PRIORITIES FOR CARNIVORE CONSERVATION IN THE CARIBOO-CHILCOTIN REGION

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EXECUTIVE SUMMARY

$ A regional analysis based on habitat models for eight native large and mesocarnivore species found that the areas in the Cariboo-Chilcotin region with the greatest value for carnivore conservation were located on the southern edge of the study region in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area, as well as on the northern edge of the region surrounding Kluskoil Lake Park and the larger Blackwater River area.

$ Carnivores may be good focal species for a larger range of biodiversity values. Thus the priority areas identified here can not only conserve carnivores but can also supplement coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and highlight trends at the broader geographic scale such as the effects of loss of connectivity.

$ Although they cannot utilize detailed local-scale habitat data, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying drivers of species vulnerability. As the landscape matrix becomes developed, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. Current reserves alone are generally not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable.

$ A preliminary viability analysis for grizzly bear and wolf in western North America highlighted the Chilcotin region as of high importance on a continental scale, especially for wolf populations, due to the combination of relatively high productivity (in comparison to the Canadian Mountain Parks) and relatively low levels of roads and

human population (in comparison to other forested regions to the south). These characteristics will likely be resilient to climate change if a well-designed network of refugia can be implemented.

$ The Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may be key to preserving connectivity and viability of carnivore populations over a larger region of western Canada that holds the greatest remaining diversity of large carnivores in North America.

"Human activities combined with climatic change can precipitate ecological changes of much greater magnitude than would be expected from climatic changes alone... continuation of recent climate warming trends and/or intensification of forest management could lead to rapid irreversible vegetation changes within boreal forests that are not readily predicted from our observations of their current dynamics." Chapin et al. 2004

INTRODUCTION

Over the next half-century, anthropogenic climate change is predicted to dramatically alter the composition and structure of ecosystems worldwide. Climate change not only impacts ecosystems through gradual trends in temperature or precipitation but also through disturbance events such as insect outbreaks and forest fires. The speed and widespread nature of these disturbances will challenge the ability of species to persist by means of gradual shifts in distribution. Many areas of the boreal and subboreal forest, including the Cariboo-Chilcotin region of central British Columbia, are currently experiencing widespread mortality from pine and spruce bark beetle outbreaks linked to unusually warm winters (Safranyik 1990, Carroll 2001). In order to utilize the beetle-killed trees while they are still commercially valuable, the forest industry is proposing to accelerate cut levels substantially across the Cariboo-Chilcotin region, compressing 40 to 60 years of harvest into the next 15 years. This level of harvest has the potential to greatly alter ecosystems across the region and lessen their resilience to the effects of ecosystem stressors linked to climate change, such as altered rainfall patterns, insect and disease outbreaks.

Although the boreal and subboreal forest is not as speciose as tropical biodiversity "hotspots", planners increasingly recognize the important role of these and other "coldspots" in

sustaining global ecosystem processes and populations of area-limited species (Kareiva and Marvier 2003). Two types of measures can be taken to increase the resilience of biodiversity values in the Cariboo-Chilcotin region to climate change and other ecosystem stressors. Site-level prescriptions and fine-scale riparian and old-growth management areas can help mitigate impacts of accelerated timber harvest on a local scale. However, the widespread nature of the beetle outbreak and subsequent logging also requires regional-scale planning to identify retention areas that will not be salvage-logged even if they are attacked by mountain pine beetles. If these retention areas are distributed based on the principles of conservation planning, they can mitigate, to an extent, the effect of accelerated harvest on ecosystem processes that operate over large areas and upon species with large area and connectivity requirements for viable populations, such as grizzly bear (Ursus arctos) and woodland caribou (Rangifer tarandus caribou). In turn, wide-ranging species such as large carnivores can serve as focal and indicator species to help plan and evaluate the adequacy of the conservation measures such as the proposed retention areas (Lambeck 1997). This is because these species' stringent area and connectivity requirements make factors affecting their viability illustrative of the link between larger regional processes and biodiversity at the local scale (Carroll et al. 2001). In this report, I summarize lessons from a systematic reserve design study focusing on conservation of native carnivore species (Carroll et al. 2003, 2004), and suggest how these results can help inform retention area planning for the Cariboo-Chilcotin region.

METHODS

MODELING TECHNIQUES

The purpose of the Rocky Mountain Carnivore (RMC) Research Project (Carroll et al. 2001, 2003, 2004), sponsored by World Wildlife Fund-Canada with assistance from The Nature Conservancy, the Wilburforce Foundation and other groups, was to develop the data necessary to support long-term conservation of a broad suite of native carnivore species across a large portion of their range in the northern U.S. and Canada. The RMC study considered the habitat needs of eight native carnivore species - grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), gray wolf (*Canis lupus*), lynx (*Lynx canadensis*), mountain lion (*Puma concolor*), wolverine (*Gulo gulo*), fisher (*Martes pennanti*), and marten (*Martes americana*). The RMC analysis encompassed a study area stretching along the Rocky Mountains of Canada and the United States from the Yukon/British Columbia border to the Greater Yellowstone Ecosystem, and extending westward to encompass the Fraser Plateau.

The RMC study area covers most of the Cariboo Chilcotin Land Use Plan (CCLUP) area, except for a strip along the southwestern margin of the CCLUP (Figure 1). However, it is important to recognize that conservation priorities derived from any planning process are to some extent a function of the planning region's boundaries. For example, a planning exercise for the CCLUP region alone might prioritize regionally-rare ecosystem types that would be lower priorities in a province-wide plan. Because of its large extent, the RMC results are most informative at a large geographic scale that spans many ecoregions. However, we anticipated this scale issue by incorporating the principle of representation into the priority-setting process. As detailed below, we sought to capture a proportion of the best carnivore habitat within each of the

ecosection-based subunits of the larger study area. This insured that a geographically-widespread population, containing uniquely-adapted ecotypes, could be protected by the resulting conservation network, and increased the relevance of our results to ecoregional-scale planning processes.

We (the author of this document and his co-authors on the RMC study) created empirical models - resource selection functions (RSF) (Manly et al. 1993) - for the four species for which we had detailed survey data: black bear, lynx, wolverine, and fisher. Details of these models are presented in Carroll et al. (2001a,2002,2003). For example, we created conceptual models for the grizzly bear, wolf, marten, and mountain lion based on published information on species-habitat associations. The conceptual models for the grizzly bear (Carroll et al. 2001a) and wolf (Carroll et al. 2001b, 2003) combined surrogates of productivity, as measured by a satellite-imagery derived metric (tasselled-cap greenness (Crist and Cicone 1984)), and human-associated mortality risk, as measured by road density and human population (Merrill et al. 1999). Topography was an additional component of the wolf model (Carroll et al. 2001b, 2003). Because the analysis covered a very large and ecologically diverse region, the GIS models for fecundity and survival for grizzly bear and wolf used very general habitat data that is available in every province and state. This is a lesser problem for the survival input layer, because roads and human population have a similar negative effect on large carnivore survival in diverse habitats (e.g., Thiel 1985, Fuller et al. 2003). Estimating large carnivore fecundity (reproductive rates) across such a large region is more difficult. Although they cannot utilize the more detailed habitat data available at the local scale, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying

drivers of species vulnerability that can make conservation policy more effective.

After developing the static habitat suitability models, we performed population viability analyses using the program PATCH (Schumaker 1998). PATCH is a spatially-explicit population model that links the survival and fecundity of individual animals to GIS data on mortality risk and habitat productivity measured at the location of the individual or pack territory. The model tracks the demographics of the population through time as individuals are born, disperse, reproduce, and die, predicting population size, time to extinction, and migration and recolonization rates. We used PATCH simulations to evaluate long term persistence probability, i.e., the capacity for an area to support a carnivore species over 200 years, rather than transient dynamics such as time to extinction.

CONSERVATION PLANNING TECHNIQUES

A principal tool of modern conservation planning is the reserve selection algorithm (Margules and Pressey 2000). The objective is to conserve biodiversity efficiently within a network of reserves. As used here, the term "reserves" may encompass a variety of land management designations, from gazetted parks through the retention areas considered here. An efficient reserve design meets conservation objectives with a minimal investment of area by building a network from complementary sites. Many current tools, such as the SITES model used here (Possingham et al. 2000), employ heuristic algorithms to identify one or more "near-optimal" solutions that fulfill the selected goals efficiently. SITES uses a simulated annealing algorithm to reduce "cost" while maximizing attainment of conservation goals in a compact set of sites. The function SITES seeks to minimize is Cost + Species Penalty + Boundary Length, where Cost is the total monetary or area cost of all planning units selected for the network,

Species Penalty is a cost imposed for failing to meet target goals, and Boundary Length is a cost determined by the total boundary length of the network (Possingham et al. 2000). Hence, SITES attempts to select the smallest overall area needed to meet stated goals and select clustered rather than dispersed planning units. Goals were expressed as a percentage of total habitat value for a species, as derived from the RSF or conceptual model output. Because most habitat value was contained within the highest quality habitats, capturing e.g., 30% of habitat value would require far less than 30% of the total region.

If a single overall habitat goal is used for each species, SITES may locate proposed reserves entirely in the most remote portions of the large RMC study region (e.g., in the Canadian Northern Rocky Mountains). However, this solution poorly meets the goal of maintaining well-distributed and connected populations. Therefore, we stratified goals by subdividing the study area into 88 sections derived from subregional ecosection classifications (e.g., Demarchi and Lea 1992) which we modified to produce a system of sections of similar size across the study region. To balance the need for a well-distributed reserve network with the need for efficiency, we set the overall regional goal higher than the local section-level goal. For example, with a 40% regional/30% local goal, SITES sought to capture 30% of the habitat value in each section, and added another 10% of habitat value wherever in the region this could be achieved at least cost.

In addition to trying to maximize goals based on the static habitat suitability models for the eight species within the reserve network, we also sought to maximize habitat goals derived from the PATCH models for grizzly bear, wolf, and wolverine. These goals can be conceptualized as representing information on two characteristics of potential reserve locations:

their irreplaceability and vulnerability (Margules and Pressey 2000). Irreplaceability provides a quantitative measure of the relative contribution different areas make to reaching conservation goals, thus helping planners choose among alternative sites. Irreplaceability can be defined in two ways: 1) the likelihood that a particular area is needed to achieve an explicit conservation goal; or 2) the extent to which the options for achieving an explicit goal are narrowed if an area is not conserved (Margules and Pressey 2000). Irreplaceability in this context is the relative value of an area as source habitat (lambda, or population growth rate, from the PATCH model). Although measured at the scale of an individual territory, it can also be summarized at the scale of a region or of the planning units used in the SITES model (Figure 2). Source habitat is an appropriate metric because it is the key to population persistence (Pulliam 1988). Vulnerability is measured here as the predicted decline in demographic value (lambda) over the next 25 years.

SITES performed 1,000,000 iterative attempts to find the minimum cost solution per run and performed 100 such runs for each alternative conservation scenario we explored. The best (lowest cost) solution from each run of 1,000,000 iterations is reported, as well as which out of those 100 top candidates has the lowest cost. Besides identifying this latter solution, the "best run," SITES also rates areas by how often they were selected in the best solutions of the 100 alternate runs. An area that scored highly in this "summed runs" output might not be included in the best solution, but could be considered a suitable alternative site.

Our design built upon the existing protected area network by locking existing protected areas into the SITES solution, so that the program only adds planning units with targets that are missing from the current park system. Locking in protected areas recognizes that, from a practical standpoint, achieving conservation goals within protected areas is easier than adding

currently unprotected areas. SITES scenarios that build reserve networks by first including existing protected areas are generally the most informative for practical planning. However, we also analyzed the sensitivity of our results to this decision by performing additional simulations where we did not lock in existing protected areas, in order to assess the distribution of biodiversity across the landscape without regard to political boundaries.

We built an overall conservation design by starting from the best run solution from SITES and adding additional areas to serve as linkages based on information on regional population structure derived from the PATCH models. Once information on the general location of linkages was derived from PATCH, the exact location was determined using the SITES summed runs results, which identify areas that are nearly as important as those included in the best run. Setting conservation goals in a reserve selection algorithm is often difficult because information is unavailable on the threshold amount of habitat necessary to insure population viability. To address this question, we used PATCH to evaluate the adequacy of SITES scenarios with a range of potential percentage habitat goals for preserving viable carnivore populations. Based on these evaluations, we selected the habitat value goal of 40% regional/30% local as offering the best balance between efficiency (minimum area) and viability (Carroll et al. 2003).

RESULTS

PRIORITIES WITHIN THE CARIBOO-CHILCOTIN REGION

In the context of the study area boundary used in Carroll et al. (2003, 2004), the areas in the Cariboo-Chilcotin region with the greatest contribution to a network focused on preserving habitat for the eight native large and mesocarnivore species, were located on the southern edge of the study region (Figure 1a) in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area. Other priority areas were identified on the northern edge of the region surrounding Kluskoil Lake Park, as well as the Victoria/Gerimi and Mackin BMUs (Williams Lake District), and Moffat/Black Creek BMUs (Horsefly District). When protected areas were not locked into the solution, areas identified were similar, but with additional emphasis on the Blackwater River area (extending eastward to connect with a linkage area to Bowron Lake Park) and areas south and east of Itcha Ilgachuz Park (Figure 1b). Similarly, he PATCH simulations predicted that source habitat for grizzly bear (Figure 3) within the CCLUP region lies in the areas on the northwestern and southern edges of the region and on the edges of Wells-Gray and Bowron Lakes Parks.

The commonalities between the locked and non-locked solutions (Figure 1a vs. 1b) suggest that the priority areas identified, including current protected areas, are of high biological value. This is not necessarily true in other regions, as parks are usually established for diverse reasons unrelated to biodiversity and thus reserve networks starting from existing parks may be highly “inefficient” in protecting biodiversity. The larger percentage of the CCLUP region prioritized in the non-locked vs. locked solutions (Figure 1b vs. 1a) is due to the fact that the CCLUP region as a whole has higher carnivore habitat value and lower protected area

designation than most areas of the RMC study area, for example the southern Canadian Rockies (Carroll et al. 2004). Therefore, the non-locked solution increases the CCLUP region's share of priority areas, in order to more efficiently capture the areas of highest value carnivore habitat within the overall RMC study area. This is relevant to planning at the scale of the CCLUP region in that it underscores the region's value in the larger provincial context.

