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ASSESSING THE FUTURE WILDLIFE IMPACTS OF CONSERVATION AND DEVELOPMENT IN THE MACKENZIE WATERSHED

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Abstract. Located in northwestern Canada, the Mackenzie watershed's intact boreal ecosystems support a diversity of wildlife including hundreds of migratory bird species and sensitive mammals such as the Woodland Caribou (Rangifer tarandus caribou). The watershed also contains abundant timber and hydrocarbon resources such as the oil sands region in northern Alberta and undeveloped gas fields in the Northwest Territories. We conducted a scenario analysis to explore the long-term impacts of natural resource development to the watershed's landscapes and wildlife. Land use simulations using A Landscape Cumulative Effects Simulator (ALCES) computer model compared a business-as-usual development scenario and a conservation scenario that increased protection and implemented practices to reduce the impact of forestry and energy development. The business-as-usual scenario was predicted to reduce older forest and increase anthropogenic footprint. These simulated landscape transformations caused declines in songbird species such as the Canada Warbler (Wilsonia canadensis), Black-throated Green Warbler (Dendroica virens) and Ovenbird (Seiurus aurocapillus), and led to the extirpation of Woodland Caribou. By reducing landscape disturbance, the conservation scenario lessened the predicted impacts to wildlife. The scenario analysis demonstrates the importance of implementing effective conservation strategies prior to wide-scale development in boreal ecosystems.

Key Words: Boreal, conservation, energy, forestry, Mackenzie watershed, scenario analysis, songbirds.

ÉVALUATION DES IMPACTS SUR LA FAUNE QUE REPRÉSENTENT LA CONSERVATION ET LE DÉVELOPPEMENT DANS LE BASSIN VERSANT DU FLEUVE MACKENZIE

Resumé. Situés dans le nord-ouest du Canada, les écosystèmes boréaux intacts du bassin versant du fleuve Mackenzie soutiennent une grande variété d'animaux sauvages, dont des centaines d'espèces d'oiseaux migrateurs et de mammifères vulnérables, comme le caribou des bois. Le bassin versant renferme aussi énormément de bois et de ressources en hydrocarbures, comme les sables bitumineux du nord de l'Alberta et les champs de gaz naturel des Territoires du Nord-Ouest. Nous avons effectué une analyse de scénarios pour étudier les conséquences à long terme de l'exploitation des ressources naturelles sur le paysage terrestre et la faune du bassin versant. Des simulations d'utilisation du sol à l'aide du modèle informatique ALCES ont permis de comparer un scénario d'exploitation maintenant le statu quo avec un scénario de conservation qui augmente la protection et met en place des pratiques visant à diminuer les conséquences du développement forestier et énergique. Il a été estimé que le scénario de maintien du statu quo diminuerait la forêt plus âgée et augmenterait l'empreinte anthropique. Ces transformations simulées du paysage terrestre engendreraient un déclin des espèces d'oiseaux chanteurs comme la paruline du Canada (*Wilsonia canadensis*), la paruline à gorge noire (*Dendroica virens)* et la paruline couronnée (*Seiurus aurocapillus*) et entraîneraient l'extirpation du caribou des bois (*Rangifer tarandus caribou*). En amoindrissant la perturbation du paysage, le scénario de conservation réduirait pour sa part les conséquences prévisibles sur la faune. L'analyse de scénarios démontre donc l'importance de mettre en place des stratégies de conservation efficaces avant d'exploiter à grande échelle les écosystèmes boréaux.

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INTRODUCTION

The Mackenzie watershed spans more than 170 million hectares in northwestern Canada, two thirds of which are intact and undisturbed by development (Anielski and Wilson 2007). In large part due to its intactness, the region is of immense ecological value. More than 100 bird species have greater than 10% of their North American breeding range located in the watershed (Wells 2006), and make up part of the billions of birds that breed in Canada's Boreal Forest each year prior to migrating south to the United States and Central and South America (Blancher 2003). Northern Canada, including the Mackenzie watershed, is also a stronghold for mammals such as the Woodland Caribou (*Rangifer tarandus caribou*) that have suffered declines in their southern range (Laliberte and Ripple 2004).

