Appendix 1. Summary of conceptual models for the boreal forest ecosystem of northern Alberta Canada

Additional material for individual species is available from the authors by request or through Research Gate: https://www.researchgate.net/publication/281112203_Conceptual_models_of_migratory_birds_and_human_development_as_relevant_to_the_oil_sands_of_Canada

BACKGROUND

The study area contains conventional oil and gas deposits, commercial forestry, agriculture, urbanization, a transportation network to support those industries and other, smaller economic interests (see Fig. 1 in the main manuscript, Table A1.1). These activities are in addition to the large scale influence of an active fire regime, insect disturbance and climate change. There is a long history of research and monitoring of birds in the oil sands area, including substantial work from 1975-1985 (under the Alberta Oilsands Environmental Research Program) and more recent monitoring work by companies under the Ecological Monitoring Committee for the Lower Athabasca, as well as agencies such as Alberta Biodiversity Monitoring Institute (ABMI) and the Alberta government. However, development of conceptual models for birds appears to have been limited to simple models used for recent environmental assessments (e.g., section 7.4 in Shell Canada Limited 2007). Models for remediation (Frid and Daniel 2012; Ciborowski and others 2013), as well as for other (non-bird) disciplines (Government of Alberta 2013) have also been created.

Table A1.1. Summary statistics for footprints originating from a variety of types of human disturbance across all sectors in the oil sands area of northern Alberta. Footprint data from ABMI (2010). The significant proportion of all disturbance by agriculture and forestry is highlighted in bold.

Type of disturbance	Total length of disturbance (km)	Total area of disturbance (km^2)	Percent of all disturbance	Percent of total area
Borrow-pits / dugouts / sumps	1,839	27.0	0.14	0.02
Canals	70	0.4	0.00	0.00
Cultivation (crop, pasture, bare ground)	**82,301**	**10,489.9**	**54.37**	**6.32**
Cut blocks	**89,180**	**4,175.0**	**21.64**	**2.52**
High density livestock operation	23	1.1	0.01	0.00
Industrial site rural	1,209	75.9	0.39	0.05
Mine site	7,387	726.6	3.77	0.44
Municipal (water and sewage)	112	8.5	0.04	0.01
Other disturbed vegetation	579	22.9	0.12	0.01
Peat mine	89	10.7	0.06	0.01
Pipeline	51,077	528.2	2.74	0.32
Rail with hard surface	1,807	8.3	0.04	0.01
Rail with vegetated verge	3,094	10.6	0.06	0.01
Reservoirs	175	17.3	0.09	0.01
Road with hard surface	42,432	239.0	1.24	0.14
Road with vegetated verge	84,036	392.4	2.03	0.24
Road / trail (vegetated)	32,096	177.8	0.92	0.11
Rural (residential / industrial)	11,053	355.7	1.84	0.21
Seismic line	498,767	1,237.6	6.41	0.75
Transmission line	5,513	83.1	0.43	0.05
Urban	1,461	44.1	0.23	0.03
Well site	30,975	662.2	3.43	0.40
Totals	**945,274**	**19,294.2**	**100.00**	**11.63**

METHODS

We began with a literature review to identify key features and types of conceptual models that would suit our needs (e.g., Jorgensen 1988; Fischenich 2008). We then selected model types that would best serve the varying target audiences, systems and processes of interest, levels of specificity, and information availability. We developed conceptual models at a hierarchy of scales – ecosystem, landscape, guild and species – given the ecological complexity of the study area and breadth of monitoring needs. There was an intentional decrease in breadth and increase in specificity in these models moving from the highest to lowest levels in the hierarchy. A systems model was used for the ecosystem level to illustrate the breadth of human stressors and natural drivers that influence the ecology of the study area. A state and transition model was used for the landscape level to represent habitat states and transitional processes that influence habitat dynamics, while a life cycle model was used to represent population dynamics for the migratory and resident terrestrial species occupying the study area. Life cycle models were also used for the guild level (and species level) to represent interactions between the environment and all forest and wetland dependent birds (or individual species) that migrate annually from or through the study area. Pathways-of-effect were prioritized using these guild-level models.

