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Does expected future landscape condition support proposed population objectives for boreal birds?

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ABSTRACT

Assessing the feasibility of proposed Bird Conservation Region (BCR) population objectives requires comparing expected future population size estimates to proposed population objectives. Linking statistical bird habitat models with landscape simulation models can provide a direct method for assessing the ecological and economic implications of alternative land and resource scenarios within a BCR or BCR subregion. We demonstrate our approach for analyses of future habitat supply and population size for a suite of priority landbird species using the ALCES® landscape simulation model and empirical bird habitat models within a multi-use landscape located in northeast Alberta, Canada and BCR 6-Boreal Taiga Plains. We used ALCES® to simulate future landscape condition over a 100 year time period under three scenarios: business as usual, protected areas, and climate change. Shortfalls between simulated population size estimates at year 30 and proposed population objectives existed for each of the four priority bird species examined suggesting that expected future landscape condition will not support proposed population objectives for these species. Boreal species strongly associated with mature and old forest habitats exhibited population declines over the 100 year simulation period. One habitat generalist, a species associated with both early and late seral stages, appeared to benefit from the range of land use scenarios examined. Our approach improves upon current static approaches used to step down BCR scale population objectives to sub-regional scale habitat objectives by utilizing statistical bird population response models to estimate density and a dynamic landscape simulation model to estimate expected future habitat condition.

1. Introduction

The North American Bird Conservation Initiative (NABCI) was formed in 1999 with the mission to deliver bird conservation through regionally based, biologically driven, landscape oriented partnerships across Canada, the United States, and Mexico. To facilitate integration and cooperation among various avian conservation partners NABCI (1) defined ecologically distinct regions with similar bird communities, habitats, and resource management issues known as Bird Conservation Regions (BCRs), and (2) set continental objectives for population size for most North American birds that were based largely on reversing population declines over the next 30 years (Rich et al., 2004). Conservation partners are now stepping down continental population objectives to the BCR scale to direct on-the-ground conservation. This includes the development and application of regional scale habitat objectives that, if achieved across BCRs, will help reach continental population objectives. Fundamental steps in the process to create habitat objectives are (1) conducting habitat assessments across the BCR, (2) estimating bird density and population size by habitat, and (3) applying population estimates to habitat assessments to determine the quantity and quality of breeding habitats needed to meet population objectives at the BCR scale (Will et al., 2005). This process assumes that amount of breeding habitat is the main factor limiting avian populations and that reversing long-term population declines at BCR or landscape scales will be achieved by increasing the availability of suitable breeding habitat.

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A number of approaches have been proposed to link bird population size estimates with habitat assessments at BCR and landscape scales in order to develop habitat objectives (Jones-Farrand et al., 2011; Rosenberg and Blancher, 2005; Thogmartin et al., 2004; Thogmartin and Knutson, 2007; Tirpak et al., 2009) (for a review see Fitzgerald et al., 2009). A major limitation of these approaches is the static nature of the habitat assessments. Existing regional and sub-regional land use and resource development plans are documents that could be used to (1) anticipate future landscape change and subsequent influences on habitat supply, bird population sizes, and conservation design, and (2) assess whether regional population objectives are feasible. A variety of advanced landscape simulation models such as ALCES (A Landscape Cumulative Effects Simulator; Schneider et al., 2003), LANDIS (Forest Landscape Disturbance and Succession; Mladenoff and He, 1999), LMS (Landscape Management System; McCarter et al., 1998), and SELES (Spatially Explicit Landscape Event Simulator; Fall et al., 2001) can be used by land managers to project future habitat conditions (i.e., age, species composition of vegetation types) across complex, multi-use landscapes. In forested systems, these models allow users to specify rates of forest growth and succession, natural disturbance, resource development, urban expansion, and habitat reclamation or recovery, and then project future changes in habitat supply given alternative management scenarios. Many studies have used the output from these landscape simulation models in tandem with wildlife habitat suitability indices (HSI) to evaluate the effects of alternative scenarios of forest management on the quality and quantity of wildlife habitat (Larson et al., 2004; Marzluff et al., 2002; Shifley et al., 2006).

One limitation of the HSI–landscape modeling approach is that HSI models do not estimate bird density which is required to generate population size estimates. Habitat models that estimate avian densities relative to forest type and forest age can be applied to dynamic landscape models so that the effects of simulated changes in future habitat supply (e.g., the amount, type, and age of forests) can be evaluated in terms of their impacts on avian population sizes. Ideally avian densities should be empirically estimated from avian survey data and adjusted for incomplete detection probabilities and how these vary among habitats, temporal sampling frames, and differences in survey protocols (i.e., count duration and count radius) (Matsuoka et al., 2012; Sólymos et al., 2013).

In this study our objective was to demonstrate a new approach for stepping down BCR population objectives for four priority landbirds within the 6.86 million ha Forest Management Agreement area of Alberta-Pacific Forest Industries Incorporated in Bird Conservation Region 6-Boreal Taiga Plains (hereafter BCR 6). Although this landscape is largely intact, resource development is diverse, intensive at local scales, extensive in spatial extent, and occurring at a rapid rate. This landscape provides a unique opportunity to assess whether proposed aspirational BCR population objectives can be achieved. Our approach uses a comprehensive modeling procedure that combines a landscape simulation model with statistical bird habitat models that estimate species density. We used a land use accounting model, A Landscape Cumulative Effects Simulator III (hereafter ALCES®; Schneider et al., 2003), to simulate changes in habitat supply for three land use scenarios over a 100 year time period within a rapidly changing, multi-use landscape in northeast Alberta, Canada. We used an extensive database of point counts in northern Alberta, forest attribute data, and a new density estimator (Sólymos et al., 2013) to model bird-habitat relationships and derive habitat-specific density estimates. We then evaluated each scenario and the associated impacts on the population size of our four priority landbird species by applying habitat-specific estimates of avian density to simulated ALCES® output. Finally, we assessed the feasibility of the proposed BCR 6 population objectives, by comparing these population objectives against our simulations of future population sizes from each land use scenario.

2. Methods

2.1. Study site

Our study area comprised the Forest Management Agreement (hereafter FMA) area of Alberta-Pacific Forest Industries Incorporated (hereafter Al-Pac) located in northeast Alberta, Canada and BCR 6. The Al-Pac FMA encompasses 6.86 million ha in northeastern Alberta, Canada (Fig. 1) and is found within the Boreal Forest natural region and the Central Mixedwood, Dry Mixedwood, and Boreal Highlands natural subregions (Beckingham and Archibald, 1996). The Boreal Mixedwood ecological area dominates the subregions found within the Al-Pac FMA. Summer (May, June, July, August) mean temperature ranges from 7.2 to 20.2 °C and mean total precipitation is 2.4 cm. Within the Boreal Mixedwood, mesic sites in upland areas are dominated by pure and mixed stands of trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) mixed with balsam poplar (*Populus balsamifera*), white birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*), while drier upland sites are dominated by jack pine (*Pinus banksiana*). Lowland areas are composed of wetlands in the form of marshes, swamps, and black spruce (*Picea mariana*) and tamarack (*Larix laricina*) dominated bogs and fens (Beckingham and Archibald, 1996).