THE CARIBOO-CHILCOTIN REGION IN A MULTI- REGIONAL CONTEXT

Results of a preliminary analysis of habitat and viability for grizzly bear and wolf in western North America (Carroll et al. 2005b) highlight the Chilcotin region as of high importance on a continental scale, especially for wolf populations (Figure 4). This is due to the combination of relatively high productivity (in comparison to the "rock and ice" of the Canadian Mountain Parks) and relatively low levels of roads and human population (in comparison to other forested regions to the south). These two factors may also help explain why British Columbia has highest range overlap of large carnivore species in North America (Figure 5). In the PATCH analyses (Carroll et al. 2005b), habitat value is higher for wolf than grizzly bear due to relatively low topographic relief of much of the Chilcotin, which allows coursing predators such as wolves to hunt more easily than in highly rugged areas such as the southern Canadian Rockies.

DISCUSSION

RESILIENCE TO CLIMATE CHANGE

A major goal of conservation planning for the CCLUP region is to maintain the area's biodiversity values in the face of climate change and associated changes in disturbance regimes such as fire and insect outbreaks. The emerging science of "non-equilibrium" ecology has identified the potential for ecosystems that pass climatic thresholds to undergo sudden phase transitions to novel states with new species combinations and altered forest structure (Chapin et al. 2004). Ecosystems that are otherwise resilient to climate change may experience sudden transitions when exposed to both climate change and intensive human activities (Chapin et al. 2004). However, planners can use reserve design and other tools to manage forest regions to increase their resilience and ability to maintain biodiversity values in the face of these threats. The three principles of representation (establishing populations across the full array of potential habitats), resiliency (protecting populations large enough to remain viable), and redundancy (saving enough copies of those populations that some can be lost without a loss of the species) are widely invoked guidelines for ensuring conservation of threatened species, even in the face of geographically widespread threats such as climate change (Shaffer and Stein 2000). Noss (2001) considered both species and ecosystem-level biodiversity goals and recommended that planners should strive to increase representation of elevational gradients and climatic refugia in forest reserves, as well areas of importance for connectivity.

The priority areas identified in the SITES modeling meet several of these goals. Areas identified are generally large enough to hold viable populations of area-limited species such as grizzly bears and woodland caribou. Furthermore, the proposed priority areas are connected

amongst themselves and with existing protected areas. Because the SITES solutions were relatively robust to the decision to “lock in” protected areas, we can be confident that the proposed priority areas do have high biodiversity value rather than simply connecting or expanding existing reserves. For example, the priority areas centered around Itcha Ilgachuz Provincial Park protect a large area holding ecosystem types that are underrepresented elsewhere, and provide the most robust refugia for the southern mountain population of woodland caribou. Areas highlighted along the southwestern edge of the CCLUP region encompass strong elevational gradients and hence a diversity of ecosystem types, and thus may serve as climatic refugia. Although increased severity of insect outbreaks may trigger a shift in ecosystem composition due to disturbance-dependent migration of southerly tree species and other factors (Johnstone et al. 2003), many of the characteristics that give the CCLUP region high value for carnivore conservation will likely be resilient to climate change if a well-designed network of refugia can be implemented. These characteristics include large areas with low levels of direct human impacts (e.g., roads) coupled with relatively high ecosystem productivity and hence prey densities (e.g., when compared to the Canadian Mountain Parks).

THE RELEVANCE OF ISLAND BIOGEOGRAPHY

The results described here highlight the relevance of the principles of island biogeography to regional conservation planning (MacArthur and Wilson 1967). As the landscape matrix becomes developed either through human settlement or through industrial activities such as logging and its associated roads and infrastructure, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. In a subsequent analysis (Carroll et al. 2004), we used the PATCH results described above to evaluate the ability of the existing

reserve network in the RMC study area to sustain populations of grizzly bear and wolves. Comparison of habitat models between the southern, central, and northern portions of the RMC study region suggested that as the landscape matrix between reserves became more developed, only the largest and most connected reserves sustained viable carnivore populations. In the northern portion of the study area (the Cariboo-Chilcotin region and the Rockies north of Jasper Park), current reserves were, with the exception of the Tweedsmuir and Muskwa-Kechika protected areas, not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable (Carroll et al. 2004). Thus many reserves which currently hold these species were predicted to lose them unless steps were taken to increase their effective size or connectivity.

CARNIVORES AS FOCAL SPECIES

Although area and connectivity factors are especially important in conserving the carnivore species analyzed here, it is increasingly evident that carnivores may be good focal species for a larger range of biodiversity values (Ray et al. 2005). The use of particular focal species in developing regional conservation plans (Carroll et al. 2001a) complements two other major tracks of conservation planning; special elements and ecosystem representation (Noss et al. 2002). The special elements approach concentrates on occurrences of imperiled species, plant communities, and other rare natural features, as are found in conservation data center databases (Groves 2003). The representation approach seeks to capture examples of all geoclimatic or vegetation types in a network of protected areas. Ecosystem-based conservation strategies include the goal of representing all major environmental gradients. This “coarse filter” is hypothesized to capture occurrences of species about which little is known and therefore would

not be captured by the special elements or focal species approaches (Groves 2003). Carroll et al. (2003) assessed the ability of carnivore-based reserve designs to serve other conservation goals in the central Canadian Rockies. Although a reserve network based on carnivore conservation goals was poor at capturing localized rare species (special elements), it incidentally protected 76% of ecosystem types, suggesting the value of carnivore-based analyses in coarse-filter approaches. Thus the results presented here can 1) help devise effective conservation strategies for the eight focal carnivore species themselves, 2) supplement other coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and 3) highlight trends at the broader geographic scale such as the effects of loss of connectivity on a larger group of threatened species and ecosystems.

COMPARISON WITH OTHER PLANNING PROCESSES

Many regional-scale conservation planning processes have occurred in British Columbia since 1980, and diverse decision-support tools have been used. Early processes used ad-hoc approaches, but more recently, quantitative tools such as SITES (Possingham et al. 2000) have become more common. SITES has been used in numerous ecoregional plans completed by The Nature Conservancy, including the Canadian Rockies plan which was informed by the RMC project results discussed above (Rumsey et al. 2003). SITES has also been applied to the Central Coast planning process (Gonzales et al. 2003, Wells et al. 2003). Gonzales et al. (2003) used a goal-setting approach similar to that used in the RMC study, seeking to represent a proportion of all ecosystem types (Broad Ecosystem Units divided amongst Biogeoclimatic Ecosystem Classification zones). However, in contrast to our analysis, although wildlife habitat goals were incorporated, no subregional stratification was used for the wildlife goals, thus potentially

preserving less well-distributed populations. There was also no consideration of the effect of the connectivity or area of reserves on focal species viability. The resulting reserve design (Gonzales et al. 2003) thus efficiently achieves representation goals in a minimum area but proposes a system of relatively small and scattered reserves that might poorly protect species with large area requirements such as grizzly bear. In addition, unlike the PATCH model used here, the wildlife habitat suitability models used in Gonzales et al. (2003) do not gauge the vulnerability of proposed reserves to future landscape change. Based on the PATCH results for western North America (Carroll 2005), the Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may thus be key to preserving connectivity and viability of carnivore populations over a much larger region that holds the greatest remaining diversity of large carnivores in North America (Figure 5).

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FIGURES

Figure 1. Prioritization of areas for carnivore conservation in the Cariboo/Chilcotin region based on the SITES model results with 40% regional/30% local goals for capturing habitat value. Areas shown in red were included in one or more of 100 replicate SITES solutions, with darker red indicating inclusion in a larger proportion of the 100 solutions. Figure 1a shows solutions which began from inclusion of current protected areas, whereas Figure 1b shows SITES-based prioritizations that did not take into account current management status

Figure 2. Example of PATCH-based goals used in SITES runs. Areas shown in red lie in Quadrant 1 (top-right) of the irreplaceability/vulnerability graph for grizzly bear, that is, areas with both high value as source habitats and high threat. Areas shown in green are the highest value source habitats, that is, the upper portions of quadrants 1 and 2 (top-left) of the irreplaceability/vulnerability graph for grizzly bear. (Areas which meet both goals are also shown in red).

Figure 3. Potential distribution and demography of grizzly bears in the Cariboo/Chilcotin region as predicted by the PATCH model under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25%in yellow.

Figure 4. Potential distribution and demography of wolves as predicted by the PATCH model in western Canada and Alaska under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25% are shown as “low occupancy”.

Figure 5. Range overlap among ten large carnivore species in North America. Wildlife

Conservation Society Global Carnivore Program, Large Carnivore Mapping Project, used with permission.

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For
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EXECUTIVE SUMMARY

$ A regional analysis based on habitat models for eight native large and mesocarnivore species found that the areas in the Cariboo-Chilcotin region with the greatest value for carnivore conservation were located on the southern edge of the study region in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area, as well as on the northern edge of the region surrounding Kluskoil Lake Park and the larger Blackwater River area.

$ Carnivores may be good focal species for a larger range of biodiversity values. Thus the priority areas identified here can not only conserve carnivores but can also supplement coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and highlight trends at the broader geographic scale such as the effects of loss of connectivity.

$ Although they cannot utilize detailed local-scale habitat data, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying drivers of species vulnerability. As the landscape matrix becomes developed, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. Current reserves alone are generally not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable.

$ A preliminary viability analysis for grizzly bear and wolf in western North America highlighted the Chilcotin region as of high importance on a continental scale, especially for wolf populations, due to the combination of relatively high productivity (in comparison to the Canadian Mountain Parks) and relatively low levels of roads and

human population (in comparison to other forested regions to the south). These characteristics will likely be resilient to climate change if a well-designed network of refugia can be implemented.

$ The Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may be key to preserving connectivity and viability of carnivore populations over a larger region of western Canada that holds the greatest remaining diversity of large carnivores in North America.

"Human activities combined with climatic change can precipitate ecological changes of much greater magnitude than would be expected from climatic changes alone... continuation of recent climate warming trends and/or intensification of forest management could lead to rapid irreversible vegetation changes within boreal forests that are not readily predicted from our observations of their current dynamics." Chapin et al. 2004

INTRODUCTION

Over the next half-century, anthropogenic climate change is predicted to dramatically alter the composition and structure of ecosystems worldwide. Climate change not only impacts ecosystems through gradual trends in temperature or precipitation but also through disturbance events such as insect outbreaks and forest fires. The speed and widespread nature of these disturbances will challenge the ability of species to persist by means of gradual shifts in distribution. Many areas of the boreal and subboreal forest, including the Cariboo-Chilcotin region of central British Columbia, are currently experiencing widespread mortality from pine and spruce bark beetle outbreaks linked to unusually warm winters (Safranyik 1990, Carroll 2001). In order to utilize the beetle-killed trees while they are still commercially valuable, the forest industry is proposing to accelerate cut levels substantially across the Cariboo-Chilcotin region, compressing 40 to 60 years of harvest into the next 15 years. This level of harvest has the potential to greatly alter ecosystems across the region and lessen their resilience to the effects of ecosystem stressors linked to climate change, such as altered rainfall patterns, insect and disease outbreaks.

Although the boreal and subboreal forest is not as speciose as tropical biodiversity "hotspots", planners increasingly recognize the important role of these and other "coldspots" in

sustaining global ecosystem processes and populations of area-limited species (Kareiva and Marvier 2003). Two types of measures can be taken to increase the resilience of biodiversity values in the Cariboo-Chilcotin region to climate change and other ecosystem stressors. Site-level prescriptions and fine-scale riparian and old-growth management areas can help mitigate impacts of accelerated timber harvest on a local scale. However, the widespread nature of the beetle outbreak and subsequent logging also requires regional-scale planning to identify retention areas that will not be salvage-logged even if they are attacked by mountain pine beetles. If these retention areas are distributed based on the principles of conservation planning, they can mitigate, to an extent, the effect of accelerated harvest on ecosystem processes that operate over large areas and upon species with large area and connectivity requirements for viable populations, such as grizzly bear (Ursus arctos) and woodland caribou (Rangifer tarandus caribou). In turn, wide-ranging species such as large carnivores can serve as focal and indicator species to help plan and evaluate the adequacy of the conservation measures such as the proposed retention areas (Lambeck 1997). This is because these species' stringent area and connectivity requirements make factors affecting their viability illustrative of the link between larger regional processes and biodiversity at the local scale (Carroll et al. 2001). In this report, I summarize lessons from a systematic reserve design study focusing on conservation of native carnivore species (Carroll et al. 2003, 2004), and suggest how these results can help inform retention area planning for the Cariboo-Chilcotin region.

METHODS

MODELING TECHNIQUES

The purpose of the Rocky Mountain Carnivore (RMC) Research Project (Carroll et al. 2001, 2003, 2004), sponsored by World Wildlife Fund-Canada with assistance from The Nature Conservancy, the Wilburforce Foundation and other groups, was to develop the data necessary to support long-term conservation of a broad suite of native carnivore species across a large portion of their range in the northern U.S. and Canada. The RMC study considered the habitat needs of eight native carnivore species - grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), gray wolf (*Canis lupus*), lynx (*Lynx canadensis*), mountain lion (*Puma concolor*), wolverine (*Gulo gulo*), fisher (*Martes pennanti*), and marten (*Martes americana*). The RMC analysis encompassed a study area stretching along the Rocky Mountains of Canada and the United States from the Yukon/British Columbia border to the Greater Yellowstone Ecosystem, and extending westward to encompass the Fraser Plateau.

The RMC study area covers most of the Cariboo Chilcotin Land Use Plan (CCLUP) area, except for a strip along the southwestern margin of the CCLUP (Figure 1). However, it is important to recognize that conservation priorities derived from any planning process are to some extent a function of the planning region's boundaries. For example, a planning exercise for the CCLUP region alone might prioritize regionally-rare ecosystem types that would be lower priorities in a province-wide plan. Because of its large extent, the RMC results are most informative at a large geographic scale that spans many ecoregions. However, we anticipated this scale issue by incorporating the principle of representation into the priority-setting process. As detailed below, we sought to capture a proportion of the best carnivore habitat within each of the

ecosection-based subunits of the larger study area. This insured that a geographically-widespread population, containing uniquely-adapted ecotypes, could be protected by the resulting conservation network, and increased the relevance of our results to ecoregional-scale planning processes.