Five steps were followed to develop the conceptual models (adapted from Grant and others 1997; Fischenich 2008) on top of the technical guidance provided by Noon (2002). First, model objectives were stated according to intended uses and audiences. The ecosystem-level model was made for informed decision makers to provide them with a high-level understanding of the inter-relationships among all components of the terrestrial environment and diverse monitoring needs. The landscape-level models were developed to provide ecologists with an overview of the natural drivers and human stressors that influence species and habitats and to provide a consistent framework from which to develop more detailed guild- and species-level models. The guild-level model was targeted towards avian ecologists to represent the key natural and human processes that influence all migratory bird species and to serve as a template for developing species-level models. It was also developed to help prioritize monitoring needs and inform the avian monitoring design. Species-level models were intended to help avian ecologists develop investigations of causes of change in status or trend of the species.

Second, models were bounded according to subsystems of interest and related spatial / temporal boundaries. The focus (breadth) and level of specificity (depth) for each model were first clarified. This included understanding the development sectors, human activities, stressors, natural drivers, and valued ecosystem components (i.e., species and habitats) that were being represented. Each model's focus and specificity was driven in part by the model's purpose and intended audience, recognizing that more technical audiences require a greater level of specificity and complexity. The geographic extent was constrained to the oil sands area of northern Alberta and temporal horizon constrained to generations (i.e., decades). The annual life cycle of terrestrial biota (e.g., migratory forest birds) was also an important temporal frame for structuring the conceptual models.

Third, model components were identified. We assembled a range of evidence to identify the drivers, outcomes, and linkages to be represented in the conceptual models using summary or review literature relevant to the model scales. This evidence included information that was both specific and non-specific to the study area and was supplemented with the authors' experience and knowledge about ecosystem interactions. Drivers included natural influences and human stressors that affect the behaviour or state of the ecosystems' components. Outcomes included the direct and indirect results, impacts, or consequences of particular drivers. Linkages represented the connections between drivers and outcomes, such that each linkage was associated with an "effect" and a series of linkages from an initial driver to a final outcome was considered a "pathway-of-effects". Substantial effort was required to determine the appropriate level of specificity and language for describing human stressors and outcomes. The number of modeled stressors and outcomes needed to be manageable so they could be feasibly represented across levels of the hierarchy and be broadly relevant across many diverse development sectors and valued ecosystem components. For instance, we used the term "biomass extraction" to represent many forms of extraction as opposed to representing each specific activity separately (e.g., forest harvesting, agricultural harvesting, peat harvesting, and hunting).

The fourth step was to build the conceptual models to illustrate relationships among the drivers, outcomes, and linkages at each level in the hierarchy. All models were mechanistic in nature to illustrate the sequence of causal linkages or pathway-of-effects between a driver and an outcome of interest, even though field observations may not have been available to describe each step in the cause-effect chain. Models were also developed with the intention of being both independent of and interdependent with others (i.e., higher level models inform lower levels models). Models had to balance the requirement to represent all development sectors, stressors, habitats, and species for a large spatial area with the many interconnected and overlapping relationships among the stressors and biological outcomes at each level.

Lastly, models were qualitatively evaluated for consistency and robustness. Alternative scenarios of human development and ecosystem interactions were considered to test if the drivers, outcomes, and linkages were representative of and robust to the imagined range of driving conditions. Gaps were found in all cases because models did not sufficiently address the breadth or depth of interactions that were necessary at a particular level in the hierarchy. These gaps were ultimately addressed through multiple iterations of the models and accompanying narratives.