Stand boundaries (polygons), forest type (composition), and forest age were derived from Alberta Vegetation Inventory, a forest resource inventory database provided by Al-Pac that is used for resource industry and land-use planning applications. The inventory is created by interpreting medium-scale (1:60,000 or 1:40,000) aerial photographs to map vegetation cover types and determine the origin year (age) in forested stands and other vegetated and non-vegetated cover types. Vegetation plots, air calls (low elevation over-flights of area to be mapped), and past plots and surveys (temporary or permanent sample plots, regeneration surveys) are also used as information sources to map current vegetation conditions (Alberta Sustainable Resource Development, 2005). Classification error is unknown but potential map classification errors likely exist for the two spruce-dominated forest types: white spruce and hygric softwood/black spruce. Within the Al-Pac FMA, 4.77 million ha is not commercially productive, while 2.10 million ha is managed for timber harvest. The study area is managed using sustainable forest management, which considers ecological or biodiversity objectives (e.g., habitat), economic objectives (e.g., wood supply), and social objectives (e.g., heritage resources) when managing human activities within forest ecosystems (Alberta-Pacific Forest Industries, 2007). The operational harvesting currently being conducted within the Al-Pac FMA is within its first forest rotation (rotation age is the number of years required to establish and grow timber to maturity) although planning to identify harvest levels (annual allowable cut) is being conducted for a period equivalent to two forest rotations (200 years). In addition to forest harvesting, large-scale oil sands development that involves bitumen exploration, extraction (mines, in-situ sites), and infrastructure construction is co-occurring within the Al-Pac FMA.

2.2. Landscape simulation approach

We used the dynamic land use accounting model ALCES® to (1) specify the current landscape condition within the Al-Pac FMA, and (2) simulate future changes in forest habitat supply for existing and alternative land use scenarios (www.alces.ca). ALCES® is a non-spatially explicit simulation model designed to track the cumulative effects of ecological processes and human activities under alternative management scenarios (Carlson et al., 2011;

Fig. 1. Map of the Alberta-Pacific Forest Management Agreement area (hatched) within Bird Conservation Region 6-Boreal Taiga Plains (shaded).

Schneider et al., 2010). Within the Al-Pac FMA, ALCES® has been used to quantify the cumulative effects of natural disturbance and anthropogenic disturbance resulting from current resource development and explore alternative land and resource management scenarios (Schneider et al., 2003). By specifying the initial state of the Al-Pac FMA and providing quantitative assumptions about forest growth and succession, natural disturbance, resource development, urban expansion, and regeneration trajectories, the model tracks and updates the state of the landscape in one-year time steps for 100 years (Schneider et al., 2003). A variety of sources were used to parameterize ALCES® including inventories of vegetation types, industrial disturbances and footprint, and human settlement. Assumptions regarding future resource development were based on both the availability of natural resources and historical rates of resource development. To model the future trajectory of key land use disturbances, the development rate and lifespan of primary footprint types were assessed using historical data (Carlson, 2011; Schneider et al., 2003). For example, forest harvesting procedures were matched to industry practices in use in Alberta, Canada including harvest levels, rotation length, silvicultural systems, and stand growth and yield curves. To model the future trajectory of wildfire, the average historical burn rate for the Al-Pac FMA was used to estimate long-term rates of fire (Carlson, 2011). For the analysis presented here we limited the natural disturbances to wildfire and the land use disturbances to: forest harvesting; bitumen exploration and development (bitumen mining, bitumen extraction using in-situ techniques); transportation; and human settlements. Simulations tracked primary footprint types created by future land use disturbances including: gravel pits and transmission lines for forest harvesting (harvest units were tracked as cover types); bitumen mine sites, industrial plants, seismic lines, pipelines, and production and exploration wellsites for bitumen development; major and minor roads (including all forestry and energy access roads) for transportation development; and cities, towns, and acreages for human settlement. ALCES® does not track the spatial location of all landscape features but instead stratifies the landscape into multiple subunits (e.g., forest types, forest type-age classes) that can be tracked independently.

We used an analysis of forest resource inventory and footprint inventory data to specify the initial state (2011) of the Al-Pac FMA. We assessed the initial area of forested habitat types (hereafter forest types) and non-forested habitat types within the Al-Pac FMA from forest resource inventory data (Table A1). The initial age class distribution of forest types was estimated by determining the area of each age class (10–20 year age classes) for five forest types: hardwood, mixedwood, white spruce, pine, hygric softwood/black spruce. We assessed the age of each forest type using the number of elapsed years since the last stand-replacing disturbance event (Table A2). We assessed the initial distribution of primary footprint types by intersecting footprint inventory data (Table A3) with habitat types except for footprint types that exist as cover types within forest resource inventory data (industrial, rural residential, town and gravel pit). Primary footprint types are the key activities associated with the land use disturbances tracked by ALCES® (forest harvesting, bitumen exploration and development, transportation and settlement). We focused our analyses on the five forest types within the Al-Pac FMA due to our interest in understanding how land use activities influence both habitat supply and population size estimates for forest-associated priority landbird species. We used the same estimates of the initial state of the Al-Pac land base for all scenarios to minimize bias in our ALCES® output and subsequent bias in our landbird population estimates.

2.3. Scenario descriptions

We used ALCES® to simulate changes in forest types for the existing land use scenario, business as usual, and two alternative land use scenarios, protected areas, and climate change, in order to assess impacts on future habitat supply and population size estimates of our four priority landbird species. Scenarios represented existing and proposed management and conservation policies in northeast Alberta (Table A4). In the Al-Pac FMA, the business as usual simulation represents a continuation of current land use practices and all associated anthropogenic footprint: forest harvesting (harvest units, gravel pits and transmission lines), bitumen exploration and development (bitumen mine sites, industrial plants, seismic lines, pipelines, and production and exploration wellsites), transportation (major and minor roads), and human settlements (towns/cities and acreages). The protected areas simulation represents a key regional conservation objective in the Lower Athabasca Regional Planning area (Alberta Environment Sustainable Resource Development, 2012). The protected areas simulation designates 20% of the FMA (distributed evenly across all forest types) to serve as conservation/protected areas (removed from the harvest schedule). The climate change scenario increases the fire rate to a maximum of 2.28% per year over the course of 100 years (from the current rate of 0.61% per year) due to expected future changes in air temperature and fuel moisture within forest types. Projected burn rates were obtained for the 2.5° cell that overlaps with the majority of the study area. The average burn rate was calculated for 25 year intervals and represents a low emissions (slow climate change) scenario (Balshi et al., 2009). ALCES® tracked the age-class distribution of each forest type in response to continuous changes in forest growth and succession, natural disturbance, resource development, urban expansion, and regeneration trajectories and presented the output in one-year time steps.

2.4. Bird habitat models

We focus here on four priority landbird species in BCR 6 (Environment Canada, 2013) to demonstrate our approach for stepping down BCR 6 population objectives. Priority landbird species in BCR 6 were selected after applying both continental and BCR scale assessment criteria that include breeding distribution, population size and trend, relative density, and threats during the breeding and non-breeding seasons (Environment Canada, 2013; Rich et al., 2004). We selected four priority landbird species with (1) decreasing or unknown population trends in BCR 6, and (2) diverse habitat use patterns within forest types represented in the Al-Pac FMA: Black-throated Green Warbler (*Setophaga virens*), Boreal Chickadee (*Poecile hudsonica*), Western Tanager (*Piranga ludoviciana*), and White-throated Sparrow (*Zonotrichia albicollis*). We developed statistical bird-habitat models to predict species abundance using existing point count data from a variety of data sources in the Boreal Forest natural region of Alberta. Data sourced only from Breeding Bird Survey routes are inappropriate for deriving population estimates in boreal regions because of placement of routes and roadside effects (Rosenberg and Blancher, 2005; Thogmartin et al., 2006).