We (the author of this document and his co-authors on the RMC study) created empirical models - resource selection functions (RSF) (Manly et al. 1993) - for the four species for which we had detailed survey data: black bear, lynx, wolverine, and fisher. Details of these models are presented in Carroll et al. (2001a,2002,2003). For example, we created conceptual models for the grizzly bear, wolf, marten, and mountain lion based on published information on species-habitat associations. The conceptual models for the grizzly bear (Carroll et al. 2001a) and wolf (Carroll et al. 2001b, 2003) combined surrogates of productivity, as measured by a satellite-imagery derived metric (tasselled-cap greenness (Crist and Cicone 1984)), and human-associated mortality risk, as measured by road density and human population (Merrill et al. 1999). Topography was an additional component of the wolf model (Carroll et al. 2001b, 2003). Because the analysis covered a very large and ecologically diverse region, the GIS models for fecundity and survival for grizzly bear and wolf used very general habitat data that is available in every province and state. This is a lesser problem for the survival input layer, because roads and human population have a similar negative effect on large carnivore survival in diverse habitats (e.g., Thiel 1985, Fuller et al. 2003). Estimating large carnivore fecundity (reproductive rates) across such a large region is more difficult. Although they cannot utilize the more detailed habitat data available at the local scale, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying

drivers of species vulnerability that can make conservation policy more effective.

After developing the static habitat suitability models, we performed population viability analyses using the program PATCH (Schumaker 1998). PATCH is a spatially-explicit population model that links the survival and fecundity of individual animals to GIS data on mortality risk and habitat productivity measured at the location of the individual or pack territory. The model tracks the demographics of the population through time as individuals are born, disperse, reproduce, and die, predicting population size, time to extinction, and migration and recolonization rates. We used PATCH simulations to evaluate long term persistence probability, i.e., the capacity for an area to support a carnivore species over 200 years, rather than transient dynamics such as time to extinction.

CONSERVATION PLANNING TECHNIQUES

A principal tool of modern conservation planning is the reserve selection algorithm (Margules and Pressey 2000). The objective is to conserve biodiversity efficiently within a network of reserves. As used here, the term “reserves” may encompass a variety of land management designations, from gazetted parks through the retention areas considered here. An efficient reserve design meets conservation objectives with a minimal investment of area by building a network from complementary sites. Many current tools, such as the SITES model used here (Possingham et al. 2000), employ heuristic algorithms to identify one or more “near-optimal” solutions that fulfill the selected goals efficiently. SITES uses a simulated annealing algorithm to reduce “cost” while maximizing attainment of conservation goals in a compact set of sites. The function SITES seeks to minimize is Cost + Species Penalty + Boundary Length, where Cost is the total monetary or area cost of all planning units selected for the network,

Species Penalty is a cost imposed for failing to meet target goals, and Boundary Length is a cost determined by the total boundary length of the network (Possingham et al. 2000). Hence, SITES attempts to select the smallest overall area needed to meet stated goals and select clustered rather than dispersed planning units. Goals were expressed as a percentage of total habitat value for a species, as derived from the RSF or conceptual model output. Because most habitat value was contained within the highest quality habitats, capturing e.g., 30% of habitat value would require far less than 30% of the total region.

If a single overall habitat goal is used for each species, SITES may locate proposed reserves entirely in the most remote portions of the large RMC study region (e.g., in the Canadian Northern Rocky Mountains). However, this solution poorly meets the goal of maintaining well-distributed and connected populations. Therefore, we stratified goals by subdividing the study area into 88 sections derived from subregional ecosection classifications (e.g., Demarchi and Lea 1992) which we modified to produce a system of sections of similar size across the study region. To balance the need for a well-distributed reserve network with the need for efficiency, we set the overall regional goal higher than the local section-level goal. For example, with a 40% regional/30% local goal, SITES sought to capture 30% of the habitat value in each section, and added another 10% of habitat value wherever in the region this could be achieved at least cost.

In addition to trying to maximize goals based on the static habitat suitability models for the eight species within the reserve network, we also sought to maximize habitat goals derived from the PATCH models for grizzly bear, wolf, and wolverine. These goals can be conceptualized as representing information on two characteristics of potential reserve locations:

their irreplaceability and vulnerability (Margules and Pressey 2000). Irreplaceability provides a quantitative measure of the relative contribution different areas make to reaching conservation goals, thus helping planners choose among alternative sites. Irreplaceability can be defined in two ways: 1) the likelihood that a particular area is needed to achieve an explicit conservation goal; or 2) the extent to which the options for achieving an explicit goal are narrowed if an area is not conserved (Margules and Pressey 2000). Irreplaceability in this context is the relative value of an area as source habitat (lambda, or population growth rate, from the PATCH model). Although measured at the scale of an individual territory, it can also be summarized at the scale of a region or of the planning units used in the SITES model (Figure 2). Source habitat is an appropriate metric because it is the key to population persistence (Pulliam 1988). Vulnerability is measured here as the predicted decline in demographic value (lambda) over the next 25 years.

SITES performed 1,000,000 iterative attempts to find the minimum cost solution per run and performed 100 such runs for each alternative conservation scenario we explored. The best (lowest cost) solution from each run of 1,000,000 iterations is reported, as well as which out of those 100 top candidates has the lowest cost. Besides identifying this latter solution, the "best run," SITES also rates areas by how often they were selected in the best solutions of the 100 alternate runs. An area that scored highly in this "summed runs" output might not be included in the best solution, but could be considered a suitable alternative site.

Our design built upon the existing protected area network by locking existing protected areas into the SITES solution, so that the program only adds planning units with targets that are missing from the current park system. Locking in protected areas recognizes that, from a practical standpoint, achieving conservation goals within protected areas is easier than adding

currently unprotected areas. SITES scenarios that build reserve networks by first including existing protected areas are generally the most informative for practical planning. However, we also analyzed the sensitivity of our results to this decision by performing additional simulations where we did not lock in existing protected areas, in order to assess the distribution of biodiversity across the landscape without regard to political boundaries.

We built an overall conservation design by starting from the best run solution from SITES and adding additional areas to serve as linkages based on information on regional population structure derived from the PATCH models. Once information on the general location of linkages was derived from PATCH, the exact location was determined using the SITES summed runs results, which identify areas that are nearly as important as those included in the best run. Setting conservation goals in a reserve selection algorithm is often difficult because information is unavailable on the threshold amount of habitat necessary to insure population viability. To address this question, we used PATCH to evaluate the adequacy of SITES scenarios with a range of potential percentage habitat goals for preserving viable carnivore populations. Based on these evaluations, we selected the habitat value goal of 40% regional/30% local as offering the best balance between efficiency (minimum area) and viability (Carroll et al. 2003).

RESULTS

PRIORITIES WITHIN THE CARIBOO-CHILCOTIN REGION

In the context of the study area boundary used in Carroll et al. (2003, 2004), the areas in the Cariboo-Chilcotin region with the greatest contribution to a network focused on preserving habitat for the eight native large and mesocarnivore species, were located on the southern edge of the study region (Figure 1a) in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area. Other priority areas were identified on the northern edge of the region surrounding Kluskoil Lake Park, as well as the Victoria/Gerimi and Mackin BMUs (Williams Lake District), and Moffat/Black Creek BMUs (Horsefly District). When protected areas were not locked into the solution, areas identified were similar, but with additional emphasis on the Blackwater River area (extending eastward to connect with a linkage area to Bowron Lake Park) and areas south and east of Itcha Ilgachuz Park (Figure 1b). Similarly, he PATCH simulations predicted that source habitat for grizzly bear (Figure 3) within the CCLUP region lies in the areas on the northwestern and southern edges of the region and on the edges of Wells-Gray and Bowron Lakes Parks.

The commonalities between the locked and non-locked solutions (Figure 1a vs. 1b) suggest that the priority areas identified, including current protected areas, are of high biological value. This is not necessarily true in other regions, as parks are usually established for diverse reasons unrelated to biodiversity and thus reserve networks starting from existing parks may be highly “inefficient” in protecting biodiversity. The larger percentage of the CCLUP region prioritized in the non-locked vs. locked solutions (Figure 1b vs. 1a) is due to the fact that the CCLUP region as a whole has higher carnivore habitat value and lower protected area

designation than most areas of the RMC study area, for example the southern Canadian Rockies (Carroll et al. 2004). Therefore, the non-locked solution increases the CCLUP region's share of priority areas, in order to more efficiently capture the areas of highest value carnivore habitat within the overall RMC study area. This is relevant to planning at the scale of the CCLUP region in that it underscores the region's value in the larger provincial context.

THE CARIBOO-CHILCOTIN REGION IN A MULTI- REGIONAL CONTEXT

Results of a preliminary analysis of habitat and viability for grizzly bear and wolf in western North America (Carroll et al. 2005b) highlight the Chilcotin region as of high importance on a continental scale, especially for wolf populations (Figure 4). This is due to the combination of relatively high productivity (in comparison to the "rock and ice" of the Canadian Mountain Parks) and relatively low levels of roads and human population (in comparison to other forested regions to the south). These two factors may also help explain why British Columbia has highest range overlap of large carnivore species in North America (Figure 5). In the PATCH analyses (Carroll et al. 2005b), habitat value is higher for wolf than grizzly bear due to relatively low topographic relief of much of the Chilcotin, which allows coursing predators such as wolves to hunt more easily than in highly rugged areas such as the southern Canadian Rockies.

DISCUSSION

RESILIENCE TO CLIMATE CHANGE

A major goal of conservation planning for the CCLUP region is to maintain the area's biodiversity values in the face of climate change and associated changes in disturbance regimes such as fire and insect outbreaks. The emerging science of "non-equilibrium" ecology has identified the potential for ecosystems that pass climatic thresholds to undergo sudden phase transitions to novel states with new species combinations and altered forest structure (Chapin et al. 2004). Ecosystems that are otherwise resilient to climate change may experience sudden transitions when exposed to both climate change and intensive human activities (Chapin et al. 2004). However, planners can use reserve design and other tools to manage forest regions to increase their resilience and ability to maintain biodiversity values in the face of these threats. The three principles of representation (establishing populations across the full array of potential habitats), resiliency (protecting populations large enough to remain viable), and redundancy (saving enough copies of those populations that some can be lost without a loss of the species) are widely invoked guidelines for ensuring conservation of threatened species, even in the face of geographically widespread threats such as climate change (Shaffer and Stein 2000). Noss (2001) considered both species and ecosystem-level biodiversity goals and recommended that planners should strive to increase representation of elevational gradients and climatic refugia in forest reserves, as well areas of importance for connectivity.

The priority areas identified in the SITES modeling meet several of these goals. Areas identified are generally large enough to hold viable populations of area-limited species such as grizzly bears and woodland caribou. Furthermore, the proposed priority areas are connected

amongst themselves and with existing protected areas. Because the SITES solutions were relatively robust to the decision to "lock in" protected areas, we can be confident that the proposed priority areas do have high biodiversity value rather than simply connecting or expanding existing reserves. For example, the priority areas centered around Itcha Ilgachuz Provincial Park protect a large area holding ecosystem types that are underrepresented elsewhere, and provide the most robust refugia for the southern mountain population of woodland caribou. Areas highlighted along the southwestern edge of the CCLUP region encompass strong elevational gradients and hence a diversity of ecosystem types, and thus may serve as climatic refugia. Although increased severity of insect outbreaks may trigger a shift in ecosystem composition due to disturbance-dependent migration of southerly tree species and other factors (Johnstone et al. 2003), many of the characteristics that give the CCLUP region high value for carnivore conservation will likely be resilient to climate change if a well-designed network of refugia can be implemented. These characteristics include large areas with low levels of direct human impacts (e.g., roads) coupled with relatively high ecosystem productivity and hence prey densities (e.g., when compared to the Canadian Mountain Parks).

THE RELEVANCE OF ISLAND BIOGEOGRAPHY

The results described here highlight the relevance of the principles of island biogeography to regional conservation planning (MacArthur and Wilson 1967). As the landscape matrix becomes developed either through human settlement or through industrial activities such as logging and its associated roads and infrastructure, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. In a subsequent analysis (Carroll et al. 2004), we used the PATCH results described above to evaluate the ability of the existing

reserve network in the RMC study area to sustain populations of grizzly bear and wolves. Comparison of habitat models between the southern, central, and northern portions of the RMC study region suggested that as the landscape matrix between reserves became more developed, only the largest and most connected reserves sustained viable carnivore populations. In the northern portion of the study area (the Cariboo-Chilcotin region and the Rockies north of Jasper Park), current reserves were, with the exception of the Tweedsmuir and Muskwa-Kechika protected areas, not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable (Carroll et al. 2004). Thus many reserves which currently hold these species were predicted to lose them unless steps were taken to increase their effective size or connectivity.

CARNIVORES AS FOCAL SPECIES

Although area and connectivity factors are especially important in conserving the carnivore species analyzed here, it is increasingly evident that carnivores may be good focal species for a larger range of biodiversity values (Ray et al. 2005). The use of particular focal species in developing regional conservation plans (Carroll et al. 2001a) complements two other major tracks of conservation planning; special elements and ecosystem representation (Noss et al. 2002). The special elements approach concentrates on occurrences of imperiled species, plant communities, and other rare natural features, as are found in conservation data center databases (Groves 2003). The representation approach seeks to capture examples of all geoclimatic or vegetation types in a network of protected areas. Ecosystem-based conservation strategies include the goal of representing all major environmental gradients. This “coarse filter” is hypothesized to capture occurrences of species about which little is known and therefore would

not be captured by the special elements or focal species approaches (Groves 2003). Carroll et al. (2003) assessed the ability of carnivore-based reserve designs to serve other conservation goals in the central Canadian Rockies. Although a reserve network based on carnivore conservation goals was poor at capturing localized rare species (special elements), it incidentally protected 76% of ecosystem types, suggesting the value of carnivore-based analyses in coarse-filter approaches. Thus the results presented here can 1) help devise effective conservation strategies for the eight focal carnivore species themselves, 2) supplement other coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and 3) highlight trends at the broader geographic scale such as the effects of loss of connectivity on a larger group of threatened species and ecosystems.