MODEL DESCRIPTIONS

Fourteen conceptual models were developed: one ecosystem, two landscape, two bird guild, and nine species models. To illustrate results across a range of hierarchies and landscape types (e.g., upland forests and wetlands), six models are described in text below. The remaining models are presented as figures and detailed descriptions or supporting text is available by contacting the authors or through Research Gate (https://www.researchgate.net/publication/281112203_Conceptual_models_of_migratory_birds_and_human_development_as_relevant_to_the_oil_sands_of_Canada)

Ecosystem model

The ecosystem model represents the entire extent of the study area which is within the Boreal Forest Natural Region of northern Alberta (Natural Regions Committee 2006, i.e. the area encompassed by Fig. 1 in the main manuscript). Model development was based on ecological information pertaining to the study area (Natural Regions Committee 2006; Demarchi 2010; PEG 2011), an understanding of regionally relevant human actions (ASRD 2002; CEMA 2008; Environment Canada 2011; Government of Alberta 2011) and an international system for classifying human threats (Salafsky and others 2008). Fig. A1.1 is the simplified model while Fig. A1.2 provides a more comprehensive representation of the ecosystem.

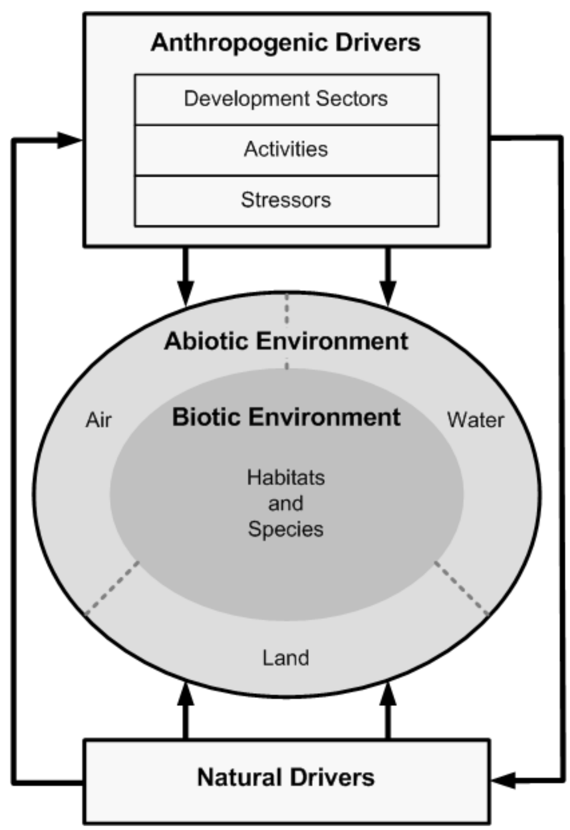

Fig. A1.1. Simplified ecosystem model for the study area.

The model is built around abiotic (air, land, and water) and biotic (all habitats and species) components with dashed boundaries representing interactions among them (e.g., atmospheric influences on land and water, riparian interface between land and water, reliance of species and habitats on land, water, and air). Physical boundaries and important characteristics are included as ways of characterizing abiotic components. A looping arrow represents the dynamic relationship between habitats and species. As well, changes in habitat conditions affect the composition of species that can be supported in a particular habitat. A broad (though not exhaustive) set of outcomes are listed which can include the pattern, composition, and processes used to describe habitats. Pattern-based outcomes are intended to include measures of the spatial configuration of habitats, such as patch-size distribution, area by habitat type, amount of forest edge, amount of interior forest area, and contiguousness. Composition-based outcomes include biodiversity, age-class distribution, availability of food resources, and existence of habitat structures. Process-based outcomes represent the connectivity of the landscape, barriers to movement, predator-prey dynamics, trophic interactions, fuel loads, carbon sequestration, and water retention, among others. Species outcomes are grouped according to different scales of biological organization – individual, population, species, and community levels. Each level represents complementary information about a species, including growth, survival and reproduction for individuals, abundance, trend, distribution, demographics, and capacity for populations, as well as species composition, species diversity and intactness at the community level.