The region is also of economic importance due to its vast natural resources including timber, minerals, and especially oil and natural gas. The Athabasca oil sands region, located within the Alberta portion of the watershed, has the second largest oil reserve in the world at 27.7 billion cubic meters (Alberta Energy 2006). In the Northwest Territories, a proposed pipeline to transport gas from the Mackenzie Delta-Beaufort Sea natural gas fields would transect the watershed and make it more feasible to develop these and other gas deposits located in the region.

The extraction of natural resources from the Mackenzie watershed generates a gross domestic product of approximately $42 billion each year, and the footprint created by this development is estimated to cover 15% of the watershed (Anielski and Wilson 2007). Conservation has not kept pace with the rapid advance of development. Only 6% of the region is protected (Anielski and Wilson 2007). In addition, concerns have been raised that practices used by industry to extract natural resources from the region are unsustainable (Cizek et al. 2002, Schneider and Dyer 2006).

In response to concerns about threats to Canada's Boreal Forest (Senate Subcommittee on the Boreal Forest 1999) and the unique opportunity to plan proactively due to the relative intactness of the region, a group of First Nation, industry, and conservation organizations formed the Boreal Leadership Council in 2003 and developed a vision for boreal conservation called the Boreal Forest Conservation Framework (Canadian Boreal Initiative 2003). Guided by the principles of conservation science and supported by 1500 scientists (Canadian Boreal Initiative 2007), the Framework recommends: 1) protection of at least 50% of the region in a comprehensive network of large protected areas that safeguards ecological services and ecosystem integrity, and 2) world-leading ecosystem-based resource management practices in the remaining landscape. Two members of the Boreal Leadership Council, the Dehcho First Nation and Alberta-Pacific Forest Industries (Al-Pac), are pursuing conservation strategies in the Mackenzie watershed.

This study explored how development of the Mackenzie watershed's natural resources may transform the region over the next 100 years. Bird and Woodland Caribou habitat was used in this study to assess the ecological effects of future land use. Our intention was two-fold. First, at a general level, we sought to increase awareness of the Mackenzie watershed and how impending economic development may alter one of the world's most intact ecosystems. Second, by assessing the future effects of conservation strategies that are being pursued by the Dehcho First Nation and Al-Pac, we evaluated the capacity of the Boreal Forest Conservation Framework to balance economic development with conservation of the watershed's ecological integrity.

METHODS

Study Areas

To explore the future effects of development to the Mackenzie watershed, land-use simulations were conducted for the Alberta-Pacific Forest Management Agreement area (Al-Pac FMA) in northeastern Alberta and a southern portion of the Dehcho Territory (southern Dehcho) in the Northwest Territories (Fig. 1). The 6.5 million ha Al-Pac FMA is one of the most heavily developed portions of this watershed and contains a substantial portion of the Athabasca oil sands. The 4.5 million ha southern Dehcho is rich in gas deposits but, unlike the Al-Pac FMA, development has been limited to date. Together, these two study areas provided an opportunity to assess and compare development impacts and conservation opportunities in areas where the allocation of natural resources to development is currently high (Al-Pac FMA) and low (southern Dehcho).

Land Use Simulations

The effects of development over a 100-year time frame were assessed using the A Landscape Cumulative Effects Simulator (ALCES) computer model (Stelfox and Farr 2005). ALCES was selected because of the model's capacity to simulate the cumulative effects of the three

FIGURE 1. Location of the Al-Pac FMA (black) and southern Dehcho Territory (grey) within the Mackenzie watershed (light grey).

major types of land use in the region (forestry, oil and gas exploration, and agriculture) and because the model is an accepted and widely applied planning tool in the region (e.g., Farr et al. 2004, Salmo Consulting Inc. 2004). ALCES was parameterized to reflect the current status of the study areas using inventories of forest and non-forest cover types and industrial disturbances including roads, well sites, seismic lines and pipelines (Carlson et al. 2007). For the southern Dehcho, forest age information was not readily available from inventories and instead was approximated using simulations of the fire regime.