We estimated bird densities for each combination of bird species, forest type, and forest age class using data from avian point count surveys (38,572 point counts) compiled by the Boreal Avian Modelling Project or conducted by the Alberta Biodiversity Monitoring Institute within boreal Alberta over the last 20 years. Point count data compiled by the Boreal Avian Modelling Project is sourced from individual research and monitoring projects, Breeding Bird Atlas programs, and the Breeding Bird Survey (1993–current). Point count data conducted by the Alberta Biodiversity Monitoring Institute has been collected using a split panel design across a systematic network of sample sites (2003–current). We used survey data from throughout boreal Alberta because we had small numbers of point counts within several combinations of forest type-age classes within the Al-Pac FMA. We used generalized linear mixed models (GLMM) to estimate the mean survey count of each bird species in each forest type-age class. We used a negative binomial error distribution because the count data were overdispersed (variance > mean). GLMM allows for the simultaneous modeling of categorical and continuous predictor variables. We adjusted the standard errors to account for lack of independence caused by repeated sampling at some point count locations within years and over multiple years. The fixed effects included the following forest stand attributes measured from forest resource inventory data within a 150 m radius circle centered on the point count: average stand age weighted by the area of each stand within the circle; standard deviation of stand age; maximum stand age; dominant forest type; proportion of circle forested; and type of non-forested habitats. We also included land use region because the Al-Pac FMA includes multiple planning regions as defined by the Alberta Land Use Framework (Table A5). Mean survey counts for each bird species in each forest type-age class represent average counts across multiple years of survey data.

We used a density estimator (Sólymos et al., 2013) to estimate the detection probability for each point count survey and used the detection probabilities to transform the GLMM predictions of survey counts to estimates of density (singing males per hectare). The density estimator (Sólymos et al., 2013) is a unified model that adjusts counts for two forms of detection bias: singing rate or the probability that a bird is singing (p) using a removal model (Farnsworth et al., 2002), and detection distance or the probability of detecting a bird at distance r from the observer given that the bird is singing (q) using distance sampling. We used the latter to estimate the effective area sampled by the point count survey (Buckland et al., 2001). For each species, we estimated p and q and how each varies with differences in survey protocol (e.g., count radius, roadside sampling, count duration) and survey conditions (e.g., time of day, day of year, and vegetation cover). We calculated the product of p and the effective area sampled as a correction factor for each combination of species, point count location, and point count visit. We then included the log of the correction factor as an offset in the GLMMs described above to transform the predicted mean counts to mean density (singing males per hectare) for each species, in each forest-type age class. For each species we calculated 95% confidence intervals for mean density estimates in each age class within each forest type.

2.5. Population estimates and scenario evaluation

To calculate the current population estimate for each priority landbird species within the Al-Pac FMA, we first calculated the total number of each bird species within each forest type-age class in the study area by multiplying the habitat-specific density estimate (singing males per ha) by the area estimate for each forest type-age class (ha). We then summed the values across all forest type-age classes in the initial or current year (2011) to obtain the total population size. Forest type-age relationships were modeled only for the five forest types (hardwood, mixedwood, white spruce, pine, hygric softwood/black spruce) resulting in 10 habitat-specific density estimates for each forest type, one for each age class tracked by ALCES®.

To calculate proposed future BCR 6 population objectives for our four priority landbird species we first determined the BCR-specific population trend (PT) score and the associated population objective. Population trend indicates the direction and magnitude of changes in population size over the past 30 years (1966–present). The score is a value from 1 to 5 where PT 1 = ⩾50% increase (large population increase), PT 2 = 15–49% increase (possible or moderate population increase or population stable), PT 3 = N/A (uncertain population trend), PT 4 = 15–49% decrease (possible or moderate population decrease), and PT 5 = ⩾50% decrease (large population decrease). BCR-specific population trend scores were obtained from the Partners in Flight species assessment database. The associated population objective is based on the population trend score and the goal of reversing population declines over the next 30 years (Rich et al., 2004). For example, for a species with PT = 1 or 2, the population objective is to maintain future populations at or above current levels. For a species with PT = 3, the population objective is to maintain slightly higher future populations until sufficient data can be acquired to measure trend (1.1 times current population estimate). For a species with PT = 4, the population objective is to restore populations based on a 30% decline (1.4 times current population estimate). Finally, for a species with PT = 5, the population objective is to restore populations based on a 50% decline (2 times current population estimate). We then calculated the proposed future population objective for each priority landbird spe-

Table 1
Current population estimates, proposed future population objectives, and simulated population estimates at year 30 (2041) under the business as usual, protected areas, and climate change land use scenarios applied to the Alberta-Pacific Forest Management Agreement area.

Species	Current population estimate[a]	BCR 6 Population Trend[b]	BCR 6 population objective[c]	Proposed population objective[d]	Simulated Population Estimate Business As Usual[e]	Simulated Population Estimate Protected Areas[f]	Simulated Population Estimate Climate Change[g]
Black-throated Green Warbler	51,250	4	1.4× Population	71,750	54,496	54,500	51,762
Boreal Chickadee	214,171	5	2× Population	428,342	170,695	170,270	168,637
Western Tanager	89,620	3	1.1× Population	98,582	81,569	82,153	77,442
White-throated Sparrow	843,280	4	1.4× Population	1,180,592	1,039,627	1,042,007	1,076,758

[a] Current population estimates presented here are calculated by multiplying habitat-specific density estimates for priority landbird species by the amount of available habitat in each forest type-age class.

[b] Bird Conservation Region (BCR) 6 population trend (PT) indicates vulnerability due to the direction and magnitude of changes in population size over the past 30 years (1966–present). Population trend is a score based on the best available breeding or non-breeding data. Simplified scores are: PT 1 = ⩾50% increase (large population increase), PT 2 = 15–49% increase (possible or moderate population increase or population stable), PT 3 = N/A (uncertain population trend), PT 4 = 15–49% decrease (possible or moderate population decrease), PT 5 = ⩾50% decrease (large population decrease). For detailed definitions and descriptions of scores see Panjabi et al. (2005).

[c] Population objectives are based on population trend scores (Rich et al., 2004; Rosenberg and Blancher, 2005). For a species with PT = 1 or PT = 2, the population objective is to maintain future populations at or above current levels. For a species with PT = 3, the population objective is to maintain slightly higher future populations until sufficient data can be acquired to measure trend (1.1 times current population estimate). For a species with PT = 4, the population objective is to restore populations based on a 30% decline (1.4 times current population estimate). For a species with PT = 5, the population objective is to restore populations based on a 50% decline (2 times current population estimate). Partners in Flight population objectives are based on reversing population declines over the next 30 years (Rich et al., 2004).

[d] Proposed future population objectives presented here are calculated by multiplying the current population estimate for priority landbird species by the BCR 6 population objective.

[e] Simulated population estimates presented here are calculated by multiplying habitat-specific density estimates for priority landbird species by the amount of available habitat in each forest type-age class and summing the values across all forest type-age classes in year 2041 of the business as usual scenario (e.g., year 30 in business as usual simulation).