The abiotic and biotic components are influenced by natural and anthropogenic drivers from within the study area. External influences from outside the study area are not explicitly represented, though they will occur (e.g., long-range transport of contaminants, pollution of downstream habitats). Natural drivers are grouped into five categories of processes: weather and climate, energy flow and nutrient cycling, natural disturbances, geomorphology, and hydrologic. Anthropogenic drivers are first represented by the range of development sectors occurring

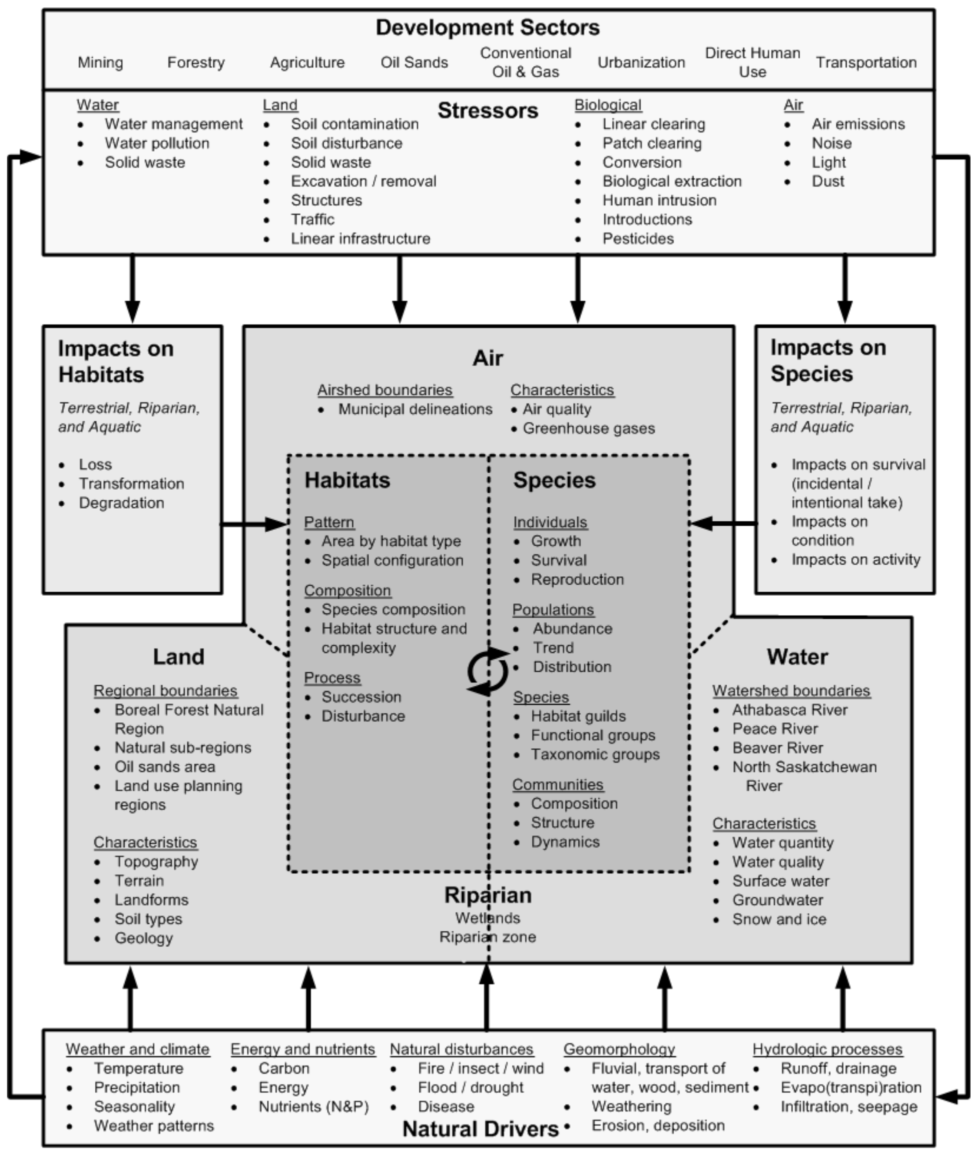

Fig. A1.2. The detailed ecosystem model representing biotic and abiotic components, as well as linkages to human stressors (top boxes) and natural drivers (bottom box) across the study area.

on the landscape. Although not explicitly represented, many activities (e.g., road building, mining, forest harvesting) can be associated with these sectors. Each activity can be further associated with a generalized set of stressors (e.g., linear clearing, excavation, biomass extraction), such that the relationship between sectors and stressors is many-to-many. This list of stressors is not exhaustive; rather it is intended to capture the breadth of potential stresses to which the ecosystem is exposed. Stressors are grouped based on the dominant pathway by which their effect is mediated (e.g., water, land, air, biological). These groupings are fuzzy categorizations since certain stressors may affect multiple components of the environment under different conditions. As indicated by arrows, stressors can directly affect the natural drivers and abiotic components of the system, as well as lead to direct impacts on habitats (loss, transformation, or degradation) and species (lethal or sub-lethal effects).