COMPARISON WITH OTHER PLANNING PROCESSES

Many regional-scale conservation planning processes have occurred in British Columbia since 1980, and diverse decision-support tools have been used. Early processes used ad-hoc approaches, but more recently, quantitative tools such as SITES (Possingham et al. 2000) have become more common. SITES has been used in numerous ecoregional plans completed by The Nature Conservancy, including the Canadian Rockies plan which was informed by the RMC project results discussed above (Rumsey et al. 2003). SITES has also been applied to the Central Coast planning process (Gonzales et al. 2003, Wells et al. 2003). Gonzales et al. (2003) used a goal-setting approach similar to that used in the RMC study, seeking to represent a proportion of all ecosystem types (Broad Ecosystem Units divided amongst Biogeoclimatic Ecosystem Classification zones). However, in contrast to our analysis, although wildlife habitat goals were incorporated, no subregional stratification was used for the wildlife goals, thus potentially

preserving less well-distributed populations. There was also no consideration of the effect of the connectivity or area of reserves on focal species viability. The resulting reserve design (Gonzales et al. 2003) thus efficiently achieves representation goals in a minimum area but proposes a system of relatively small and scattered reserves that might poorly protect species with large area requirements such as grizzly bear. In addition, unlike the PATCH model used here, the wildlife habitat suitability models used in Gonzales et al. (2003) do not gauge the vulnerability of proposed reserves to future landscape change. Based on the PATCH results for western North America (Carroll 2005), the Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may thus be key to preserving connectivity and viability of carnivore populations over a much larger region that holds the greatest remaining diversity of large carnivores in North America (Figure 5).

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FIGURES

Figure 1. Prioritization of areas for carnivore conservation in the Cariboo/Chilcotin region based on the SITES model results with 40% regional/30% local goals for capturing habitat value. Areas shown in red were included in one or more of 100 replicate SITES solutions, with darker red indicating inclusion in a larger proportion of the 100 solutions. Figure 1a shows solutions which began from inclusion of current protected areas, whereas Figure 1b shows SITES-based prioritizations that did not take into account current management status

Figure 2. Example of PATCH-based goals used in SITES runs. Areas shown in red lie in Quadrant 1 (top-right) of the irreplaceability/vulnerability graph for grizzly bear, that is, areas with both high value as source habitats and high threat. Areas shown in green are the highest value source habitats, that is, the upper portions of quadrants 1 and 2 (top-left) of the irreplaceability/vulnerability graph for grizzly bear. (Areas which meet both goals are also shown in red).

Figure 3. Potential distribution and demography of grizzly bears in the Cariboo/Chilcotin region as predicted by the PATCH model under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25%in yellow.

Figure 4. Potential distribution and demography of wolves as predicted by the PATCH model in western Canada and Alaska under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25% are shown as “low occupancy”.

Figure 5. Range overlap among ten large carnivore species in North America. Wildlife

Conservation Society Global Carnivore Program, Large Carnivore Mapping Project, used with permission.

PRIORITIES FOR CARNIVORE CONSERVATION IN THE CARIBOO-CHILCOTIN REGION

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EXECUTIVE SUMMARY

$ A regional analysis based on habitat models for eight native large and mesocarnivore species found that the areas in the Cariboo-Chilcotin region with the greatest value for carnivore conservation were located on the southern edge of the study region in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area, as well as on the northern edge of the region surrounding Kluskoil Lake Park and the larger Blackwater River area.

$ Carnivores may be good focal species for a larger range of biodiversity values. Thus the priority areas identified here can not only conserve carnivores but can also supplement coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and highlight trends at the broader geographic scale such as the effects of loss of connectivity.

$ Although they cannot utilize detailed local-scale habitat data, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying drivers of species vulnerability. As the landscape matrix becomes developed, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. Current reserves alone are generally not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable.

$ A preliminary viability analysis for grizzly bear and wolf in western North America highlighted the Chilcotin region as of high importance on a continental scale, especially for wolf populations, due to the combination of relatively high productivity (in comparison to the Canadian Mountain Parks) and relatively low levels of roads and

human population (in comparison to other forested regions to the south). These characteristics will likely be resilient to climate change if a well-designed network of refugia can be implemented.

$ The Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may be key to preserving connectivity and viability of carnivore populations over a larger region of western Canada that holds the greatest remaining diversity of large carnivores in North America.

“Human activities combined with climatic change can precipitate ecological changes of much greater magnitude than would be expected from climatic changes alone... continuation of recent climate warming trends and/or intensification of forest management could lead to rapid irreversible vegetation changes within boreal forests that are not readily predicted from our observations of their current dynamics.” Chapin et al. 2004

INTRODUCTION

Over the next half-century, anthropogenic climate change is predicted to dramatically alter the composition and structure of ecosystems worldwide. Climate change not only impacts ecosystems through gradual trends in temperature or precipitation but also through disturbance events such as insect outbreaks and forest fires. The speed and widespread nature of these disturbances will challenge the ability of species to persist by means of gradual shifts in distribution. Many areas of the boreal and subboreal forest, including the Cariboo-Chilcotin region of central British Columbia, are currently experiencing widespread mortality from pine and spruce bark beetle outbreaks linked to unusually warm winters (Safranyik 1990, Carroll 2001). In order to utilize the beetle-killed trees while they are still commercially valuable, the forest industry is proposing to accelerate cut levels substantially across the Cariboo-Chilcotin region, compressing 40 to 60 years of harvest into the next 15 years. This level of harvest has the potential to greatly alter ecosystems across the region and lessen their resilience to the effects of ecosystem stressors linked to climate change, such as altered rainfall patterns, insect and disease outbreaks.

Although the boreal and subboreal forest is not as speciose as tropical biodiversity “hotspots”, planners increasingly recognize the important role of these and other “coldspots” in

sustaining global ecosystem processes and populations of area-limited species (Kareiva and Marvier 2003). Two types of measures can be taken to increase the resilience of biodiversity values in the Cariboo-Chilcotin region to climate change and other ecosystem stressors. Site-level prescriptions and fine-scale riparian and old-growth management areas can help mitigate impacts of accelerated timber harvest on a local scale. However, the widespread nature of the beetle outbreak and subsequent logging also requires regional-scale planning to identify retention areas that will not be salvage-logged even if they are attacked by mountain pine beetles. If these retention areas are distributed based on the principles of conservation planning, they can mitigate, to an extent, the effect of accelerated harvest on ecosystem processes that operate over large areas and upon species with large area and connectivity requirements for viable populations, such as grizzly bear (Ursus arctos) and woodland caribou (Rangifer tarandus caribou). In turn, wide-ranging species such as large carnivores can serve as focal and indicator species to help plan and evaluate the adequacy of the conservation measures such as the proposed retention areas (Lambeck 1997). This is because these species' stringent area and connectivity requirements make factors affecting their viability illustrative of the link between larger regional processes and biodiversity at the local scale (Carroll et al. 2001). In this report, I summarize lessons from a systematic reserve design study focusing on conservation of native carnivore species (Carroll et al. 2003, 2004), and suggest how these results can help inform retention area planning for the Cariboo-Chilcotin region.

METHODS

MODELING TECHNIQUES

The purpose of the Rocky Mountain Carnivore (RMC) Research Project (Carroll et al. 2001, 2003, 2004), sponsored by World Wildlife Fund-Canada with assistance from The Nature Conservancy, the Wilburforce Foundation and other groups, was to develop the data necessary to support long-term conservation of a broad suite of native carnivore species across a large portion of their range in the northern U.S. and Canada. The RMC study considered the habitat needs of eight native carnivore species - grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), gray wolf (*Canis lupus*), lynx (*Lynx canadensis*), mountain lion (*Puma concolor*), wolverine (*Gulo gulo*), fisher (*Martes pennanti*), and marten (*Martes americana*). The RMC analysis encompassed a study area stretching along the Rocky Mountains of Canada and the United States from the Yukon/British Columbia border to the Greater Yellowstone Ecosystem, and extending westward to encompass the Fraser Plateau.

The RMC study area covers most of the Cariboo Chilcotin Land Use Plan (CCLUP) area, except for a strip along the southwestern margin of the CCLUP (Figure 1). However, it is important to recognize that conservation priorities derived from any planning process are to some extent a function of the planning region's boundaries. For example, a planning exercise for the CCLUP region alone might prioritize regionally-rare ecosystem types that would be lower priorities in a province-wide plan. Because of its large extent, the RMC results are most informative at a large geographic scale that spans many ecoregions. However, we anticipated this scale issue by incorporating the principle of representation into the priority-setting process. As detailed below, we sought to capture a proportion of the best carnivore habitat within each of the

ecosection-based subunits of the larger study area. This insured that a geographically-widespread population, containing uniquely-adapted ecotypes, could be protected by the resulting conservation network, and increased the relevance of our results to ecoregional-scale planning processes.

We (the author of this document and his co-authors on the RMC study) created empirical models - resource selection functions (RSF) (Manly et al. 1993) - for the four species for which we had detailed survey data: black bear, lynx, wolverine, and fisher. Details of these models are presented in Carroll et al. (2001a,2002,2003). For example, we created conceptual models for the grizzly bear, wolf, marten, and mountain lion based on published information on species-habitat associations. The conceptual models for the grizzly bear (Carroll et al. 2001a) and wolf (Carroll et al. 2001b, 2003) combined surrogates of productivity, as measured by a satellite-imagery derived metric (tasselled-cap greenness (Crist and Cicone 1984)), and human-associated mortality risk, as measured by road density and human population (Merrill et al. 1999). Topography was an additional component of the wolf model (Carroll et al. 2001b, 2003). Because the analysis covered a very large and ecologically diverse region, the GIS models for fecundity and survival for grizzly bear and wolf used very general habitat data that is available in every province and state. This is a lesser problem for the survival input layer, because roads and human population have a similar negative effect on large carnivore survival in diverse habitats (e.g., Thiel 1985, Fuller et al. 2003). Estimating large carnivore fecundity (reproductive rates) across such a large region is more difficult. Although they cannot utilize the more detailed habitat data available at the local scale, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying

drivers of species vulnerability that can make conservation policy more effective.

After developing the static habitat suitability models, we performed population viability analyses using the program PATCH (Schumaker 1998). PATCH is a spatially-explicit population model that links the survival and fecundity of individual animals to GIS data on mortality risk and habitat productivity measured at the location of the individual or pack territory. The model tracks the demographics of the population through time as individuals are born, disperse, reproduce, and die, predicting population size, time to extinction, and migration and recolonization rates. We used PATCH simulations to evaluate long term persistence probability, i.e., the capacity for an area to support a carnivore species over 200 years, rather than transient dynamics such as time to extinction.

CONSERVATION PLANNING TECHNIQUES

A principal tool of modern conservation planning is the reserve selection algorithm (Margules and Pressey 2000). The objective is to conserve biodiversity efficiently within a network of reserves. As used here, the term “reserves” may encompass a variety of land management designations, from gazetted parks through the retention areas considered here. An efficient reserve design meets conservation objectives with a minimal investment of area by building a network from complementary sites. Many current tools, such as the SITES model used here (Possingham et al. 2000), employ heuristic algorithms to identify one or more “near-optimal” solutions that fulfill the selected goals efficiently. SITES uses a simulated annealing algorithm to reduce “cost” while maximizing attainment of conservation goals in a compact set of sites. The function SITES seeks to minimize is Cost + Species Penalty + Boundary Length, where Cost is the total monetary or area cost of all planning units selected for the network,

Species Penalty is a cost imposed for failing to meet target goals, and Boundary Length is a cost determined by the total boundary length of the network (Possingham et al. 2000). Hence, SITES attempts to select the smallest overall area needed to meet stated goals and select clustered rather than dispersed planning units. Goals were expressed as a percentage of total habitat value for a species, as derived from the RSF or conceptual model output. Because most habitat value was contained within the highest quality habitats, capturing e.g., 30% of habitat value would require far less than 30% of the total region.

If a single overall habitat goal is used for each species, SITES may locate proposed reserves entirely in the most remote portions of the large RMC study region (e.g., in the Canadian Northern Rocky Mountains). However, this solution poorly meets the goal of maintaining well-distributed and connected populations. Therefore, we stratified goals by subdividing the study area into 88 sections derived from subregional ecosection classifications (e.g., Demarchi and Lea 1992) which we modified to produce a system of sections of similar size across the study region. To balance the need for a well-distributed reserve network with the need for efficiency, we set the overall regional goal higher than the local section-level goal. For example, with a 40% regional/30% local goal, SITES sought to capture 30% of the habitat value in each section, and added another 10% of habitat value wherever in the region this could be achieved at least cost.

In addition to trying to maximize goals based on the static habitat suitability models for the eight species within the reserve network, we also sought to maximize habitat goals derived from the PATCH models for grizzly bear, wolf, and wolverine. These goals can be conceptualized as representing information on two characteristics of potential reserve locations:

their irreplaceability and vulnerability (Margules and Pressey 2000). Irreplaceability provides a quantitative measure of the relative contribution different areas make to reaching conservation goals, thus helping planners choose among alternative sites. Irreplaceability can be defined in two ways: 1) the likelihood that a particular area is needed to achieve an explicit conservation goal; or 2) the extent to which the options for achieving an explicit goal are narrowed if an area is not conserved (Margules and Pressey 2000). Irreplaceability in this context is the relative value of an area as source habitat (lambda, or population growth rate, from the PATCH model). Although measured at the scale of an individual territory, it can also be summarized at the scale of a region or of the planning units used in the SITES model (Figure 2). Source habitat is an appropriate metric because it is the key to population persistence (Pulliam 1988). Vulnerability is measured here as the predicted decline in demographic value (lambda) over the next 25 years.

SITES performed 1,000,000 iterative attempts to find the minimum cost solution per run and performed 100 such runs for each alternative conservation scenario we explored. The best (lowest cost) solution from each run of 1,000,000 iterations is reported, as well as which out of those 100 top candidates has the lowest cost. Besides identifying this latter solution, the "best run," SITES also rates areas by how often they were selected in the best solutions of the 100 alternate runs. An area that scored highly in this "summed runs" output might not be included in the best solution, but could be considered a suitable alternative site.

Our design built upon the existing protected area network by locking existing protected areas into the SITES solution, so that the program only adds planning units with targets that are missing from the current park system. Locking in protected areas recognizes that, from a practical standpoint, achieving conservation goals within protected areas is easier than adding

currently unprotected areas. SITES scenarios that build reserve networks by first including existing protected areas are generally the most informative for practical planning. However, we also analyzed the sensitivity of our results to this decision by performing additional simulations where we did not lock in existing protected areas, in order to assess the distribution of biodiversity across the landscape without regard to political boundaries.