ALCES simulated land use in each study area under two development scenarios. A business-as-usual scenario was simulated to explore the effects of expected resource development and conventional conservation strategies. A Boreal Forest Conservation Framework (Framework) scenario was also simulated to explore the effects of an increased conservation effort. In keeping with the Framework, the scenario consisted of increased levels of protection and strategies to mitigate disturbance from resource development being pursued by Alberta-Pacific Forest Industries (Alberta-Pacific Forest Industries 2004) and the Dehcho First Nations (Dehcho Land Use Planning Committee 2006) (Table 1).

The future rate of development simulated for study areas was based on information gathered from a variety of sources that reflects both the availability of natural resources and the likely rate at which the resources will be developed

TABLE 1. Protection and sustainable management measures implemented in the Framework scenario for the Al-Pac FMA and southern Dehcho study areas.

Al-Pac FMA	Southern Dehcho
Increased proportion of protected land base from 3% to 6%	Increased proportion of protected land base from 0% to 48%
Reduced seismic line width from 5 meters to 1 meter. Reduced seismic line lifespan from 46 years to four years.	Reduced seismic line width from 3.5 meters to 1 meter. Reduced seismic line lifespan from 59 years to four years.
Reduced reclamation time for well sites and access roads from 25 years to immediately after cessation of production.	Reduced reclamation time for well sites and access roads from 25 years to immediately after cessation of production.
Prevented forestry activity from reducing the relative abundance of old forest below 25% of total deciduous forest, 19% of total mixedwood forest and 16% of total white spruce forest.	

(Carlson et al. 2007). The simulations tracked landscape disturbances created by future development including: seismic lines, pipelines, access roads, production well sites and exploratory well sites for hydrocarbon development; cut blocks, forestry roads and landings for forestry development; and cropland and pasture for agricultural expansion. Simulated intensity and lifespan of these disturbances were based on regional data (Carlson et al. 2007). The impact of fire was also included in simulations based on regional burn rates (Carlson et al. 2007). A constant rather than random annual fire rate was simulated so that sporadic large fire years did not obscure scenario comparisons.

Wildlife Models

Habitat models based on knowledge of species' habitat associations were combined with simulated changes in landscape composition to evaluate bird and Woodland Caribou response to future land-use activities. The wildlife models are summarized here and explained in greater detail by Carlson et al. (2007).

Bird species for the analysis were selected to provide a diversity of habitat associations. Included were species associated with old forest (Black-throated Green Warbler [*Dendroica virens*], Bay-breasted Warbler [*Dendroica castanea*] and Canada Warbler [*Wilsonia canadensis*]), mature forest (Ovenbird [*Seiurus aurocapillus*]) and younger forest (White-throated Sparrow [*Zonotrichia albicollis*]). When selecting species with these traits, preference was given to species for which information was available on the effect of industrial disturbances (Ovenbirds and Canada Warbler). Ovenbirds treat linear disturbances as territory boundaries, which can result in a negative relationship between disturbance density and Ovenbird abundance (Bayne et al. 2005, Machtans 2006). Canada Warbler density at the landscape scale is influenced by the amount of industrial footprint associated with forestry and hydrocarbon development (unpublished analysis by Steve Cumming (Université Laval) and Fiona Schmiegelow (University of Alberta)).

Bird habitat models were estimated using extensive bird data from the region provided by Erin Bayne, Fiona Schmiegelow and Steve Cumming. The total number of Black-throated Green Warbler, Bay-breasted Warbler, Ovenbird and White-throated Sparrow singing males was modeled using a random effects model with a Poisson distribution fitted using 22 995 point count samples collected mainly in the Al-Pac FMA. The random effect was the researcher who provided data, with the rationale that differences in researcher methodology may play a role in influencing estimates of bird abundance. Model covariates were the proportion of area around each point count that was coniferous trees, age of the forest, and a log-ratio vector describing the leading species.