Landscape models

The two sub-models for the landscape-scale are in Figs. A1.3 and A1.4. In addition to the citations used to develop the ecosystem model, this model relied upon established classification systems to define habitat types (ABMI 2009a), wetlands (Halsey and others 2004) and human footprints (ABMI 2010) for the study area.

The habitat dynamics sub-model (Fig. A1.3) represents the upland / forested and lowland / wetland habitat states (boxes) as well as the natural and human processes driving transitions among them (arrows). Upland areas (upper portion of model) consist of different types of forest and shrubland habitats, while lowland areas (lower portion of model) consist of different types of wetland habitats. The middle portion represents anthropogenic habitats, originating from transitions from both upland and lowland habitats (habitat states are described in Table A1.2). Major transitions among states affect the quantity of these habitats on the landscape (quality is not represented), which can result from both natural drivers (dashed lines) and human stressors (solid lines). Only a subset of the important drivers identified in the ecosystem model are relevant since only a portion affect quantity of terrestrial habitats leading to the exclusion of lower intensity influences (e.g., low severity ground fires) and stressors on habitat quality from this model.

The population dynamics sub-model (Fig. A1.4) illustrates how a population may interact with other species (i.e., competitors, predator, or prey), as well as how it is influenced by changes in the quantity and quality of habitats across the landscape. It is intended to represent the majority of terrestrial species occupying the study area. From right to left the model illustrates pathways-of-effects leading from natural drivers / human stressors to changes in habitat characteristics (habitat loss, transformation, or degradation) and species responses (change in mortality, activity, or condition) to proximate impacts on populations (births, deaths, immigration, and emigration) to population level effects (distribution, trend, and abundance).