We built an overall conservation design by starting from the best run solution from SITES and adding additional areas to serve as linkages based on information on regional population structure derived from the PATCH models. Once information on the general location of linkages was derived from PATCH, the exact location was determined using the SITES summed runs results, which identify areas that are nearly as important as those included in the best run. Setting conservation goals in a reserve selection algorithm is often difficult because information is unavailable on the threshold amount of habitat necessary to insure population viability. To address this question, we used PATCH to evaluate the adequacy of SITES scenarios with a range of potential percentage habitat goals for preserving viable carnivore populations. Based on these evaluations, we selected the habitat value goal of 40% regional/30% local as offering the best balance between efficiency (minimum area) and viability (Carroll et al. 2003).

RESULTS

PRIORITIES WITHIN THE CARIBOO-CHILCOTIN REGION

In the context of the study area boundary used in Carroll et al. (2003, 2004), the areas in the Cariboo-Chilcotin region with the greatest contribution to a network focused on preserving habitat for the eight native large and mesocarnivore species, were located on the southern edge of the study region (Figure 1a) in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area. Other priority areas were identified on the northern edge of the region surrounding Kluskoil Lake Park, as well as the Victoria/Gerimi and Mackin BMUs (Williams Lake District), and Moffat/Black Creek BMUs (Horsefly District). When protected areas were not locked into the solution, areas identified were similar, but with additional emphasis on the Blackwater River area (extending eastward to connect with a linkage area to Bowron Lake Park) and areas south and east of Itcha Ilgachuz Park (Figure 1b). Similarly, he PATCH simulations predicted that source habitat for grizzly bear (Figure 3) within the CCLUP region lies in the areas on the northwestern and southern edges of the region and on the edges of Wells-Gray and Bowron Lakes Parks.

The commonalities between the locked and non-locked solutions (Figure 1a vs. 1b) suggest that the priority areas identified, including current protected areas, are of high biological value. This is not necessarily true in other regions, as parks are usually established for diverse reasons unrelated to biodiversity and thus reserve networks starting from existing parks may be highly “inefficient” in protecting biodiversity. The larger percentage of the CCLUP region prioritized in the non-locked vs. locked solutions (Figure 1b vs. 1a) is due to the fact that the CCLUP region as a whole has higher carnivore habitat value and lower protected area

designation than most areas of the RMC study area, for example the southern Canadian Rockies (Carroll et al. 2004). Therefore, the non-locked solution increases the CCLUP region's share of priority areas, in order to more efficiently capture the areas of highest value carnivore habitat within the overall RMC study area. This is relevant to planning at the scale of the CCLUP region in that it underscores the region's value in the larger provincial context.

THE CARIBOO-CHILCOTIN REGION IN A MULTI- REGIONAL CONTEXT

Results of a preliminary analysis of habitat and viability for grizzly bear and wolf in western North America (Carroll et al. 2005b) highlight the Chilcotin region as of high importance on a continental scale, especially for wolf populations (Figure 4). This is due to the combination of relatively high productivity (in comparison to the "rock and ice" of the Canadian Mountain Parks) and relatively low levels of roads and human population (in comparison to other forested regions to the south). These two factors may also help explain why British Columbia has highest range overlap of large carnivore species in North America (Figure 5). In the PATCH analyses (Carroll et al. 2005b), habitat value is higher for wolf than grizzly bear due to relatively low topographic relief of much of the Chilcotin, which allows coursing predators such as wolves to hunt more easily than in highly rugged areas such as the southern Canadian Rockies.

DISCUSSION

RESILIENCE TO CLIMATE CHANGE

A major goal of conservation planning for the CCLUP region is to maintain the area's biodiversity values in the face of climate change and associated changes in disturbance regimes such as fire and insect outbreaks. The emerging science of "non-equilibrium" ecology has identified the potential for ecosystems that pass climatic thresholds to undergo sudden phase transitions to novel states with new species combinations and altered forest structure (Chapin et al. 2004). Ecosystems that are otherwise resilient to climate change may experience sudden transitions when exposed to both climate change and intensive human activities (Chapin et al. 2004). However, planners can use reserve design and other tools to manage forest regions to increase their resilience and ability to maintain biodiversity values in the face of these threats. The three principles of representation (establishing populations across the full array of potential habitats), resiliency (protecting populations large enough to remain viable), and redundancy (saving enough copies of those populations that some can be lost without a loss of the species) are widely invoked guidelines for ensuring conservation of threatened species, even in the face of geographically widespread threats such as climate change (Shaffer and Stein 2000). Noss (2001) considered both species and ecosystem-level biodiversity goals and recommended that planners should strive to increase representation of elevational gradients and climatic refugia in forest reserves, as well areas of importance for connectivity.

The priority areas identified in the SITES modeling meet several of these goals. Areas identified are generally large enough to hold viable populations of area-limited species such as grizzly bears and woodland caribou. Furthermore, the proposed priority areas are connected

amongst themselves and with existing protected areas. Because the SITES solutions were relatively robust to the decision to “lock in” protected areas, we can be confident that the proposed priority areas do have high biodiversity value rather than simply connecting or expanding existing reserves. For example, the priority areas centered around Itcha Ilgachuz Provincial Park protect a large area holding ecosystem types that are underrepresented elsewhere, and provide the most robust refugia for the southern mountain population of woodland caribou. Areas highlighted along the southwestern edge of the CCLUP region encompass strong elevational gradients and hence a diversity of ecosystem types, and thus may serve as climatic refugia. Although increased severity of insect outbreaks may trigger a shift in ecosystem composition due to disturbance-dependent migration of southerly tree species and other factors (Johnstone et al. 2003), many of the characteristics that give the CCLUP region high value for carnivore conservation will likely be resilient to climate change if a well-designed network of refugia can be implemented. These characteristics include large areas with low levels of direct human impacts (e.g., roads) coupled with relatively high ecosystem productivity and hence prey densities (e.g., when compared to the Canadian Mountain Parks).

THE RELEVANCE OF ISLAND BIOGEOGRAPHY

The results described here highlight the relevance of the principles of island biogeography to regional conservation planning (MacArthur and Wilson 1967). As the landscape matrix becomes developed either through human settlement or through industrial activities such as logging and its associated roads and infrastructure, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. In a subsequent analysis (Carroll et al. 2004), we used the PATCH results described above to evaluate the ability of the existing

reserve network in the RMC study area to sustain populations of grizzly bear and wolves. Comparison of habitat models between the southern, central, and northern portions of the RMC study region suggested that as the landscape matrix between reserves became more developed, only the largest and most connected reserves sustained viable carnivore populations. In the northern portion of the study area (the Cariboo-Chilcotin region and the Rockies north of Jasper Park), current reserves were, with the exception of the Tweedsmuir and Muskwa-Kechika protected areas, not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable (Carroll et al. 2004). Thus many reserves which currently hold these species were predicted to lose them unless steps were taken to increase their effective size or connectivity.

CARNIVORES AS FOCAL SPECIES

Although area and connectivity factors are especially important in conserving the carnivore species analyzed here, it is increasingly evident that carnivores may be good focal species for a larger range of biodiversity values (Ray et al. 2005). The use of particular focal species in developing regional conservation plans (Carroll et al. 2001a) complements two other major tracks of conservation planning; special elements and ecosystem representation (Noss et al. 2002). The special elements approach concentrates on occurrences of imperiled species, plant communities, and other rare natural features, as are found in conservation data center databases (Groves 2003). The representation approach seeks to capture examples of all geoclimatic or vegetation types in a network of protected areas. Ecosystem-based conservation strategies include the goal of representing all major environmental gradients. This “coarse filter” is hypothesized to capture occurrences of species about which little is known and therefore would

not be captured by the special elements or focal species approaches (Groves 2003). Carroll et al. (2003) assessed the ability of carnivore-based reserve designs to serve other conservation goals in the central Canadian Rockies. Although a reserve network based on carnivore conservation goals was poor at capturing localized rare species (special elements), it incidentally protected 76% of ecosystem types, suggesting the value of carnivore-based analyses in coarse-filter approaches. Thus the results presented here can 1) help devise effective conservation strategies for the eight focal carnivore species themselves, 2) supplement other coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and 3) highlight trends at the broader geographic scale such as the effects of loss of connectivity on a larger group of threatened species and ecosystems.

COMPARISON WITH OTHER PLANNING PROCESSES

Many regional-scale conservation planning processes have occurred in British Columbia since 1980, and diverse decision-support tools have been used. Early processes used ad-hoc approaches, but more recently, quantitative tools such as SITES (Possingham et al. 2000) have become more common. SITES has been used in numerous ecoregional plans completed by The Nature Conservancy, including the Canadian Rockies plan which was informed by the RMC project results discussed above (Rumsey et al. 2003). SITES has also been applied to the Central Coast planning process (Gonzales et al. 2003, Wells et al. 2003). Gonzales et al. (2003) used a goal-setting approach similar to that used in the RMC study, seeking to represent a proportion of all ecosystem types (Broad Ecosystem Units divided amongst Biogeoclimatic Ecosystem Classification zones). However, in contrast to our analysis, although wildlife habitat goals were incorporated, no subregional stratification was used for the wildlife goals, thus potentially

preserving less well-distributed populations. There was also no consideration of the effect of the connectivity or area of reserves on focal species viability. The resulting reserve design (Gonzales et al. 2003) thus efficiently achieves representation goals in a minimum area but proposes a system of relatively small and scattered reserves that might poorly protect species with large area requirements such as grizzly bear. In addition, unlike the PATCH model used here, the wildlife habitat suitability models used in Gonzales et al. (2003) do not gauge the vulnerability of proposed reserves to future landscape change. Based on the PATCH results for western North America (Carroll 2005), the Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may thus be key to preserving connectivity and viability of carnivore populations over a much larger region that holds the greatest remaining diversity of large carnivores in North America (Figure 5).

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FIGURES

Figure 1. Prioritization of areas for carnivore conservation in the Cariboo/Chilcotin region based on the SITES model results with 40% regional/30% local goals for capturing habitat value. Areas shown in red were included in one or more of 100 replicate SITES solutions, with darker red indicating inclusion in a larger proportion of the 100 solutions. Figure 1a shows solutions which began from inclusion of current protected areas, whereas Figure 1b shows SITES-based prioritizations that did not take into account current management status

Figure 2. Example of PATCH-based goals used in SITES runs. Areas shown in red lie in Quadrant 1 (top-right) of the irreplaceability/vulnerability graph for grizzly bear, that is, areas with both high value as source habitats and high threat. Areas shown in green are the highest value source habitats, that is, the upper portions of quadrants 1 and 2 (top-left) of the irreplaceability/vulnerability graph for grizzly bear. (Areas which meet both goals are also shown in red).

Figure 3. Potential distribution and demography of grizzly bears in the Cariboo/Chilcotin region as predicted by the PATCH model under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25%in yellow.

Figure 4. Potential distribution and demography of wolves as predicted by the PATCH model in western Canada and Alaska under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25% are shown as “low occupancy”.

Figure 5. Range overlap among ten large carnivore species in North America. Wildlife

Conservation Society Global Carnivore Program, Large Carnivore Mapping Project, used with permission.

PRIORITIES FOR CARNIVORE CONSERVATION IN THE CARIBOO-CHILCOTIN REGION

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EXECUTIVE SUMMARY

$ A regional analysis based on habitat models for eight native large and mesocarnivore species found that the areas in the Cariboo-Chilcotin region with the greatest value for carnivore conservation were located on the southern edge of the study region in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area, as well as on the northern edge of the region surrounding Kluskoil Lake Park and the larger Blackwater River area.

$ Carnivores may be good focal species for a larger range of biodiversity values. Thus the priority areas identified here can not only conserve carnivores but can also supplement coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and highlight trends at the broader geographic scale such as the effects of loss of connectivity.

$ Although they cannot utilize detailed local-scale habitat data, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying drivers of species vulnerability. As the landscape matrix becomes developed, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. Current reserves alone are generally not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable.

$ A preliminary viability analysis for grizzly bear and wolf in western North America highlighted the Chilcotin region as of high importance on a continental scale, especially for wolf populations, due to the combination of relatively high productivity (in comparison to the Canadian Mountain Parks) and relatively low levels of roads and

human population (in comparison to other forested regions to the south). These characteristics will likely be resilient to climate change if a well-designed network of refugia can be implemented.

$ The Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may be key to preserving connectivity and viability of carnivore populations over a larger region of western Canada that holds the greatest remaining diversity of large carnivores in North America.

"Human activities combined with climatic change can precipitate ecological changes of much greater magnitude than would be expected from climatic changes alone... continuation of recent climate warming trends and/or intensification of forest management could lead to rapid irreversible vegetation changes within boreal forests that are not readily predicted from our observations of their current dynamics." Chapin et al. 2004

INTRODUCTION

Over the next half-century, anthropogenic climate change is predicted to dramatically alter the composition and structure of ecosystems worldwide. Climate change not only impacts ecosystems through gradual trends in temperature or precipitation but also through disturbance events such as insect outbreaks and forest fires. The speed and widespread nature of these disturbances will challenge the ability of species to persist by means of gradual shifts in distribution. Many areas of the boreal and subboreal forest, including the Cariboo-Chilcotin region of central British Columbia, are currently experiencing widespread mortality from pine and spruce bark beetle outbreaks linked to unusually warm winters (Safranyik 1990, Carroll 2001). In order to utilize the beetle-killed trees while they are still commercially valuable, the forest industry is proposing to accelerate cut levels substantially across the Cariboo-Chilcotin region, compressing 40 to 60 years of harvest into the next 15 years. This level of harvest has the potential to greatly alter ecosystems across the region and lessen their resilience to the effects of ecosystem stressors linked to climate change, such as altered rainfall patterns, insect and disease outbreaks.