[f] Simulated population estimates presented here are calculated by multiplying habitat-specific density estimates for priority landbird species by the amount of available habitat in each forest type-age class and summing the values across all forest type-age classes in year 2041 of the protected areas scenario (e.g., year 30 in protected areas simulation).

[g] Simulated population estimates presented here are calculated by multiplying habitat-specific density estimates for priority landbird species by the amount of available habitat in each forest type-age class and summing the values across all forest type-age classes in year 2041 of the climate change scenario (e.g., year 30 in climate change simulation).

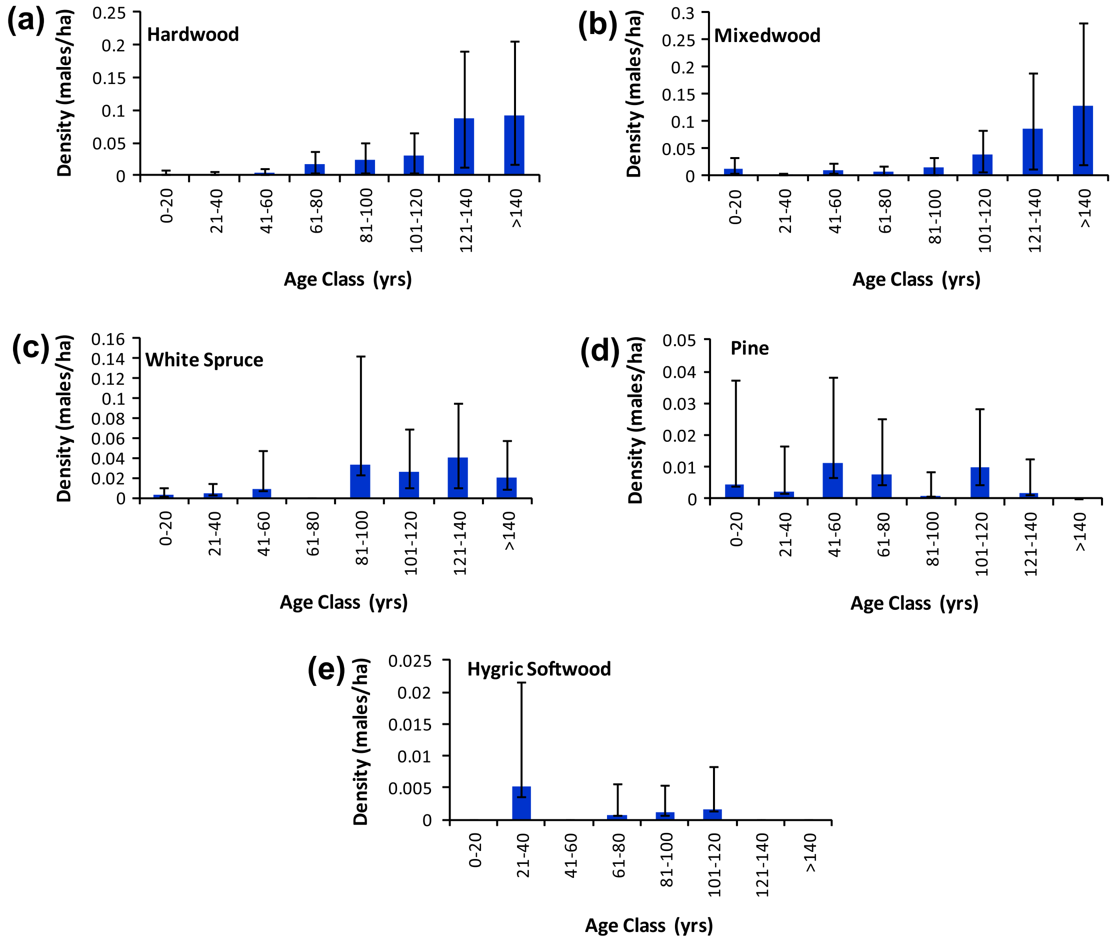

Fig. 2. Mean density estimates (±95% confidence intervals) for Black-throated Green Warbler in the Alberta-Pacific Forest Management Agreement area. (a) Hardwood; (b) mixedwood; (c) white spruce; (d) pine; (e) hygric softwood/black spruce.

cies by multiplying the current population estimate by the population objective (Table 1).

To evaluate the impacts of each land use scenario on future habitat supply and population size estimates of our four priority landbird species, we used ALCES® to simulate future changes in forest type availability for the existing business as usual land use scenario, and two alternative land use scenarios and then applied habitat-specific density estimates to output from the ALCES® simulations. For each simulated year (1–100 years), we calculated the population estimate for each priority landbird species within the Al-Pac FMA using the same procedure outlined above (multiplied the habitat-specific density estimate by the area estimate for each forest type-age class and then summed the values across all forest type-age classes in each year). We calculated the proportional change in landbird population change (% population change = current population estimate/future population estimate*100) for three future 30 year time periods (e.g., year 30, year 60, year 90). Thirty years is the time period proposed by Partners in Flight for meeting population objectives and reversing long-term population declines.

3. Results

The current forested land base within the Al-Pac FMA is dominated by hardwood (19%) followed by pine (8%), mixedwood (6%), white spruce (3%), and hygric softwood/black spruce (0.9%), while the non-forested land base is dominated by wetlands in the form of fens and bogs, marshes, and swamps (46%). All other non-forested habitat types (natural grasslands and shrublands) have proportions that are <6% of the land base (Table A1). Within the forested land base, hardwood and mixedwood forest types are dominated by mature forest stands (61–80 years), while white spruce and pine forest types are dominated by young forest stands (61–80 years). Hygric softwood/black spruce forest types are dominated by mature and old forest stands (81–100 years and >100 years respectively; Table A2).

For Black-throated Green Warblers (Fig. 2), the highest densities occurred in old forests in hardwood and mixedwood forest types (>100 years) and in mature and old forests in white spruce and pine forest types (>80 years). For Boreal Chickadee (Fig. 3), the highest densities occurred in mature and old forests in both hardwood and mixedwood forest types (>60 years) and white spruce and pine forest types (>80 years). For Western Tanagers (Fig. 4), the highest densities occurred in old forests in hardwood and mixedwood forest types (>80 years) and mature and old forests in white spruce and pine forest types (>100 years). For White-throated Sparrows (Fig. 5), a habitat generalist in the boreal forest, the highest densities occurred in both young and old forests where the presence of low and high shrub layers provide suitable nesting and foraging habitat for this species.