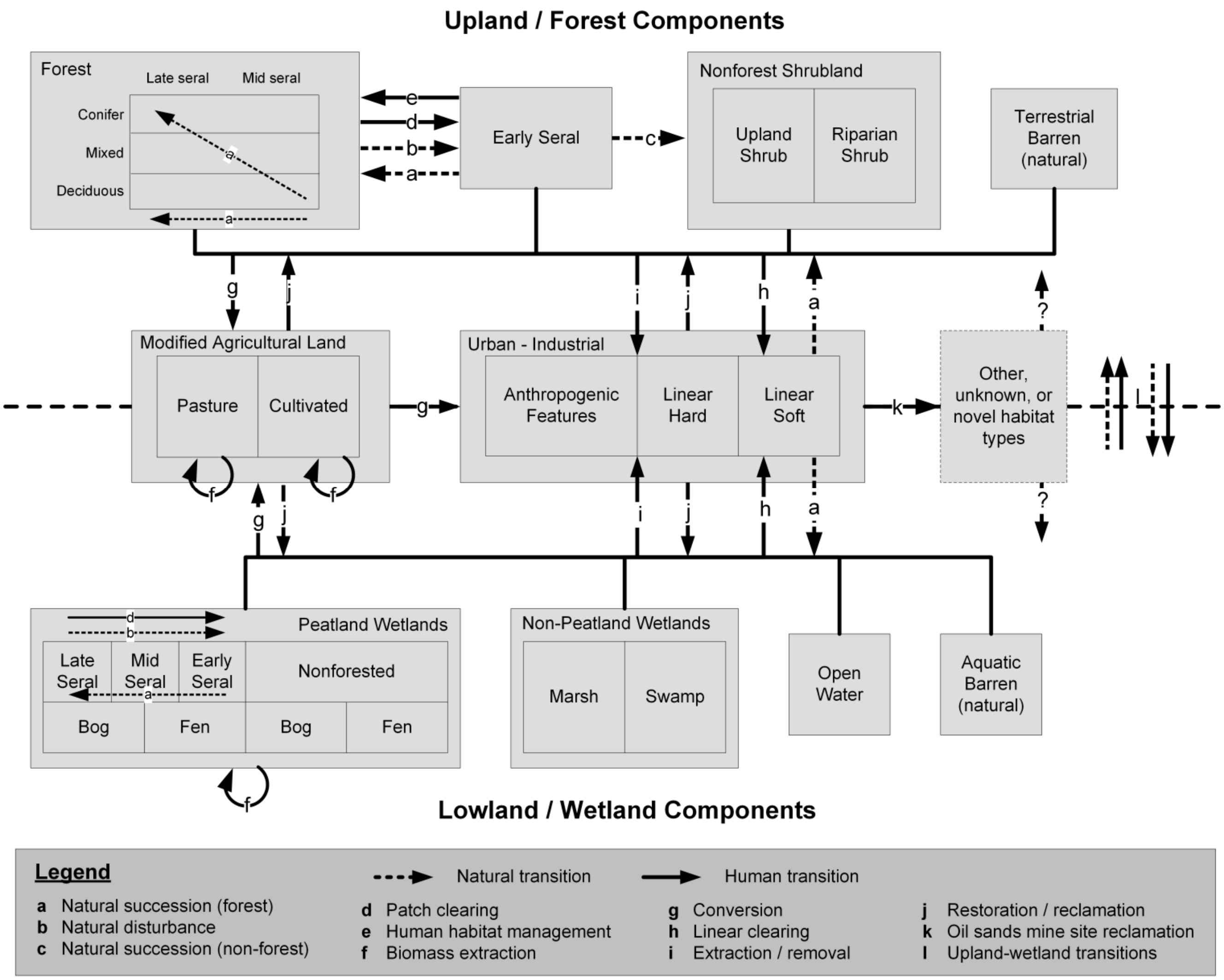

Fig. A1.3. The landscape conceptual model, presented as a state-transition model, showing the dynamics of upland/forested and lowland/wetland states (boxes) as influenced by processes transforming habitats (arrows).

The left portion of the model represents the life cycle and movement of populations relative to three regions: the study area, landscapes adjacent to the study area, as well as migration and overwintering habitats of migrant species. The study area contains the annual cycle of generic resident species and a portion of the life cycle of a generic migrating species (e.g., during the breeding season and to/from overwintering habitats). The model is based on four processes affecting regional population status (births, deaths, immigration, and emigration). Human stressors and natural drivers are represented as simultaneously occurring in other regions. Population outcomes are represented at the centre of the lifecycle.

The middle portion of the model illustrates the pathways-of-effects that connect stressors/drivers on the right to four proximate processes on the left. Pathways-of-effect are grouped into seven generalized classes of impacts (shaded boxes). The dark shaded boxes represent habitat impacts that lead to changes in habitat quantity (loss

Table A1.2. Description of habitat groupings and habitat states used in the landscape model (Fig. A1.3) and their relationship to landscape elements from the Alberta Biodiversity Monitoring Institute (ABMI 2009a).