Population size associated with a simulated landscape was then estimated by multiplying bird density per hectare of habitat from the habitat models by the number of hectares of that habitat predicted to occur by ALCES. The estimates of density were considered minimal estimates as corrections for detectability and effective sampling radius were not included. The model for the Canada Warbler estimated an index of habitat availability based on the results of an analysis of northern Alberta data completed by Kathy St. Laurent (University of Alberta). For Ovenbirds and Canada Warblers, sufficient information was available to also model the effects of industrial disturbances such as roads, seismic lines and well sites. Ovenbird population size was down-weighted to account for the dissection of habitat by linear disturbances wider than three meters and edge effects created by well pads and other industrial

facilities. Canada Warbler habitat availability index was down-weighted to account for the effect of industrial disturbances associated with forestry and energy development.

Due to their susceptibility to predation, Woodland Caribou are sensitive to industrial disturbance (Vors et al. 2007). Industrial disturbances can increase the density of alternative prey such as Moose (*Alces alces*) and facilitate access for predators such as Wolf (*Canis lupus*), resulting in predation pressure that exceeds sustainable levels. The response of Woodland Caribou to simulated landscape change was evaluated using a population model based on data from 330 female caribou that were monitored from six populations in northern Alberta between 1993 and 2001. Sorensen et al. (submitted) found that two home range attributes explained 96% of the observed changes in caribou population growth. The home range attributes were the size of the area within 250 m of industrial disturbances (roads, seismic lines, pipelines, well sites) and the size of the area burned within the last 50 years.

RESULTS

In both study areas, the business-as-usual scenario resulted in an increased density of linear disturbances and a decreased area of older productive softwood forest. Changes to the density of linear disturbances and area of older productive softwood forest often exceeded disturbance thresholds that have been proposed to protect against negative effects to wildlife, which suggested that business-as-usual development is not sustainable (Figs. 2 and 3). The conservation strategies that formed the Framework scenario reduced landscape disturbance, often to within the boundaries of disturbance thresholds. In the southern Dehcho, the density of linear disturbances remained below the disturbance threshold and half of the study area was kept free from industrial disturbance. Decline in the area of older productive softwood forest was not avoided because non-productive forest dominated the protected areas, thus illustrating the importance of adequately protecting all forest types. In the Al-Pac FMA, application of the Framework scenario was able to reduce the rate of decline in the area of older productive softwood forest. The linear disturbance threshold was exceeded, however, demonstrating that it will be challenging to avoid negative ecological effects of development in the southern Mackenzie watershed.

Simulations of a business-as-usual scenario predicted that the caribou population would decline in both study areas, indicating that the species is likely to be extirpated unless conservation strategies are improved (Fig. 4). In the southern Dehcho, the simulation predicted a 21% decline in Ovenbird and Bay-breasted Warbler populations and a 32% decline in a habitat availability index for the Canada Warbler (Fig. 5). In the Al-Pac FMA, Black-