Although the boreal and subboreal forest is not as speciose as tropical biodiversity "hotspots", planners increasingly recognize the important role of these and other "coldspots" in

sustaining global ecosystem processes and populations of area-limited species (Kareiva and Marvier 2003). Two types of measures can be taken to increase the resilience of biodiversity values in the Cariboo-Chilcotin region to climate change and other ecosystem stressors. Site-level prescriptions and fine-scale riparian and old-growth management areas can help mitigate impacts of accelerated timber harvest on a local scale. However, the widespread nature of the beetle outbreak and subsequent logging also requires regional-scale planning to identify retention areas that will not be salvage-logged even if they are attacked by mountain pine beetles. If these retention areas are distributed based on the principles of conservation planning, they can mitigate, to an extent, the effect of accelerated harvest on ecosystem processes that operate over large areas and upon species with large area and connectivity requirements for viable populations, such as grizzly bear (Ursus arctos) and woodland caribou (Rangifer tarandus caribou). In turn, wide-ranging species such as large carnivores can serve as focal and indicator species to help plan and evaluate the adequacy of the conservation measures such as the proposed retention areas (Lambeck 1997). This is because these species' stringent area and connectivity requirements make factors affecting their viability illustrative of the link between larger regional processes and biodiversity at the local scale (Carroll et al. 2001). In this report, I summarize lessons from a systematic reserve design study focusing on conservation of native carnivore species (Carroll et al. 2003, 2004), and suggest how these results can help inform retention area planning for the Cariboo-Chilcotin region.

METHODS

MODELING TECHNIQUES

The purpose of the Rocky Mountain Carnivore (RMC) Research Project (Carroll et al. 2001, 2003, 2004), sponsored by World Wildlife Fund-Canada with assistance from The Nature Conservancy, the Wilburforce Foundation and other groups, was to develop the data necessary to support long-term conservation of a broad suite of native carnivore species across a large portion of their range in the northern U.S. and Canada. The RMC study considered the habitat needs of eight native carnivore species - grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), gray wolf (*Canis lupus*), lynx (*Lynx canadensis*), mountain lion (*Puma concolor*), wolverine (*Gulo gulo*), fisher (*Martes pennanti*), and marten (*Martes americana*). The RMC analysis encompassed a study area stretching along the Rocky Mountains of Canada and the United States from the Yukon/British Columbia border to the Greater Yellowstone Ecosystem, and extending westward to encompass the Fraser Plateau.

The RMC study area covers most of the Cariboo Chilcotin Land Use Plan (CCLUP) area, except for a strip along the southwestern margin of the CCLUP (Figure 1). However, it is important to recognize that conservation priorities derived from any planning process are to some extent a function of the planning region's boundaries. For example, a planning exercise for the CCLUP region alone might prioritize regionally-rare ecosystem types that would be lower priorities in a province-wide plan. Because of its large extent, the RMC results are most informative at a large geographic scale that spans many ecoregions. However, we anticipated this scale issue by incorporating the principle of representation into the priority-setting process. As detailed below, we sought to capture a proportion of the best carnivore habitat within each of the

ecosection-based subunits of the larger study area. This insured that a geographically-widespread population, containing uniquely-adapted ecotypes, could be protected by the resulting conservation network, and increased the relevance of our results to ecoregional-scale planning processes.

We (the author of this document and his co-authors on the RMC study) created empirical models - resource selection functions (RSF) (Manly et al. 1993) - for the four species for which we had detailed survey data: black bear, lynx, wolverine, and fisher. Details of these models are presented in Carroll et al. (2001a,2002,2003). For example, we created conceptual models for the grizzly bear, wolf, marten, and mountain lion based on published information on species-habitat associations. The conceptual models for the grizzly bear (Carroll et al. 2001a) and wolf (Carroll et al. 2001b, 2003) combined surrogates of productivity, as measured by a satellite-imagery derived metric (tasselled-cap greenness (Crist and Cicone 1984)), and human-associated mortality risk, as measured by road density and human population (Merrill et al. 1999). Topography was an additional component of the wolf model (Carroll et al. 2001b, 2003). Because the analysis covered a very large and ecologically diverse region, the GIS models for fecundity and survival for grizzly bear and wolf used very general habitat data that is available in every province and state. This is a lesser problem for the survival input layer, because roads and human population have a similar negative effect on large carnivore survival in diverse habitats (e.g., Thiel 1985, Fuller et al. 2003). Estimating large carnivore fecundity (reproductive rates) across such a large region is more difficult. Although they cannot utilize the more detailed habitat data available at the local scale, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying

drivers of species vulnerability that can make conservation policy more effective.

After developing the static habitat suitability models, we performed population viability analyses using the program PATCH (Schumaker 1998). PATCH is a spatially-explicit population model that links the survival and fecundity of individual animals to GIS data on mortality risk and habitat productivity measured at the location of the individual or pack territory. The model tracks the demographics of the population through time as individuals are born, disperse, reproduce, and die, predicting population size, time to extinction, and migration and recolonization rates. We used PATCH simulations to evaluate long term persistence probability, i.e., the capacity for an area to support a carnivore species over 200 years, rather than transient dynamics such as time to extinction.

CONSERVATION PLANNING TECHNIQUES

A principal tool of modern conservation planning is the reserve selection algorithm (Margules and Pressey 2000). The objective is to conserve biodiversity efficiently within a network of reserves. As used here, the term “reserves” may encompass a variety of land management designations, from gazetted parks through the retention areas considered here. An efficient reserve design meets conservation objectives with a minimal investment of area by building a network from complementary sites. Many current tools, such as the SITES model used here (Possingham et al. 2000), employ heuristic algorithms to identify one or more “near-optimal” solutions that fulfill the selected goals efficiently. SITES uses a simulated annealing algorithm to reduce “cost” while maximizing attainment of conservation goals in a compact set of sites. The function SITES seeks to minimize is Cost + Species Penalty + Boundary Length, where Cost is the total monetary or area cost of all planning units selected for the network,

Species Penalty is a cost imposed for failing to meet target goals, and Boundary Length is a cost determined by the total boundary length of the network (Possingham et al. 2000). Hence, SITES attempts to select the smallest overall area needed to meet stated goals and select clustered rather than dispersed planning units. Goals were expressed as a percentage of total habitat value for a species, as derived from the RSF or conceptual model output. Because most habitat value was contained within the highest quality habitats, capturing e.g., 30% of habitat value would require far less than 30% of the total region.

If a single overall habitat goal is used for each species, SITES may locate proposed reserves entirely in the most remote portions of the large RMC study region (e.g., in the Canadian Northern Rocky Mountains). However, this solution poorly meets the goal of maintaining well-distributed and connected populations. Therefore, we stratified goals by subdividing the study area into 88 sections derived from subregional ecosection classifications (e.g., Demarchi and Lea 1992) which we modified to produce a system of sections of similar size across the study region. To balance the need for a well-distributed reserve network with the need for efficiency, we set the overall regional goal higher than the local section-level goal. For example, with a 40% regional/30% local goal, SITES sought to capture 30% of the habitat value in each section, and added another 10% of habitat value wherever in the region this could be achieved at least cost.

In addition to trying to maximize goals based on the static habitat suitability models for the eight species within the reserve network, we also sought to maximize habitat goals derived from the PATCH models for grizzly bear, wolf, and wolverine. These goals can be conceptualized as representing information on two characteristics of potential reserve locations:

their irreplaceability and vulnerability (Margules and Pressey 2000). Irreplaceability provides a quantitative measure of the relative contribution different areas make to reaching conservation goals, thus helping planners choose among alternative sites. Irreplaceability can be defined in two ways: 1) the likelihood that a particular area is needed to achieve an explicit conservation goal; or 2) the extent to which the options for achieving an explicit goal are narrowed if an area is not conserved (Margules and Pressey 2000). Irreplaceability in this context is the relative value of an area as source habitat (lambda, or population growth rate, from the PATCH model). Although measured at the scale of an individual territory, it can also be summarized at the scale of a region or of the planning units used in the SITES model (Figure 2). Source habitat is an appropriate metric because it is the key to population persistence (Pulliam 1988). Vulnerability is measured here as the predicted decline in demographic value (lambda) over the next 25 years.

SITES performed 1,000,000 iterative attempts to find the minimum cost solution per run and performed 100 such runs for each alternative conservation scenario we explored. The best (lowest cost) solution from each run of 1,000,000 iterations is reported, as well as which out of those 100 top candidates has the lowest cost. Besides identifying this latter solution, the "best run," SITES also rates areas by how often they were selected in the best solutions of the 100 alternate runs. An area that scored highly in this "summed runs" output might not be included in the best solution, but could be considered a suitable alternative site.

Our design built upon the existing protected area network by locking existing protected areas into the SITES solution, so that the program only adds planning units with targets that are missing from the current park system. Locking in protected areas recognizes that, from a practical standpoint, achieving conservation goals within protected areas is easier than adding

currently unprotected areas. SITES scenarios that build reserve networks by first including existing protected areas are generally the most informative for practical planning. However, we also analyzed the sensitivity of our results to this decision by performing additional simulations where we did not lock in existing protected areas, in order to assess the distribution of biodiversity across the landscape without regard to political boundaries.

We built an overall conservation design by starting from the best run solution from SITES and adding additional areas to serve as linkages based on information on regional population structure derived from the PATCH models. Once information on the general location of linkages was derived from PATCH, the exact location was determined using the SITES summed runs results, which identify areas that are nearly as important as those included in the best run. Setting conservation goals in a reserve selection algorithm is often difficult because information is unavailable on the threshold amount of habitat necessary to insure population viability. To address this question, we used PATCH to evaluate the adequacy of SITES scenarios with a range of potential percentage habitat goals for preserving viable carnivore populations. Based on these evaluations, we selected the habitat value goal of 40% regional/30% local as offering the best balance between efficiency (minimum area) and viability (Carroll et al. 2003).

RESULTS

PRIORITIES WITHIN THE CARIBOO-CHILCOTIN REGION

In the context of the study area boundary used in Carroll et al. (2003, 2004), the areas in the Cariboo-Chilcotin region with the greatest contribution to a network focused on preserving habitat for the eight native large and mesocarnivore species, were located on the southern edge of the study region (Figure 1a) in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area. Other priority areas were identified on the northern edge of the region surrounding Kluskoil Lake Park, as well as the Victoria/Gerimi and Mackin BMUs (Williams Lake District), and Moffat/Black Creek BMUs (Horsefly District). When protected areas were not locked into the solution, areas identified were similar, but with additional emphasis on the Blackwater River area (extending eastward to connect with a linkage area to Bowron Lake Park) and areas south and east of Itcha Ilgachuz Park (Figure 1b). Similarly, he PATCH simulations predicted that source habitat for grizzly bear (Figure 3) within the CCLUP region lies in the areas on the northwestern and southern edges of the region and on the edges of Wells-Gray and Bowron Lakes Parks.

The commonalities between the locked and non-locked solutions (Figure 1a vs. 1b) suggest that the priority areas identified, including current protected areas, are of high biological value. This is not necessarily true in other regions, as parks are usually established for diverse reasons unrelated to biodiversity and thus reserve networks starting from existing parks may be highly “inefficient” in protecting biodiversity. The larger percentage of the CCLUP region prioritized in the non-locked vs. locked solutions (Figure 1b vs. 1a) is due to the fact that the CCLUP region as a whole has higher carnivore habitat value and lower protected area

designation than most areas of the RMC study area, for example the southern Canadian Rockies (Carroll et al. 2004). Therefore, the non-locked solution increases the CCLUP region's share of priority areas, in order to more efficiently capture the areas of highest value carnivore habitat within the overall RMC study area. This is relevant to planning at the scale of the CCLUP region in that it underscores the region's value in the larger provincial context.

THE CARIBOO-CHILCOTIN REGION IN A MULTI- REGIONAL CONTEXT

Results of a preliminary analysis of habitat and viability for grizzly bear and wolf in western North America (Carroll et al. 2005b) highlight the Chilcotin region as of high importance on a continental scale, especially for wolf populations (Figure 4). This is due to the combination of relatively high productivity (in comparison to the "rock and ice" of the Canadian Mountain Parks) and relatively low levels of roads and human population (in comparison to other forested regions to the south). These two factors may also help explain why British Columbia has highest range overlap of large carnivore species in North America (Figure 5). In the PATCH analyses (Carroll et al. 2005b), habitat value is higher for wolf than grizzly bear due to relatively low topographic relief of much of the Chilcotin, which allows coursing predators such as wolves to hunt more easily than in highly rugged areas such as the southern Canadian Rockies.

DISCUSSION

RESILIENCE TO CLIMATE CHANGE

A major goal of conservation planning for the CCLUP region is to maintain the area's biodiversity values in the face of climate change and associated changes in disturbance regimes such as fire and insect outbreaks. The emerging science of "non-equilibrium" ecology has identified the potential for ecosystems that pass climatic thresholds to undergo sudden phase transitions to novel states with new species combinations and altered forest structure (Chapin et al. 2004). Ecosystems that are otherwise resilient to climate change may experience sudden transitions when exposed to both climate change and intensive human activities (Chapin et al. 2004). However, planners can use reserve design and other tools to manage forest regions to increase their resilience and ability to maintain biodiversity values in the face of these threats. The three principles of representation (establishing populations across the full array of potential habitats), resiliency (protecting populations large enough to remain viable), and redundancy (saving enough copies of those populations that some can be lost without a loss of the species) are widely invoked guidelines for ensuring conservation of threatened species, even in the face of geographically widespread threats such as climate change (Shaffer and Stein 2000). Noss (2001) considered both species and ecosystem-level biodiversity goals and recommended that planners should strive to increase representation of elevational gradients and climatic refugia in forest reserves, as well areas of importance for connectivity.

The priority areas identified in the SITES modeling meet several of these goals. Areas identified are generally large enough to hold viable populations of area-limited species such as grizzly bears and woodland caribou. Furthermore, the proposed priority areas are connected

amongst themselves and with existing protected areas. Because the SITES solutions were relatively robust to the decision to "lock in" protected areas, we can be confident that the proposed priority areas do have high biodiversity value rather than simply connecting or expanding existing reserves. For example, the priority areas centered around Itcha Ilgachuz Provincial Park protect a large area holding ecosystem types that are underrepresented elsewhere, and provide the most robust refugia for the southern mountain population of woodland caribou. Areas highlighted along the southwestern edge of the CCLUP region encompass strong elevational gradients and hence a diversity of ecosystem types, and thus may serve as climatic refugia. Although increased severity of insect outbreaks may trigger a shift in ecosystem composition due to disturbance-dependent migration of southerly tree species and other factors (Johnstone et al. 2003), many of the characteristics that give the CCLUP region high value for carnivore conservation will likely be resilient to climate change if a well-designed network of refugia can be implemented. These characteristics include large areas with low levels of direct human impacts (e.g., roads) coupled with relatively high ecosystem productivity and hence prey densities (e.g., when compared to the Canadian Mountain Parks).