Habitat Groupings	Habitat States	Description of Landscape Elements (from AMBI)
Urban – Industrial	Anthropogenic Features	Anthropogenic Features: Any residential, industrial, including bare ground (does not include agricultural crops / pasture and forestry cutting that are not linear)
	Linear Hard	Linear Hard: Linear corridor hard surface / nonvegetated (with material added to increase access)
	Linear Soft	Linear Soft: Linear corridor soft surface / vegetated
Modified Agriculture	Cultivated	Cultivated: Annual cereal crops, irrigated land, and bare soil, though excluding forage and pasture
Land	Pasture	Pasture: Annual forage and pasture, including pasture in shrubland with evidence of cultivation and pasture in recently cleared land
Forest[a]	Conifer	Coniferous Dominated Forest: >80% coniferous cover based on occurrence
	Deciduous	Deciduous Dominated Forest: >80% deciduous cover based on occurrence
	Mixed	Mixed Wood Dominated Forest: 20 -80% mixed wood cover based on occurrence
	Mid-Seral and Late-Seral	Coniferous, Deciduous and Mixed Wood Forests: Distinguished based on age class of forest 11-30, 31-55, 56-80, >80 years
n/a	Early Seral[b]	Early Seral: Combines several major landscape types: Natural Disturbed Forests in Very Early Stages of Succession, Nonforest Grassland, Upland Nonforest Forbs, Upland Nonforest Forbs, Human Modified Forest Land, and Forested Land with Human Disturbance Not Visible Throughout the Stand
NonForest	Upland Shrub	Closed / Open Upland Shrub: >25% shrub cover and <6% tree cover upland shrub
Shrubland[c]	Riparian Shrub	Closed / Open Riparian Shrub: >25% shrub cover and <6% tree cover riparian shrub
n/a	Open Water[d]	Standing and Flowing Open Water: Lakes, ponds, reservoirs, rivers and streams
n/a	Terrestrial Barren (natural)	Barren Terrestrial: Includes rock, talus, alluvial deposit, badland, blowout zone, and upland dune field, <6% vegetation cover
n/a	Aquatic Barren (natural)	Barren Aquatic: Includes alkali flat, mud flat, and beaches
Peatland Wetlands	Early, Mid, and Late Seral Forest	No ABMI equivalent, though represents succession of forested wetlands analogous to upland forests
	Bog – Forested	Bog – Treed: Peatlands with >6 crown closure
	Fen – Forested	Fen: Woodland fen
	Bog – Nonforested	Bog – Open: Peatlands with <6 crown closure
	Fen – Nonforested	No ABMI equivalent, though consistent with Alberta Wetland Inventory Classification System (Halsey and others 2004)
Non-Peatland	Marsh	Marsh: Wetlands dominated by emergent vegetation (cattails)
Wetlands	Swamp	Swamp: Graminoid Wetlands (sedges/grasses/forbs)

Footnotes:

[a] Landscape model reflects a more generalized classification of habitat states and forest age classes than ABMI. For instance, it does not differentiate among stand types based on canopy closure and/or species composition.
[b] Landscape model does not differentiate among early seral stages of grassland, forbland, bryophyte, shrubland and forest.
[c] Landscape model does not differentiate between closed and open shrublands.
[d] Landscape model does not differentiate between standing and flowing open water.