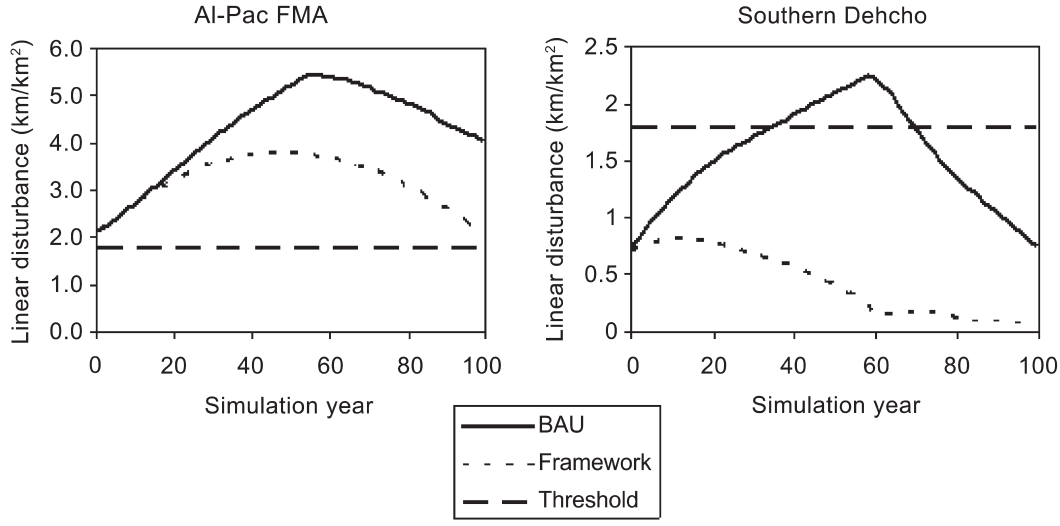

FIGURE 2. Simulated density of linear disturbances in response to business-as-usual (BAU) and Framework land-use scenarios. A threshold of 1.8 km per km^2 has been proposed for the region based on a review of the cumulative impacts to wildlife (Salmo Consulting Inc. 2004). The threshold is displayed on the graphs to aid interpretation.

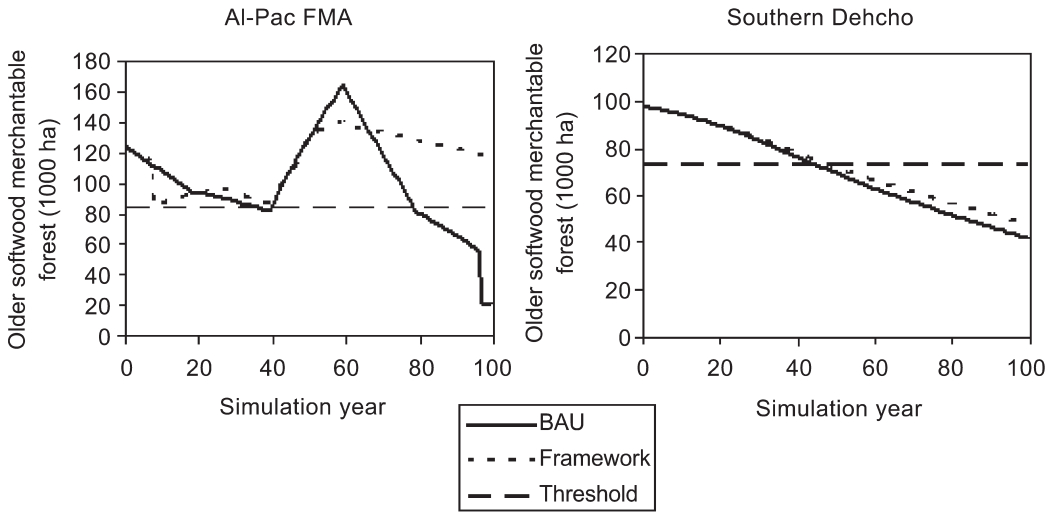

Figure 3. Simulated older (>120 year) productive softwood forest area in response to business-as-usual (BAU) and Framework land-use scenarios. Alberta-Pacific Forest Industries (2004) sets a target of maintaining at least 75% of the average area of older forest expected solely from fire. This threshold is indicated on each graph to aid interpretation.