For all priority landbird species, shortfalls exist between the proposed future BCR 6 population objective and the simulated population estimate for each of the land use scenarios for year 2041 (year 30 in each simulation). The shortfall was relatively small for species with only a moderate proposed population in-

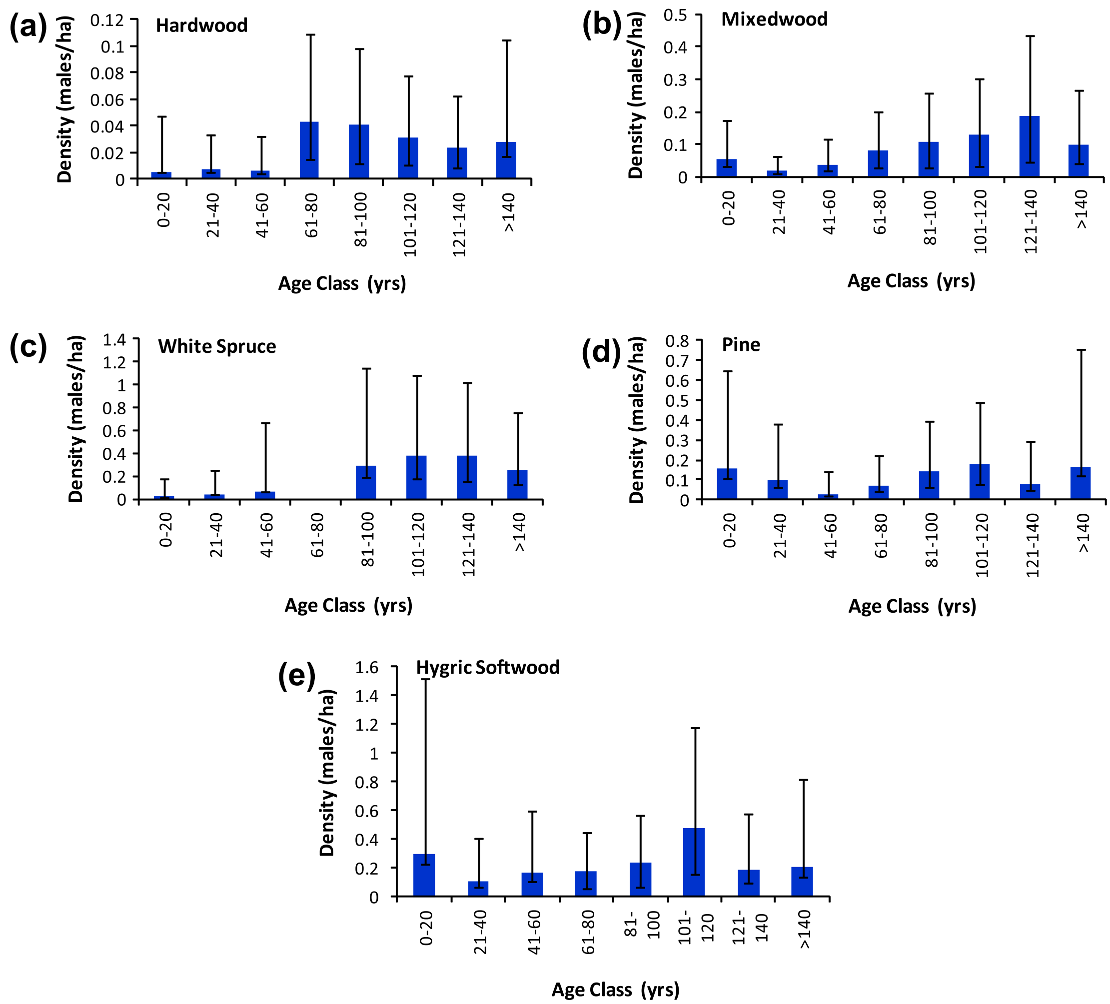

Fig. 3. Mean density estimates (±95% confidence intervals) for Boreal Chickadee in the Alberta-Pacific Forest Management Agreement area. (a) Hardwood; (b) mixedwood; (c) white spruce; (d) pine; (e) hygric softwood/black spruce.

crease (i.e., population trend score of three or a 1.1 times population increase) like the Western Tanager (<21,500 individuals for all scenarios or 24% of the total current population size estimate). The shortfall was large for species with a large proposed population increase (i.e., population trend score of five or a two times population increase) like the Boreal Chickadee (>260,000 individuals for all scenarios which exceeds the current population size estimate for this species; Table 1).

Simulated changes in population size (number of singing males) over a 100 year time period for each scenario suggest that population declines will occur for the Black-throated Green Warbler (Fig. 6), Boreal Chickadee (Fig. 7), and Western Tanager (Fig. 8). Only the White-throated Sparrow (Fig. 9) will undergo a population increase over the next 100 years. For each species (except White-throated Sparrow), the protected areas scenario resulted in higher population sizes across the simulated time period and the climate change scenario resulted in lower population sizes across the simulated time period. For the White-throated Sparrow, the climate change scenario resulted in the highest population sizes across the simulated time period, with the business as usual and protected areas scenarios following similar trajectories over the 100 year time period.

Proportional change in population size for three time periods under the business as usual scenario suggests that two of the four priority landbird species examined here (Boreal Chickadee and Western Tanager) will decline in the next 30 years losing approximately 10–25% of their population in response to land use change. These same species will undergo further declines in the next 60 years, losing approximately 20–58% of their population in response to land use change. In the next 90 years, all of the mature and old forest associated landbird species (Black-throated Green Warbler, Boreal Chickadee, Western Tanager) will undergo population declines of 44–75% in response to projected land and resource development and the associated declines in habitat supply (Table 2). The White-throated Sparrow, a species associated with a range of forest types and age classes, is the only species to undergo consistent population increases over the next 30 years (19% increase), 60 years (28% increase) and 90 years (26% increase). For each of the four priority landbird species, the proportional change in population size for the three time periods under the protected areas scenario closely follow the business as usual scenario.

Proportional change in population size under the climate change scenario suggests higher rates of population declines in response to land use and climate change for all of the mature and old forest associated species (Black-throated Green Warbler, Boreal Chickadee, and Western Tanager) in the next 60 years (37–66% declines) and 90 years (85–130% declines). The White-throated Sparrow is the only species to undergo consistent population increases under a climate change scenario over the next 30 years (21% increase), 60 years (33% increase) and 90 years (34% increase) (Table 2).