THE RELEVANCE OF ISLAND BIOGEOGRAPHY

The results described here highlight the relevance of the principles of island biogeography to regional conservation planning (MacArthur and Wilson 1967). As the landscape matrix becomes developed either through human settlement or through industrial activities such as logging and its associated roads and infrastructure, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. In a subsequent analysis (Carroll et al. 2004), we used the PATCH results described above to evaluate the ability of the existing

reserve network in the RMC study area to sustain populations of grizzly bear and wolves. Comparison of habitat models between the southern, central, and northern portions of the RMC study region suggested that as the landscape matrix between reserves became more developed, only the largest and most connected reserves sustained viable carnivore populations. In the northern portion of the study area (the Cariboo-Chilcotin region and the Rockies north of Jasper Park), current reserves were, with the exception of the Tweedsmuir and Muskwa-Kechika protected areas, not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable (Carroll et al. 2004). Thus many reserves which currently hold these species were predicted to lose them unless steps were taken to increase their effective size or connectivity.

CARNIVORES AS FOCAL SPECIES

Although area and connectivity factors are especially important in conserving the carnivore species analyzed here, it is increasingly evident that carnivores may be good focal species for a larger range of biodiversity values (Ray et al. 2005). The use of particular focal species in developing regional conservation plans (Carroll et al. 2001a) complements two other major tracks of conservation planning; special elements and ecosystem representation (Noss et al. 2002). The special elements approach concentrates on occurrences of imperiled species, plant communities, and other rare natural features, as are found in conservation data center databases (Groves 2003). The representation approach seeks to capture examples of all geoclimatic or vegetation types in a network of protected areas. Ecosystem-based conservation strategies include the goal of representing all major environmental gradients. This “coarse filter” is hypothesized to capture occurrences of species about which little is known and therefore would

not be captured by the special elements or focal species approaches (Groves 2003). Carroll et al. (2003) assessed the ability of carnivore-based reserve designs to serve other conservation goals in the central Canadian Rockies. Although a reserve network based on carnivore conservation goals was poor at capturing localized rare species (special elements), it incidentally protected 76% of ecosystem types, suggesting the value of carnivore-based analyses in coarse-filter approaches. Thus the results presented here can 1) help devise effective conservation strategies for the eight focal carnivore species themselves, 2) supplement other coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and 3) highlight trends at the broader geographic scale such as the effects of loss of connectivity on a larger group of threatened species and ecosystems.

COMPARISON WITH OTHER PLANNING PROCESSES

Many regional-scale conservation planning processes have occurred in British Columbia since 1980, and diverse decision-support tools have been used. Early processes used ad-hoc approaches, but more recently, quantitative tools such as SITES (Possingham et al. 2000) have become more common. SITES has been used in numerous ecoregional plans completed by The Nature Conservancy, including the Canadian Rockies plan which was informed by the RMC project results discussed above (Rumsey et al. 2003). SITES has also been applied to the Central Coast planning process (Gonzales et al. 2003, Wells et al. 2003). Gonzales et al. (2003) used a goal-setting approach similar to that used in the RMC study, seeking to represent a proportion of all ecosystem types (Broad Ecosystem Units divided amongst Biogeoclimatic Ecosystem Classification zones). However, in contrast to our analysis, although wildlife habitat goals were incorporated, no subregional stratification was used for the wildlife goals, thus potentially

preserving less well-distributed populations. There was also no consideration of the effect of the connectivity or area of reserves on focal species viability. The resulting reserve design (Gonzales et al. 2003) thus efficiently achieves representation goals in a minimum area but proposes a system of relatively small and scattered reserves that might poorly protect species with large area requirements such as grizzly bear. In addition, unlike the PATCH model used here, the wildlife habitat suitability models used in Gonzales et al. (2003) do not gauge the vulnerability of proposed reserves to future landscape change. Based on the PATCH results for western North America (Carroll 2005), the Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may thus be key to preserving connectivity and viability of carnivore populations over a much larger region that holds the greatest remaining diversity of large carnivores in North America (Figure 5).

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FIGURES

Figure 1. Prioritization of areas for carnivore conservation in the Cariboo/Chilcotin region based on the SITES model results with 40% regional/30% local goals for capturing habitat value. Areas shown in red were included in one or more of 100 replicate SITES solutions, with darker red indicating inclusion in a larger proportion of the 100 solutions. Figure 1a shows solutions which began from inclusion of current protected areas, whereas Figure 1b shows SITES-based prioritizations that did not take into account current management status

Figure 2. Example of PATCH-based goals used in SITES runs. Areas shown in red lie in Quadrant 1 (top-right) of the irreplaceability/vulnerability graph for grizzly bear, that is, areas with both high value as source habitats and high threat. Areas shown in green are the highest value source habitats, that is, the upper portions of quadrants 1 and 2 (top-left) of the irreplaceability/vulnerability graph for grizzly bear. (Areas which meet both goals are also shown in red).

Figure 3. Potential distribution and demography of grizzly bears in the Cariboo/Chilcotin region as predicted by the PATCH model under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25%in yellow.

Figure 4. Potential distribution and demography of wolves as predicted by the PATCH model in western Canada and Alaska under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25% are shown as “low occupancy”.

Figure 5. Range overlap among ten large carnivore species in North America. Wildlife

Conservation Society Global Carnivore Program, Large Carnivore Mapping Project, used with permission.

PRIORITIES FOR CARNIVORE CONSERVATION IN THE CARIBOO-CHILCOTIN REGION

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EXECUTIVE SUMMARY

$ A regional analysis based on habitat models for eight native large and mesocarnivore species found that the areas in the Cariboo-Chilcotin region with the greatest value for carnivore conservation were located on the southern edge of the study region in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area, as well as on the northern edge of the region surrounding Kluskoil Lake Park and the larger Blackwater River area.

$ Carnivores may be good focal species for a larger range of biodiversity values. Thus the priority areas identified here can not only conserve carnivores but can also supplement coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and highlight trends at the broader geographic scale such as the effects of loss of connectivity.

$ Although they cannot utilize detailed local-scale habitat data, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying drivers of species vulnerability. As the landscape matrix becomes developed, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. Current reserves alone are generally not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable.

$ A preliminary viability analysis for grizzly bear and wolf in western North America highlighted the Chilcotin region as of high importance on a continental scale, especially for wolf populations, due to the combination of relatively high productivity (in comparison to the Canadian Mountain Parks) and relatively low levels of roads and

human population (in comparison to other forested regions to the south). These characteristics will likely be resilient to climate change if a well-designed network of refugia can be implemented.

$ The Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may be key to preserving connectivity and viability of carnivore populations over a larger region of western Canada that holds the greatest remaining diversity of large carnivores in North America.

"Human activities combined with climatic change can precipitate ecological changes of much greater magnitude than would be expected from climatic changes alone... continuation of recent climate warming trends and/or intensification of forest management could lead to rapid irreversible vegetation changes within boreal forests that are not readily predicted from our observations of their current dynamics." Chapin et al. 2004

INTRODUCTION

Over the next half-century, anthropogenic climate change is predicted to dramatically alter the composition and structure of ecosystems worldwide. Climate change not only impacts ecosystems through gradual trends in temperature or precipitation but also through disturbance events such as insect outbreaks and forest fires. The speed and widespread nature of these disturbances will challenge the ability of species to persist by means of gradual shifts in distribution. Many areas of the boreal and subboreal forest, including the Cariboo-Chilcotin region of central British Columbia, are currently experiencing widespread mortality from pine and spruce bark beetle outbreaks linked to unusually warm winters (Safranyik 1990, Carroll 2001). In order to utilize the beetle-killed trees while they are still commercially valuable, the forest industry is proposing to accelerate cut levels substantially across the Cariboo-Chilcotin region, compressing 40 to 60 years of harvest into the next 15 years. This level of harvest has the potential to greatly alter ecosystems across the region and lessen their resilience to the effects of ecosystem stressors linked to climate change, such as altered rainfall patterns, insect and disease outbreaks.

Although the boreal and subboreal forest is not as speciose as tropical biodiversity "hotspots", planners increasingly recognize the important role of these and other "coldspots" in

sustaining global ecosystem processes and populations of area-limited species (Kareiva and Marvier 2003). Two types of measures can be taken to increase the resilience of biodiversity values in the Cariboo-Chilcotin region to climate change and other ecosystem stressors. Site-level prescriptions and fine-scale riparian and old-growth management areas can help mitigate impacts of accelerated timber harvest on a local scale. However, the widespread nature of the beetle outbreak and subsequent logging also requires regional-scale planning to identify retention areas that will not be salvage-logged even if they are attacked by mountain pine beetles. If these retention areas are distributed based on the principles of conservation planning, they can mitigate, to an extent, the effect of accelerated harvest on ecosystem processes that operate over large areas and upon species with large area and connectivity requirements for viable populations, such as grizzly bear (Ursus arctos) and woodland caribou (Rangifer tarandus caribou). In turn, wide-ranging species such as large carnivores can serve as focal and indicator species to help plan and evaluate the adequacy of the conservation measures such as the proposed retention areas (Lambeck 1997). This is because these species' stringent area and connectivity requirements make factors affecting their viability illustrative of the link between larger regional processes and biodiversity at the local scale (Carroll et al. 2001). In this report, I summarize lessons from a systematic reserve design study focusing on conservation of native carnivore species (Carroll et al. 2003, 2004), and suggest how these results can help inform retention area planning for the Cariboo-Chilcotin region.

METHODS

MODELING TECHNIQUES

The purpose of the Rocky Mountain Carnivore (RMC) Research Project (Carroll et al. 2001, 2003, 2004), sponsored by World Wildlife Fund-Canada with assistance from The Nature Conservancy, the Wilburforce Foundation and other groups, was to develop the data necessary to support long-term conservation of a broad suite of native carnivore species across a large portion of their range in the northern U.S. and Canada. The RMC study considered the habitat needs of eight native carnivore species - grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), gray wolf (*Canis lupus*), lynx (*Lynx canadensis*), mountain lion (*Puma concolor*), wolverine (*Gulo gulo*), fisher (*Martes pennanti*), and marten (*Martes americana*). The RMC analysis encompassed a study area stretching along the Rocky Mountains of Canada and the United States from the Yukon/British Columbia border to the Greater Yellowstone Ecosystem, and extending westward to encompass the Fraser Plateau.

The RMC study area covers most of the Cariboo Chilcotin Land Use Plan (CCLUP) area, except for a strip along the southwestern margin of the CCLUP (Figure 1). However, it is important to recognize that conservation priorities derived from any planning process are to some extent a function of the planning region's boundaries. For example, a planning exercise for the CCLUP region alone might prioritize regionally-rare ecosystem types that would be lower priorities in a province-wide plan. Because of its large extent, the RMC results are most informative at a large geographic scale that spans many ecoregions. However, we anticipated this scale issue by incorporating the principle of representation into the priority-setting process. As detailed below, we sought to capture a proportion of the best carnivore habitat within each of the

ecosection-based subunits of the larger study area. This insured that a geographically-widespread population, containing uniquely-adapted ecotypes, could be protected by the resulting conservation network, and increased the relevance of our results to ecoregional-scale planning processes.

We (the author of this document and his co-authors on the RMC study) created empirical models - resource selection functions (RSF) (Manly et al. 1993) - for the four species for which we had detailed survey data: black bear, lynx, wolverine, and fisher. Details of these models are presented in Carroll et al. (2001a,2002,2003). For example, we created conceptual models for the grizzly bear, wolf, marten, and mountain lion based on published information on species-habitat associations. The conceptual models for the grizzly bear (Carroll et al. 2001a) and wolf (Carroll et al. 2001b, 2003) combined surrogates of productivity, as measured by a satellite-imagery derived metric (tasselled-cap greenness (Crist and Cicone 1984)), and human-associated mortality risk, as measured by road density and human population (Merrill et al. 1999). Topography was an additional component of the wolf model (Carroll et al. 2001b, 2003). Because the analysis covered a very large and ecologically diverse region, the GIS models for fecundity and survival for grizzly bear and wolf used very general habitat data that is available in every province and state. This is a lesser problem for the survival input layer, because roads and human population have a similar negative effect on large carnivore survival in diverse habitats (e.g., Thiel 1985, Fuller et al. 2003). Estimating large carnivore fecundity (reproductive rates) across such a large region is more difficult. Although they cannot utilize the more detailed habitat data available at the local scale, broad-scale analyses such as this one that encompass all components of the regional metapopulation provide important insights as to the underlying

drivers of species vulnerability that can make conservation policy more effective.

After developing the static habitat suitability models, we performed population viability analyses using the program PATCH (Schumaker 1998). PATCH is a spatially-explicit population model that links the survival and fecundity of individual animals to GIS data on mortality risk and habitat productivity measured at the location of the individual or pack territory. The model tracks the demographics of the population through time as individuals are born, disperse, reproduce, and die, predicting population size, time to extinction, and migration and recolonization rates. We used PATCH simulations to evaluate long term persistence probability, i.e., the capacity for an area to support a carnivore species over 200 years, rather than transient dynamics such as time to extinction.

CONSERVATION PLANNING TECHNIQUES

A principal tool of modern conservation planning is the reserve selection algorithm (Margules and Pressey 2000). The objective is to conserve biodiversity efficiently within a network of reserves. As used here, the term “reserves” may encompass a variety of land management designations, from gazetted parks through the retention areas considered here. An efficient reserve design meets conservation objectives with a minimal investment of area by building a network from complementary sites. Many current tools, such as the SITES model used here (Possingham et al. 2000), employ heuristic algorithms to identify one or more “near-optimal” solutions that fulfill the selected goals efficiently. SITES uses a simulated annealing algorithm to reduce “cost” while maximizing attainment of conservation goals in a compact set of sites. The function SITES seeks to minimize is Cost + Species Penalty + Boundary Length, where Cost is the total monetary or area cost of all planning units selected for the network,

Species Penalty is a cost imposed for failing to meet target goals, and Boundary Length is a cost determined by the total boundary length of the network (Possingham et al. 2000). Hence, SITES attempts to select the smallest overall area needed to meet stated goals and select clustered rather than dispersed planning units. Goals were expressed as a percentage of total habitat value for a species, as derived from the RSF or conceptual model output. Because most habitat value was contained within the highest quality habitats, capturing e.g., 30% of habitat value would require far less than 30% of the total region.