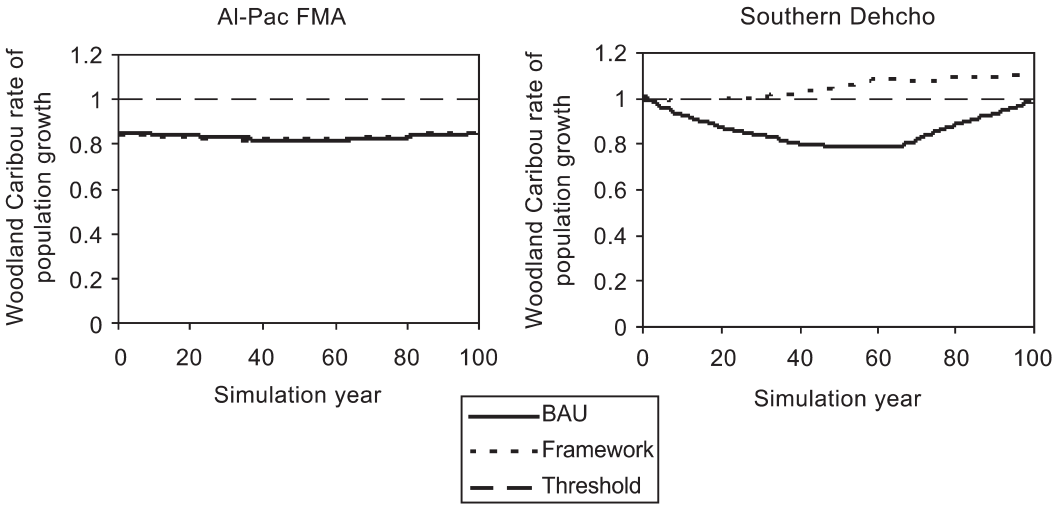

FIGURE 4. Simulated Woodland Caribou rate of population growth in response to business-as-usual (BAU) and Framework land-use scenarios. A viable population requires that the rate of population growth is ≥ 1.

throated Green Warbler population declined by 60% (Fig. 6) and Ovenbird population declined by 34%. White-throated Sparrow, on the other hand, increased in abundance by approximately 30% (Fig. 7). As such, industrial development can be expected to make common generalists more abundant and cause rare and more specialized species to decline.

The conservation strategies implemented in the Framework scenario mitigated some, but not all, of the wildlife impacts. In the southern Dehcho, long-term persistence of Woodland Caribou was achieved (Fig. 4) and the declines in Ovenbird population and Canada Warbler habitat availability index (Fig. 5) were reduced. The decline in the Bay-breasted Warbler population, on the other hand, was not avoided. In the Al-Pac FMA, old forest protection was able to substantially reduce the decline in Black-throated Green Warbler population (Fig. 6). Woodland Caribou

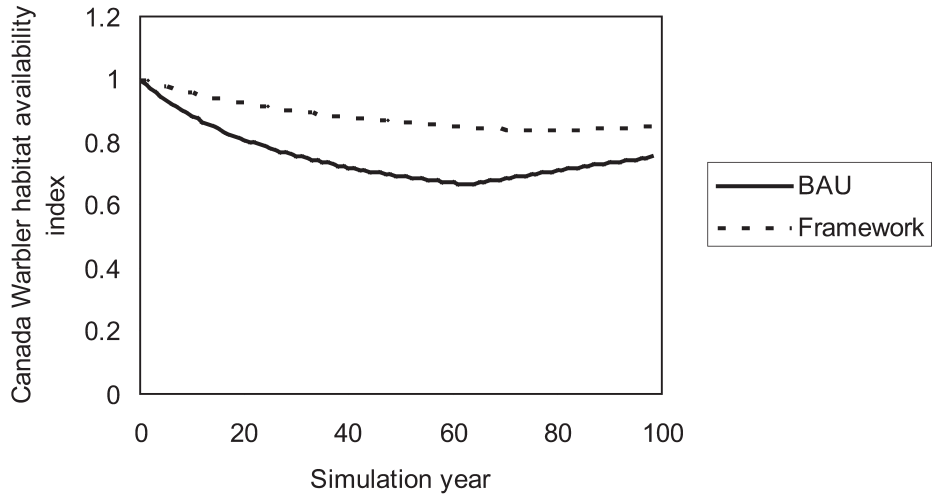

FIGURE 5. Simulated Canada Warbler habitat availability index in response to business-as-usual (BAU) and Framework land-use scenarios in the southern Dehcho. The habitat availability scores are presented as a proportion of habitat availability at the start of the simulation to aid interpretation.