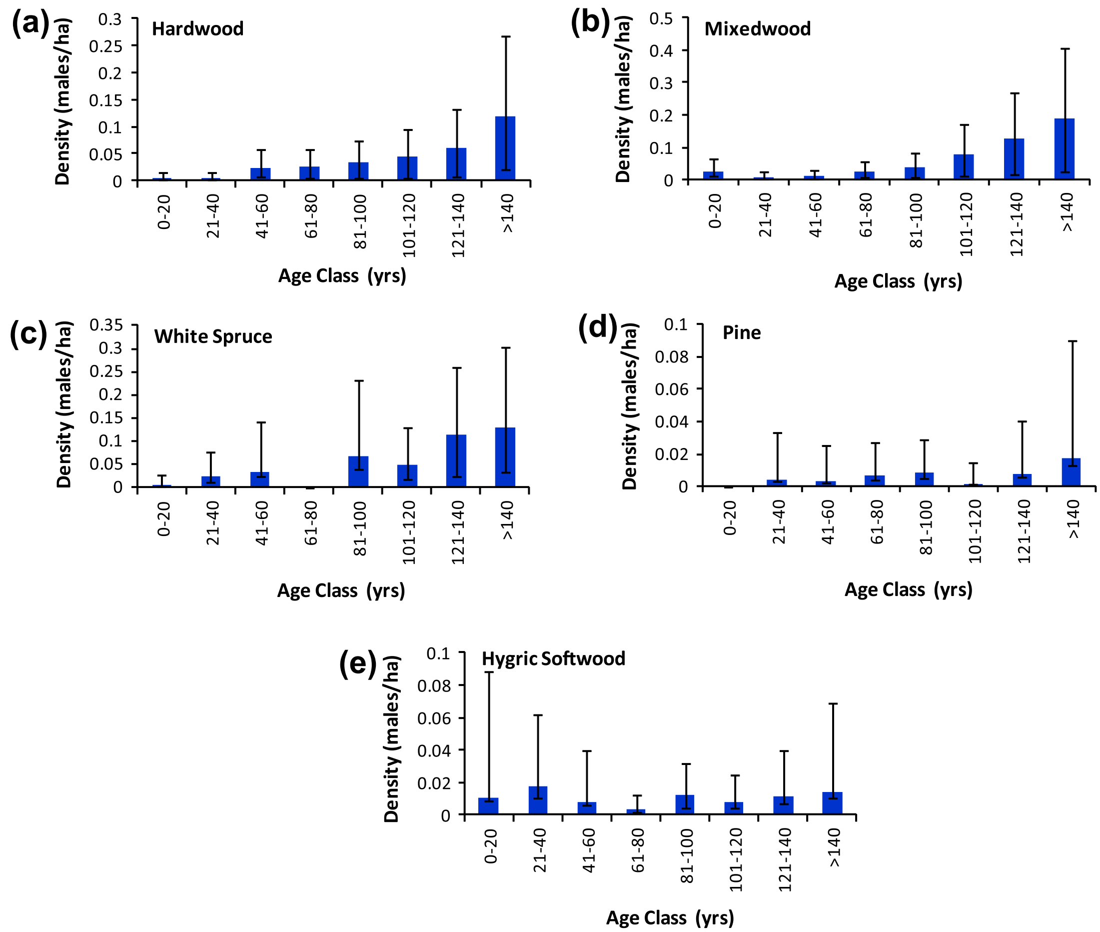

Fig. 4. Mean density estimates (±95% confidence intervals) for Western Tanager in the Alberta-Pacific Forest Management Agreement area. (a) Hardwood; (b) mixedwood; (c) white spruce; (d) pine; (e) hygric softwood/black spruce.

4. Discussion

To date, previous approaches to step down BCR scale population objectives to habitat objectives have had certain limitations such as static habitat assessments and restrictive bird-habitat models. Landscape simulation models can be used to model future changes in habitat supply and then project how these changes will influence the population sizes of priority bird species (Fitzgerald et al., 2009). Few studies have attempted to utilize realistic landscape simulation models to evaluate the feasibility of meeting proposed BCR scale population objectives using either existing (e.g., business as usual) or alternative land use scenarios (but see Jones-Farrand et al., 2009). In addition, the bird-habitat models that have been applied to habitat assessments have been limited by model structure, habitat sampling bias, detection bias, and density estimation (Jones-Farrand et al., 2011; Rosenberg and Blancher, 2005; Thogmartin et al., 2004; Tirpak et al., 2009). We believe that our study improves on existing approaches in at least three areas, including recommendations by Edenius and Mikusinski (2006) and Fitzgerald et al. (2009). First, we utilized a landscape simulation model to represent realistic resource activities and estimate future changes to habitat supply within our study area. Second, we examined trade-offs between bird conservation and reduced resource activities to determine if proposed BCR scale objectives could be met under alternative land use scenarios. Third, we developed empirical bird-habitat models using the best available point count data and forest resource inventory data to develop habitat-specific density estimates for forest habitat types that could be applied to landscape simulation model output.

Our comprehensive modeling approach directly connects management options and population estimates (Thogmartin et al., 2006). Although a number of studies throughout North American BCRs have presented approaches to step down Partners in Flight population objectives into habitat objectives (Jones-Farrand et al., 2011 in BCR-24 Central Hardwoods; Rosenberg and Blancher, 2005 in BCR 13-Lower Great Lakes/St. Lawrence Plain; and Tirpak et al., 2009 in BCR-24 and BCR-25 West Gulf Coastal Plain/Ouachitas) our study is the first to evaluate the feasibility of BCR population objectives by estimating the availability of suitable habitat for individual priority species 30 years into the future. Linking realistic landscape simulations and statistical bird-habitat models that estimate density may indicate that population objectives will not be achieved within a 30 year time period. Anticipating or predicting population trends provides an opportunity to proactively implement management and conservation actions to maintain or recover populations. Our general approach can be adapted (e.g. various landscape simulation models, multiple procedures for developing bird-habitat models) and used to (1) assess future changes in habitat supply and population size, and (2) develop feasible, realistic population objectives and habitat objectives for priority bird species within any North American BCR.

Our results to step down BCR 6 population objectives revealed shortfalls in reaching proposed regional population objectives for each of our four priority landbird species over the next 30 years within the Al-Pac FMA. These results suggest that expected future landscape condition within one region of BCR 6 will not support proposed population objectives for at least some boreal bird species. Population objectives could still be achieved for these species

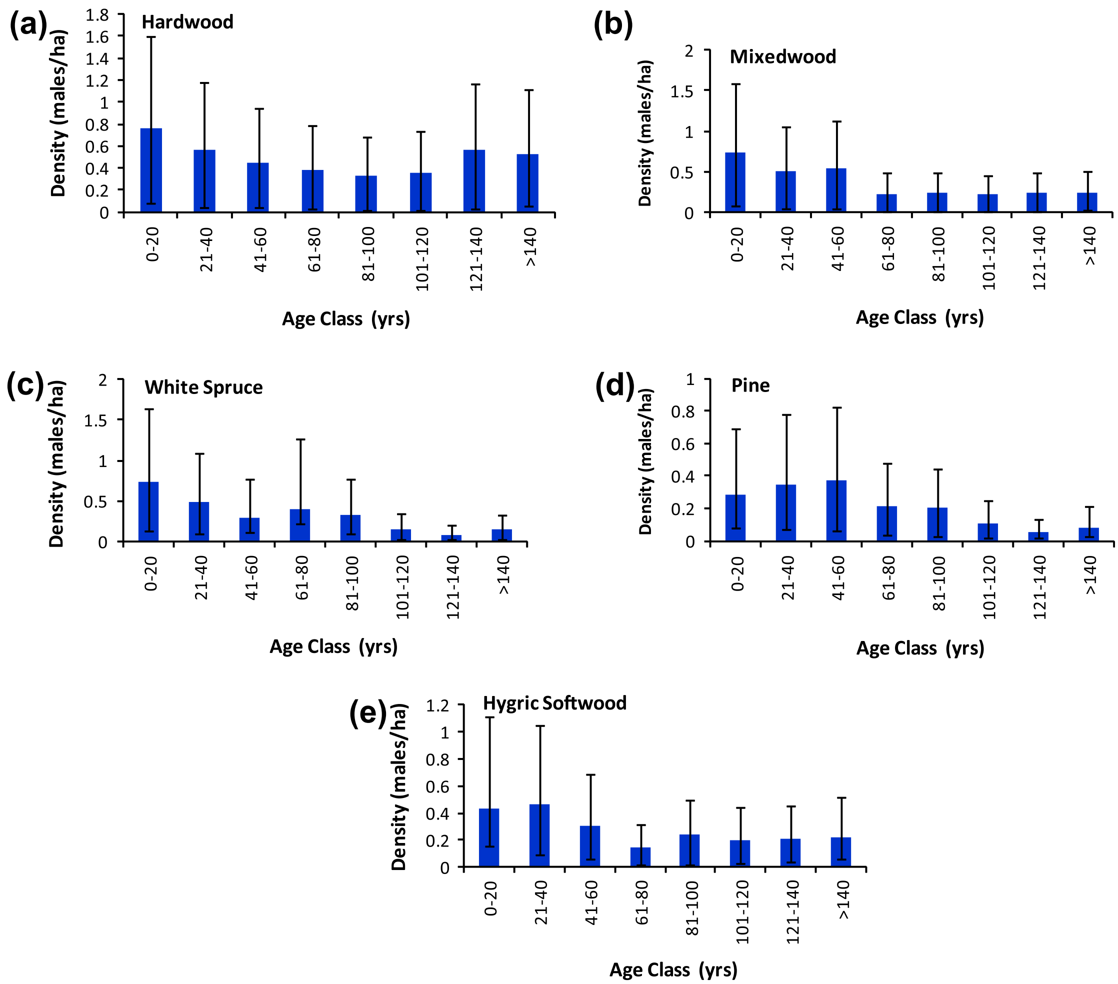

Fig. 5. Mean density estimates (±95% confidence intervals) for White-throated Sparrow in the Alberta-Pacific Forest Management Agreement area. (a) Hardwood; (b) mixedwood; (c) white spruce; (d) pine; (e) hygric softwood/black spruce.