If a single overall habitat goal is used for each species, SITES may locate proposed reserves entirely in the most remote portions of the large RMC study region (e.g., in the Canadian Northern Rocky Mountains). However, this solution poorly meets the goal of maintaining well-distributed and connected populations. Therefore, we stratified goals by subdividing the study area into 88 sections derived from subregional ecosection classifications (e.g., Demarchi and Lea 1992) which we modified to produce a system of sections of similar size across the study region. To balance the need for a well-distributed reserve network with the need for efficiency, we set the overall regional goal higher than the local section-level goal. For example, with a 40% regional/30% local goal, SITES sought to capture 30% of the habitat value in each section, and added another 10% of habitat value wherever in the region this could be achieved at least cost.

In addition to trying to maximize goals based on the static habitat suitability models for the eight species within the reserve network, we also sought to maximize habitat goals derived from the PATCH models for grizzly bear, wolf, and wolverine. These goals can be conceptualized as representing information on two characteristics of potential reserve locations:

their irreplaceability and vulnerability (Margules and Pressey 2000). Irreplaceability provides a quantitative measure of the relative contribution different areas make to reaching conservation goals, thus helping planners choose among alternative sites. Irreplaceability can be defined in two ways: 1) the likelihood that a particular area is needed to achieve an explicit conservation goal; or 2) the extent to which the options for achieving an explicit goal are narrowed if an area is not conserved (Margules and Pressey 2000). Irreplaceability in this context is the relative value of an area as source habitat (lambda, or population growth rate, from the PATCH model). Although measured at the scale of an individual territory, it can also be summarized at the scale of a region or of the planning units used in the SITES model (Figure 2). Source habitat is an appropriate metric because it is the key to population persistence (Pulliam 1988). Vulnerability is measured here as the predicted decline in demographic value (lambda) over the next 25 years.

SITES performed 1,000,000 iterative attempts to find the minimum cost solution per run and performed 100 such runs for each alternative conservation scenario we explored. The best (lowest cost) solution from each run of 1,000,000 iterations is reported, as well as which out of those 100 top candidates has the lowest cost. Besides identifying this latter solution, the "best run," SITES also rates areas by how often they were selected in the best solutions of the 100 alternate runs. An area that scored highly in this "summed runs" output might not be included in the best solution, but could be considered a suitable alternative site.

Our design built upon the existing protected area network by locking existing protected areas into the SITES solution, so that the program only adds planning units with targets that are missing from the current park system. Locking in protected areas recognizes that, from a practical standpoint, achieving conservation goals within protected areas is easier than adding

currently unprotected areas. SITES scenarios that build reserve networks by first including existing protected areas are generally the most informative for practical planning. However, we also analyzed the sensitivity of our results to this decision by performing additional simulations where we did not lock in existing protected areas, in order to assess the distribution of biodiversity across the landscape without regard to political boundaries.

We built an overall conservation design by starting from the best run solution from SITES and adding additional areas to serve as linkages based on information on regional population structure derived from the PATCH models. Once information on the general location of linkages was derived from PATCH, the exact location was determined using the SITES summed runs results, which identify areas that are nearly as important as those included in the best run. Setting conservation goals in a reserve selection algorithm is often difficult because information is unavailable on the threshold amount of habitat necessary to insure population viability. To address this question, we used PATCH to evaluate the adequacy of SITES scenarios with a range of potential percentage habitat goals for preserving viable carnivore populations. Based on these evaluations, we selected the habitat value goal of 40% regional/30% local as offering the best balance between efficiency (minimum area) and viability (Carroll et al. 2003).

RESULTS

PRIORITIES WITHIN THE CARIBOO-CHILCOTIN REGION

In the context of the study area boundary used in Carroll et al. (2003, 2004), the areas in the Cariboo-Chilcotin region with the greatest contribution to a network focused on preserving habitat for the eight native large and mesocarnivore species, were located on the southern edge of the study region (Figure 1a) in an arc stretching from Tweedsmuir Park to Itcha Ilgachuz Park and then southeastward through Nuntsi Park to the Churn Creek Protected Area. Other priority areas were identified on the northern edge of the region surrounding Kluskoil Lake Park, as well as the Victoria/Gerimi and Mackin BMUs (Williams Lake District), and Moffat/Black Creek BMUs (Horsefly District). When protected areas were not locked into the solution, areas identified were similar, but with additional emphasis on the Blackwater River area (extending eastward to connect with a linkage area to Bowron Lake Park) and areas south and east of Itcha Ilgachuz Park (Figure 1b). Similarly, he PATCH simulations predicted that source habitat for grizzly bear (Figure 3) within the CCLUP region lies in the areas on the northwestern and southern edges of the region and on the edges of Wells-Gray and Bowron Lakes Parks.

The commonalities between the locked and non-locked solutions (Figure 1a vs. 1b) suggest that the priority areas identified, including current protected areas, are of high biological value. This is not necessarily true in other regions, as parks are usually established for diverse reasons unrelated to biodiversity and thus reserve networks starting from existing parks may be highly “inefficient” in protecting biodiversity. The larger percentage of the CCLUP region prioritized in the non-locked vs. locked solutions (Figure 1b vs. 1a) is due to the fact that the CCLUP region as a whole has higher carnivore habitat value and lower protected area

designation than most areas of the RMC study area, for example the southern Canadian Rockies (Carroll et al. 2004). Therefore, the non-locked solution increases the CCLUP region's share of priority areas, in order to more efficiently capture the areas of highest value carnivore habitat within the overall RMC study area. This is relevant to planning at the scale of the CCLUP region in that it underscores the region's value in the larger provincial context.

THE CARIBOO-CHILCOTIN REGION IN A MULTI- REGIONAL CONTEXT

Results of a preliminary analysis of habitat and viability for grizzly bear and wolf in western North America (Carroll et al. 2005b) highlight the Chilcotin region as of high importance on a continental scale, especially for wolf populations (Figure 4). This is due to the combination of relatively high productivity (in comparison to the "rock and ice" of the Canadian Mountain Parks) and relatively low levels of roads and human population (in comparison to other forested regions to the south). These two factors may also help explain why British Columbia has highest range overlap of large carnivore species in North America (Figure 5). In the PATCH analyses (Carroll et al. 2005b), habitat value is higher for wolf than grizzly bear due to relatively low topographic relief of much of the Chilcotin, which allows coursing predators such as wolves to hunt more easily than in highly rugged areas such as the southern Canadian Rockies.

DISCUSSION

RESILIENCE TO CLIMATE CHANGE

A major goal of conservation planning for the CCLUP region is to maintain the area's biodiversity values in the face of climate change and associated changes in disturbance regimes such as fire and insect outbreaks. The emerging science of "non-equilibrium" ecology has identified the potential for ecosystems that pass climatic thresholds to undergo sudden phase transitions to novel states with new species combinations and altered forest structure (Chapin et al. 2004). Ecosystems that are otherwise resilient to climate change may experience sudden transitions when exposed to both climate change and intensive human activities (Chapin et al. 2004). However, planners can use reserve design and other tools to manage forest regions to increase their resilience and ability to maintain biodiversity values in the face of these threats. The three principles of representation (establishing populations across the full array of potential habitats), resiliency (protecting populations large enough to remain viable), and redundancy (saving enough copies of those populations that some can be lost without a loss of the species) are widely invoked guidelines for ensuring conservation of threatened species, even in the face of geographically widespread threats such as climate change (Shaffer and Stein 2000). Noss (2001) considered both species and ecosystem-level biodiversity goals and recommended that planners should strive to increase representation of elevational gradients and climatic refugia in forest reserves, as well areas of importance for connectivity.

The priority areas identified in the SITES modeling meet several of these goals. Areas identified are generally large enough to hold viable populations of area-limited species such as grizzly bears and woodland caribou. Furthermore, the proposed priority areas are connected

amongst themselves and with existing protected areas. Because the SITES solutions were relatively robust to the decision to “lock in” protected areas, we can be confident that the proposed priority areas do have high biodiversity value rather than simply connecting or expanding existing reserves. For example, the priority areas centered around Itcha Ilgachuz Provincial Park protect a large area holding ecosystem types that are underrepresented elsewhere, and provide the most robust refugia for the southern mountain population of woodland caribou. Areas highlighted along the southwestern edge of the CCLUP region encompass strong elevational gradients and hence a diversity of ecosystem types, and thus may serve as climatic refugia. Although increased severity of insect outbreaks may trigger a shift in ecosystem composition due to disturbance-dependent migration of southerly tree species and other factors (Johnstone et al. 2003), many of the characteristics that give the CCLUP region high value for carnivore conservation will likely be resilient to climate change if a well-designed network of refugia can be implemented. These characteristics include large areas with low levels of direct human impacts (e.g., roads) coupled with relatively high ecosystem productivity and hence prey densities (e.g., when compared to the Canadian Mountain Parks).

THE RELEVANCE OF ISLAND BIOGEOGRAPHY

The results described here highlight the relevance of the principles of island biogeography to regional conservation planning (MacArthur and Wilson 1967). As the landscape matrix becomes developed either through human settlement or through industrial activities such as logging and its associated roads and infrastructure, the size and connectedness of natural areas become increasingly important to maintaining biodiversity. In a subsequent analysis (Carroll et al. 2004), we used the PATCH results described above to evaluate the ability of the existing

reserve network in the RMC study area to sustain populations of grizzly bear and wolves. Comparison of habitat models between the southern, central, and northern portions of the RMC study region suggested that as the landscape matrix between reserves became more developed, only the largest and most connected reserves sustained viable carnivore populations. In the northern portion of the study area (the Cariboo-Chilcotin region and the Rockies north of Jasper Park), current reserves were, with the exception of the Tweedsmuir and Muskwa-Kechika protected areas, not large or connected enough to preserve viable populations of large carnivores if the landscape matrix becomes unsuitable (Carroll et al. 2004). Thus many reserves which currently hold these species were predicted to lose them unless steps were taken to increase their effective size or connectivity.

CARNIVORES AS FOCAL SPECIES

Although area and connectivity factors are especially important in conserving the carnivore species analyzed here, it is increasingly evident that carnivores may be good focal species for a larger range of biodiversity values (Ray et al. 2005). The use of particular focal species in developing regional conservation plans (Carroll et al. 2001a) complements two other major tracks of conservation planning; special elements and ecosystem representation (Noss et al. 2002). The special elements approach concentrates on occurrences of imperiled species, plant communities, and other rare natural features, as are found in conservation data center databases (Groves 2003). The representation approach seeks to capture examples of all geoclimatic or vegetation types in a network of protected areas. Ecosystem-based conservation strategies include the goal of representing all major environmental gradients. This “coarse filter” is hypothesized to capture occurrences of species about which little is known and therefore would

not be captured by the special elements or focal species approaches (Groves 2003). Carroll et al. (2003) assessed the ability of carnivore-based reserve designs to serve other conservation goals in the central Canadian Rockies. Although a reserve network based on carnivore conservation goals was poor at capturing localized rare species (special elements), it incidentally protected 76% of ecosystem types, suggesting the value of carnivore-based analyses in coarse-filter approaches. Thus the results presented here can 1) help devise effective conservation strategies for the eight focal carnivore species themselves, 2) supplement other coarse-filter approaches based on vegetation type or biogeoclimatic classifications, and 3) highlight trends at the broader geographic scale such as the effects of loss of connectivity on a larger group of threatened species and ecosystems.

COMPARISON WITH OTHER PLANNING PROCESSES

Many regional-scale conservation planning processes have occurred in British Columbia since 1980, and diverse decision-support tools have been used. Early processes used ad-hoc approaches, but more recently, quantitative tools such as SITES (Possingham et al. 2000) have become more common. SITES has been used in numerous ecoregional plans completed by The Nature Conservancy, including the Canadian Rockies plan which was informed by the RMC project results discussed above (Rumsey et al. 2003). SITES has also been applied to the Central Coast planning process (Gonzales et al. 2003, Wells et al. 2003). Gonzales et al. (2003) used a goal-setting approach similar to that used in the RMC study, seeking to represent a proportion of all ecosystem types (Broad Ecosystem Units divided amongst Biogeoclimatic Ecosystem Classification zones). However, in contrast to our analysis, although wildlife habitat goals were incorporated, no subregional stratification was used for the wildlife goals, thus potentially

preserving less well-distributed populations. There was also no consideration of the effect of the connectivity or area of reserves on focal species viability. The resulting reserve design (Gonzales et al. 2003) thus efficiently achieves representation goals in a minimum area but proposes a system of relatively small and scattered reserves that might poorly protect species with large area requirements such as grizzly bear. In addition, unlike the PATCH model used here, the wildlife habitat suitability models used in Gonzales et al. (2003) do not gauge the vulnerability of proposed reserves to future landscape change. Based on the PATCH results for western North America (Carroll 2005), the Chilcotin region may increasingly become a habitat island over the long term for large carnivores due to developed corridors along the highways leading south and westwards from Prince George, as well as development to the south. Steps taken to safeguard connectivity within the Chilcotin region may thus be key to preserving connectivity and viability of carnivore populations over a much larger region that holds the greatest remaining diversity of large carnivores in North America (Figure 5).

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FIGURES

Figure 1. Prioritization of areas for carnivore conservation in the Cariboo/Chilcotin region based on the SITES model results with 40% regional/30% local goals for capturing habitat value. Areas shown in red were included in one or more of 100 replicate SITES solutions, with darker red indicating inclusion in a larger proportion of the 100 solutions. Figure 1a shows solutions which began from inclusion of current protected areas, whereas Figure 1b shows SITES-based prioritizations that did not take into account current management status

Figure 2. Example of PATCH-based goals used in SITES runs. Areas shown in red lie in Quadrant 1 (top-right) of the irreplaceability/vulnerability graph for grizzly bear, that is, areas with both high value as source habitats and high threat. Areas shown in green are the highest value source habitats, that is, the upper portions of quadrants 1 and 2 (top-left) of the irreplaceability/vulnerability graph for grizzly bear. (Areas which meet both goals are also shown in red).

Figure 3. Potential distribution and demography of grizzly bears in the Cariboo/Chilcotin region as predicted by the PATCH model under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25%in yellow.

Figure 4. Potential distribution and demography of wolves as predicted by the PATCH model in western Canada and Alaska under landscape scenario A - current conditions (i.e, potential long-term viability given current habitat conditions). Those areas with a predicted probability of occupancy of less than 25% are shown as “low occupancy”.

Figure 5. Range overlap among ten large carnivore species in North America. Wildlife

Conservation Society Global Carnivore Program, Large Carnivore Mapping Project, used with permission.