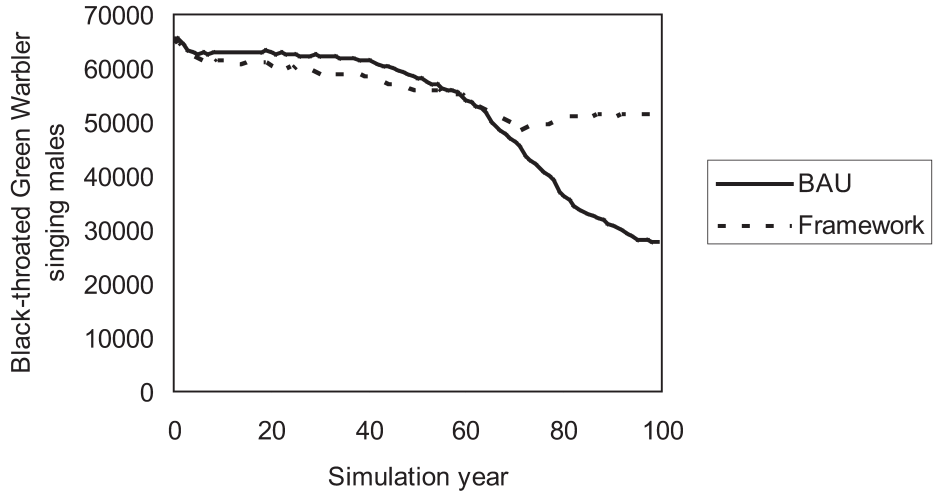

Figure 6. Simulated Black-throated Green Warbler population in response to business-as-usual (BAU) and Framework land-use scenarios in the Al-Pac FMA.

rate of population growth remained in decline in the Al-Pac FMA despite implementing the Framework scenario (Fig. 4), indicating that the conservation strategies that were simulated are unlikely to prevent caribou extirpation. If this species is to be conserved in portions of the Mackenzie watershed that are already allocated to resource development, more aggressive conservation strategies are needed, including the protection of larger areas of forest.

Simulations also tracked oil, gas and timber production to estimate the amount of resource production sacrificed by implementing conservation strategies. Although resource production declined during simulation of the Framework scenario compared with the business-as-usual scenario, the decline was small in relation to total resource production levels. The greatest decline in production was a drop of 20 billion cubic meters in gas production in the southern Dehcho, which accounted for less than 0.1% of the projected revenue generated by oil and gas production in the two study areas combined.

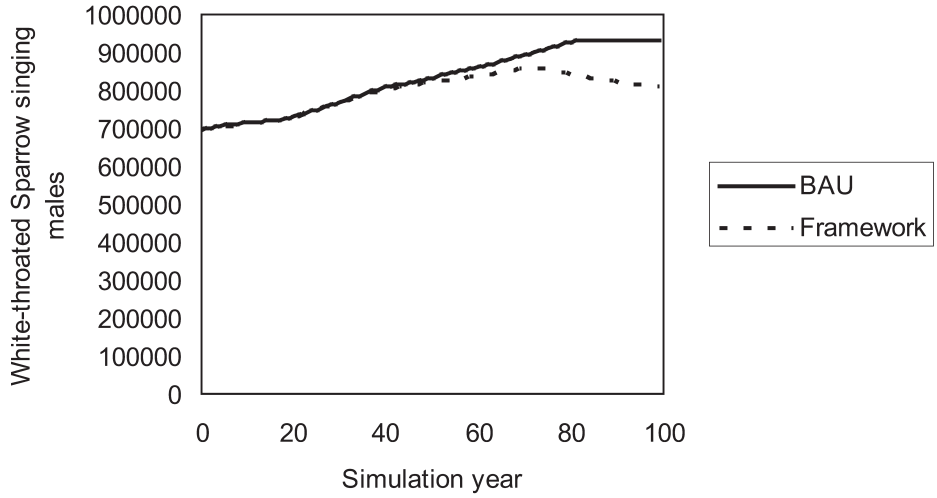

FIGURE 7. Simulated White-throated Sparrow population in response to business-as-usual (BAU) and Framework land-use scenarios in the Al-Pac FMA.

DISCUSSION

Land-use simulations predicted that the upcoming decades will bring about a profound transformation of the Mackenzie watershed. Business-as-usual development expanded industrial disturbance and diminished older forest, placing Woodland Caribou and old forest songbirds at risk of extirpation. The projected impacts, while dramatic, are similar to impacts that have already occurred in other regions such as the Fennoscandian Boreal Forest (Andersson and Ostlund 2004) and more southerly regions in North America (Laliberte and Ripple 2004). In the southern Mackenzie watershed, where industrial disturbances are abundant, Woodland Caribou herds are already in decline (McLoughlin et al. 2003) and extirpation has been predicted elsewhere (Weclaw and Hudson 2004). The present ecological integrity of the Mackenzie watershed is a result of the region's remoteness, rather than the result of intentional conservation. The region is one of the last on Earth to be developed. Should development proceed according to the status quo, ecological integrity will follow the same downward trend witnessed in developed regions worldwide.