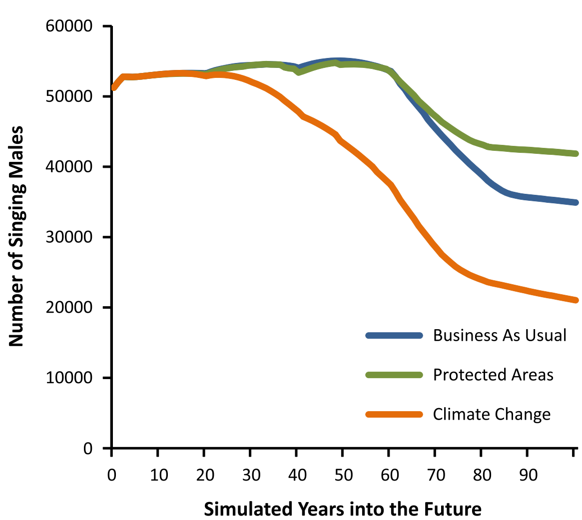

Fig. 6. Simulated population estimates (number of singing males) of Black-throated Green Warblers under the business as usual, protected areas, and climate change land use scenarios within the Alberta-Pacific Forest Management Agreement area.

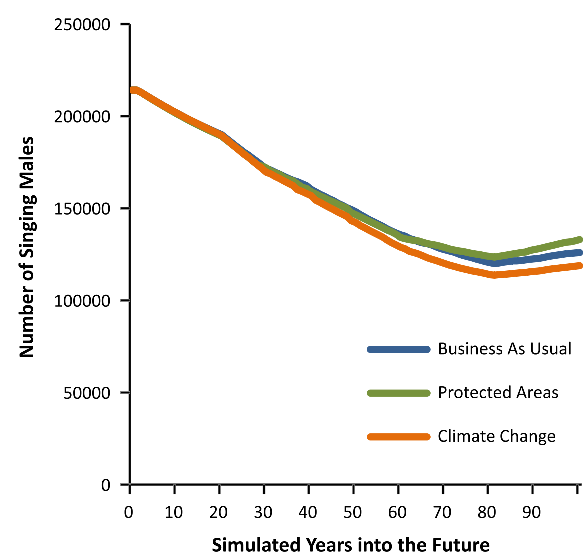

Fig. 7. Simulated population estimates (number of singing males) of Boreal Chickadees under the business as usual, protected areas, and climate change land use scenarios within the Alberta-Pacific Forest Management Agreement area.

within BCR 6 if land and resource development in other regions can mitigate or offset intensive land use change within the Al-Pac FMA. Land managers could achieve some bird conservation objectives for mature and old forest priority species (i.e., maintain future populations at current levels) by increasing stand age for all forest types across the FMA. Forest type change data in the business as usual scenario revealed that the average age of all productive forest

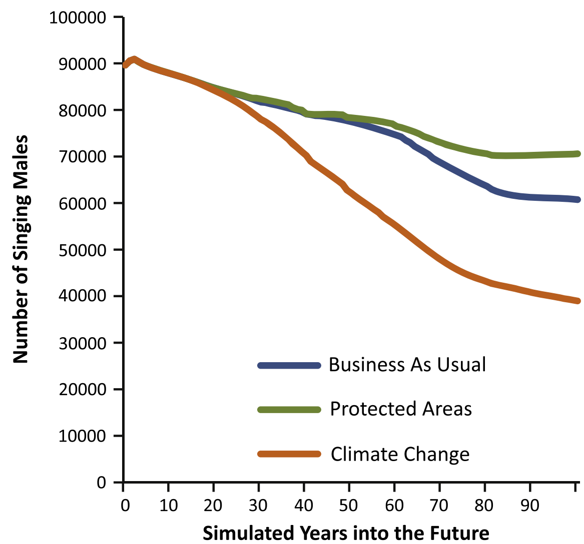

Fig. 8. Simulated population estimates (number of singing males) of Western Tanagers under the business as usual, protected areas, and climate change land use scenarios within the Alberta-Pacific Forest Management Agreement area.

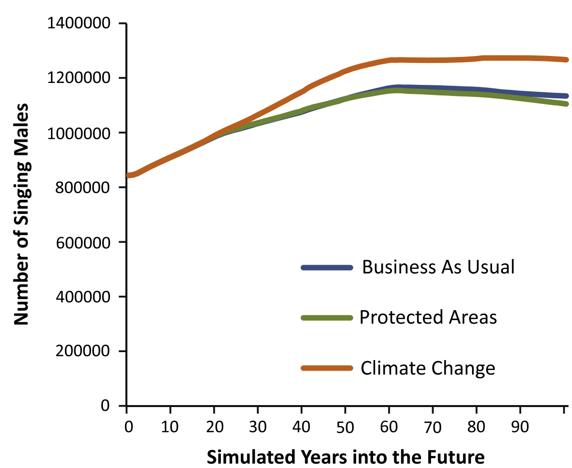

Fig. 9. Simulated population estimates (number of singing males) of White-throated Sparrows under the business as usual, protected areas, and climate change land use scenarios within the Alberta-Pacific Forest Management Agreement area.

types (hardwood, mixedwood, white spruce, pine, hygric softwood/black spruce) declined from 80 years to 50 years during the 100 year simulation period (Carlson, 2011). The area of mature and old age classes (>60 years for hardwood and mixedwood and >80 years for white spruce, pine, hygric softwood/black spruce) declined sharply over the simulation time period. In hardwood and mixedwood stands, existing old stands (>80 years) declined to below current levels by year 30. Mature and old white spruce classes (>80 years) declined to half of current levels by year 30. Although Al-Pac recently implemented an old forest strategy to reduce harvest rates by 10% at year 60, this strategy did not appear to be effective at retaining old forest types within the FMA because half of the simulated forest harvest sequencing was based on an oldest-first criterion. Retaining old forest types and the bird species associated with these habitats (e.g., Black-throated Green Warbler, Boreal Chickadee, Western Tanager) would require increased forest protection (e.g., old growth management areas where no resource development occurs; protected areas identified using multi-species systematic conservation planning analyses) and/or alternative management strategies (e.g., excluding old forest types from harvest by removing the oldest-first criteria; extending rotation ages). Currently, minimum harvest age was 60 years for hardwood and deciduous-leading mixedwood, 80 years for white spruce and conifer-leading mixedwood, and 120 years for hygric softwood/black spruce. In addition to harvest pressure, mature and old forest types are lost, subdivided, and perforated by the extensive anthropogenic footprint resulting from oil sands development which includes large surface mines and in-situ sites and an expanding network of seismic lines, pipelines, production and exploration wellsites, power/utility lines and access roads. Across the FMA, old forest stands are currently located adjacent to large rivers (e.g., Athabasca, Clearwater) or are interspersed with younger stands in a patchy mosaic created by natural and anthropogenic large and small-scale disturbance. Old forest protection strategies would need to exclude both forestry and energy-related resource activities across the Al-Pac FMA in order to maintain these rare and isolated forest stands.

