our analysis, it may be that that protecting 19% of the region would not be adequate to double populations in the next 30 years (the PIF objective for these Watch List species). Species-specific modeling and conservation design is likely to be needed to achieve these objectives.

5. Conclusions and next steps

The regions we identified as meeting avian conservation goals provide a useful starting point for conservation practitioners and resource managers in prioritizing new core areas for conservation in the Y2Y region. Highly valued patches along existing park boundaries could be managed as habitat buffers. Conservation activities should probably focus on areas subject to the highest rates of degradation such as montane forests, valley bottoms, and wetlands which are important as staging sites or breeding areas.

Although we did not use reserve selection software to specifically design a conservation area network, the logical extension of this work would be to include other parameters such as threats (e.g., road density, mining, energy development, timber harvest, competition with non-native species, urbanization). For the next steps in this analysis, we recommend that: (1) spatially explicit information be gathered on road infrastructure, land use, and land ownership, so that these and other threats or processes can be incorporated into the site selection algorithm; (2) multi-scale analyses be conducted to specifically compare results with other studies and, where feasible, field-tested to provide more fine-scale information for conservation planning; (3) stakeholders be included in deciding and refining the specific size, shape and configuration of conservation areas (e.g., the focal areas of the joint ventures); (4) tests be done on the efficacy of birds as surrogates for other taxa or species groups (e.g., species at risk of extinction) and (5) that multi-annual BBS data be used to incorporate persistence over time into the reserve selection algorithms (see Rodrigues et al. 2000b).

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