Predictions made in this study depend on the development trajectories assumed in the simulations. If future development is less than what was assumed, the environmental impacts will be diminished. This could occur if demand for oil and gas declines or if estimates of the study areas' oil and gas potential are exaggerated. Just as likely is future development that will exceed what was assumed and that realized environmental impacts will be greater than that predicted by simulations. This could occur if the study areas' oil and gas potential is underestimated due to, for example, the use of novel extraction techniques in the future.

Remote northern ecosystems such as the Dehcho Territory are, for the most part, less studied than southern portions of the Mackenzie watershed. Due to the paucity of ecological data for the Dehcho Territory, the simulated response of flora and fauna to disturbance was based predominantly on relationships estimated from southern portions of the Mackenzie watershed such as the Al-Pac FMA. Available evidence suggests that sensitivity to development may increase in northern portions of the watershed relative to the south. The simulated effect of mitigation strategies such as accelerated seismic line and well site reclamation, for example, is based on experience from the southern Mackenzie watershed and may exaggerate the capacity of mitigation strategies in the Dehcho Territory and other northern areas where habitat can take long periods to recover from disturbance (e.g., Seccombe-Hett and Walker-Larsen 2004). Similarly, a Woodland Caribou model that is being developed for the Northwest Territories is demonstrating greater sensitivity to industrial footprint than assumed by the Woodland Caribou model used in this study (John Nagy, University of Alberta, pers. comm.). As such, the simulated impact of land use to the southern Dehcho ecosystem may be underestimated. Research is needed to better understand the ecological response of the Dehcho Territory and other northern areas to land use.

This study considered the influence of future land use on landscape composition and wildlife habitat. Climate change will also affect the future status of the Mackenzie watershed. An analysis of the impacts of climate change on the watershed concluded that several negative effects are likely to occur (Cohen 1997). For example, the annual area burned by forest fire was predicted to double, which would decrease the average age of forest in the region. Other predicted changes to the ecosystem included the drying of peatlands, invasion by pests, and greater stress on caribou caused by heavier snow cover and more insects. Due to these and other impacts, the exclusion of climate change from our simulations should tend to underestimate the stresses that the Mackenzie watershed will face in the future.

While the simulations showed that the Mackenzie watershed faces real threats, they also demonstrated that viable opportunities exist to mitigate these threats. The southern Dehcho simulations demonstrated that large-scale protection combined with sustainable development can maintain the Woodland Caribou while allowing for economic development. Simulations for the Al-Pac FMA showed that old forest targets and aggressive strategies to minimize industrial disturbance can substantially reduce negative impacts to species associated with older forest, such as the Black-throated Green Warbler.

Comparison of results from the Dehcho and Al-Pac FMA simulations offers two insights into conservation opportunities in southern (e.g., Al-Pac FMA) versus northern (e.g., Dehcho) Boreal Forest areas. First, southern Boreal areas are of unique ecological value because of their higher productivity and diversity. For example, the Al-Pac FMA contains some bird species that are not found in the southern Dehcho, such as the Black-throated Green Warbler. Other bird species such as the Ovenbird, Bay-breasted Warbler and Canada Warbler are found in the southern Dehcho, but at much lower densities (i.e., 5% in the case of the Ovenbird). Therefore, it is critically important that conservation strategies are implemented in southern Boreal Forest areas to conserve values that are absent in northern Boreal areas.

Second, current levels of protection in southern Boreal Forest areas are insufficient to protect sensitive and wide-ranging wildlife such as Woodland Caribou. Given the difficulty of substantially increasing protection in heavily allocated regions, a diminished level of ecological integrity in southern Boreal areas will be unavoidable. This finding points to the importance of protecting large portions of unallocated northern Boreal regions while the opportunity remains. Attempts to build a network of protected areas in the Dehcho Territory in future decades, once resources have been allocated, will be both expensive and problematic.

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