The protected areas scenario utilized the broad objective of protecting 20% of the Lower Athabasca Regional Planning Area from land use (Alberta Environment Sustainable Resource Development, 2012). We implemented this objective in the simulation by protecting 20% of all forest types. This scenario did not maintain or substantially increase populations of priority landbird species because protected areas resulting from this analysis were not: (1) based on a range of ecologically-derived conservation target levels for priority bird species, and (2) selected to maximize specific forest types (i.e., high suitability forest types or forest types with the highest density estimates). An alternate approach for developing a protected area network for multiple species over a large spatial extent is to use a systematic conservation planning process that would first define *a priori* the conservation target level for all priority bird species (i.e., the percent of area occupied by each species within the protected area network) and then identify protected area networks that maximize conservation target levels for all species (Margules and Pressey, 2000; Pressey et al., 2007). Proposed population objectives (BCR 6 population objectives; Table 1) could be used to represent the maximum conservation target level for each species, while objectives based on maintaining current populations could be used to represent the minimum conservation target level for each species. Input data used in systematic planning

Table 2
Proportional change in priority landbird population size (% Pop Change) for three future time periods (30 years, 60 years, 90 years) under the business as usual, protected areas, and climate change land use scenarios applied to the Alberta-Pacific Forest Management Agreement area.

	Business As Usual–% Pop Change[a]			Protected Areas–% Pop Change			Climate Change–% Pop Change		
Species	30 Yrs	60 Yrs	90 Yrs	30 Yrs	60 Yrs	90 Yrs	30 Yrs	60 Yrs	90 Yrs
Black-throated Green Warbler	5.84	4.37	−43.83	5.9	4.11	−20.93	1.45	−36.99	−129.86
Boreal Chickadee	−24.88	−57.92	−74.71	−24.6	−59.62	−67.77	−26.31	−66.15	−84.98
Western Tanager	−9.75	−20.2	−46.39	−8.79	−17.21	−27.55	−14.95	−62.75	−119.89
White-throated Sparrow	18.57	27.58	26.21	18.72	26.92	24.99	21.11	33.38	33.79

[a] Proportional change in landbird population size presented here are calculated as current population estimate/future population estimate*100 for three future 30 year time periods (e.g., year 30, year 60, year 90). Thirty years is the time period proposed by Partners in Flight for meeting population objectives and reversing long-term population declines. Negative values represent a population decrease. Positive values represent a population increase.

tools like Marxan could include statistical habitat suitability models to estimate the area occupied for each species. Using habitat models as input data ensures that proposed protected area networks maximize the area of high suitability forest types for each species. Proposed protected area networks identified using this approach could then be used as input data in a landscape simulation model to assess whether both current and proposed protected areas maintain species populations through time.

The climate change scenario resulted in further population declines for all mature and old forest-associated priority landbird species because the increased fire rate resulted in an earlier and more substantial decline in old forest types compared to the business as usual scenario due to differences in fire rate among forest types and age classes (highest in conifer-dominated forests and older forests). By the end of the 100 year simulation period, old forest types accounted for <5% of the productive forest compared to 22% in year one and a high of 36% in year 40 (Carlson, 2011). Early seral age classes increased for all forest types, resulting in a population increase for the White-throated Sparrow, the only species in our suite of priority landbird species to be associated with both early seral and late seral forest types.

We acknowledge that factors limiting the populations of each of our boreal species will differ as a result of migratory and life history strategies. We suggest that for the Boreal Chickadee, a resident species in the boreal forests of Alberta, loss of suitable breeding and over-winter habitat in the form of mature and old forest types will be an important limiting factor. This species is dependent on large old trees and snags for foraging, nesting, and roosting during the breeding season and foraging and roosting during the winter (Ficken et al., 1996). All other landbird species examined are migratory species: White-throated Sparrow is a short-distance migrant, Western Tanager is a medium-distance migrant, and Black-throated Green Warbler is a long-distance migrant. For migratory species, four factors may limit overall populations (breeding habitat, winter habitat, two migration seasons) and assessing causes of population declines requires determining which factor or factors limit the population (Faaborg et al., 2010). For Western Tanager and Black-throated Green Warbler, identifying factors that limit overall populations is challenging given the data deficiencies associated with over-winter periods (distribution and range, habitat selection and suitability, and survival) and spring and fall migration periods (migration routes, migratory stopovers, migratory connectivity, and survival). In addition, for migratory species, the goal should be an understanding of how populations are limited both within and between seasons and in locations throughout the annual cycle (Faaborg et al., 2010).

While forest age and composition are the two primary drivers of bird abundance, we acknowledge that inclusion of other stand scale characteristics (e.g., crown closure, moisture, understory vegetation density) and both landscape composition and pattern metrics (e.g., patch number and size, core area, edge density and contrast, nearest-neighbour distance) assessed at biologically relevant spatial scales may improve our predictions. Understanding spatial patterns is important if the goal of land managers is to emulate the landscape variability produced by large and small-scale natural disturbances (Loehle et al., 2006; Mitchell et al., 2006; Rempel, 2007; Rempel et al., 2007). We also acknowledge that interpretation of population estimates should be sensitive to temporal variation and population fluctuations (Thogmartin et al., 2006). Since our data sources represent a long-term snapshot of bird distribution and abundance across the region, annual variation in breeding populations due to food abundance, weather, and other factors (predator-prey cycles and resource pulses) should be incorporated into our mean density estimates and estimates of precision.

Current Partners in Flight population objectives are based on reversing population trends over the last 30 years and returning to baseline population levels of the late 1960s or early 1970s. These aspirational objectives represent a precautionary and simplistic approach to regional bird conservation that does not include an understanding of bird-habitat relationships, breeding season habitat supply, or population dynamics. Aspirational objectives will be questioned in BCRs or portions of BCRs where a long history of extensive and intensive habitat modification limits habitat supply or where bird conservation objectives are at odds with social and economic objectives. A more defensible and feasible approach to developing population objectives could be achieved by utilizing some of the methods outlined here to assess risk to populations and develop habitat-based objectives required to restore or maintain populations. For example, bird-habitat and landscape simulation models and historical disturbance data can be used to: (1) characterize the pre-development landscape condition for each BCR (based on fire and other natural disturbances), (2) calculate and compare bird population size estimates between current and pre-development landscape condition to assess risk, (3) determine if any future land use scenario could produce landscape conditions similar to the pre-development condition given social and economic constraints, and (4) develop specific habitat-based objectives required to either achieve pre-development population size or maintain current population size.

In addition to bird-habitat and landscape simulation models, we suggest that landbird managers across Canada and the United States improve their understanding of threats to boreal landbird species during their annual cycle, including non-breeding season factors that influence populations (Faaborg et al., 2010). Returning to a pre-development landscape condition to increase habitat supply and increase breeding densities during the breeding season may have limited success if loss of wintering habitat or low survival during two migration seasons are the critical factors limiting population size for priority landbird species breeding in Canadian BCRs.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foreco.2013.10.025.

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