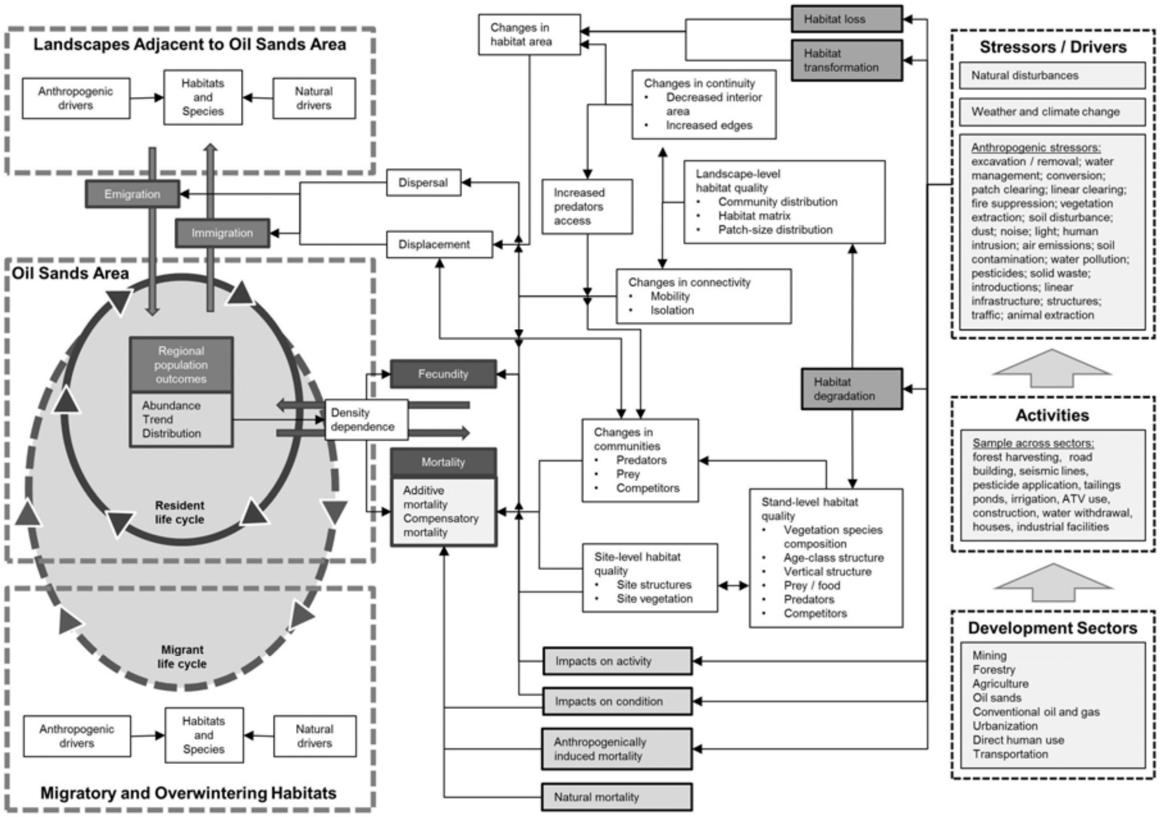

Fig. A1.4. Landscape model representing the dynamics of all terrestrial species occupying the study area. Resident species' outcomes are contained within the dashed box labeled 'Oil Sands Area', while migratory species extend to the lower dash box with the resulting set of additional drivers**.**

or transformation) or habitat quality (degradation in habitat conditions). Light shaded boxes represent classes of impacts that affect individuals within the population which lead to sub-lethal (impacts on activity or condition) or lethal (natural or anthropogenically induced) effects. These latter impact classes are shown in less detail in part because of space restrictions and because they are expanded upon in subsequent models.

The right portion of the model provides a simplified representation of the source of natural drivers and human influences on population dynamics adapting the IUCN threats classification system (Salafsky and others 2008). At the bottom right, sectors are listed to represent the types of human development occurring in the study area. These sectors are linked, in aggregate, to a subset of examples representing more specific activities within each sector. Activities are then linked to the varied stressors identified in the ecosystem model. A subset of natural drivers is also included to represent their important role as forcing agents on population dynamics. Table A1.3 provides a description and examples of the broad range of stressors across the landscape, while Table A1.4 aligns these stressors with their originating development sectors. To inform development of a monitoring program we characterized the spatio-temporal scales over which these stressors and drivers operate and the many-to-many alignment between sectors and stressors (each sector will result in a variety of stressors associated with its dominant activities and several different sectors may contribute to a similar stressor).

Table A1.3. Human stressors associated with development sectors affecting migratory bird habitats.

Stressor Grouping	Stressor	Description	Examples
Biological	Patch clearing	Removal of all major surface vegetation; polygonal footprint	Clearcut harvesting; also as a precursor to excavation / removal activities
	Linear clearing	Removal of all major surface vegetation; linear footprint	Right-of-ways for transportation and utility corridors, seismic lines
	Conversion	Transformation of natural habitat states to a different though still functioning alternate habitat state	Agricultural lands, urban parks
	Vegetation extraction	Removal of vegetation by humans	Forest harvesting, silvicultural shrub control, harvesting of non-timber forest products, grazing, mowing, cropping, haying
	Animal extraction	Removal of animals by humans	Hunting, fishing, and trapping; control of nuisance animals
	Introductions	Introduction of nonnative species	Invasive plants, invasive animals, nonnative pests, introduced agricultural crops
	Pesticides	Commercial application of herbicides / insecticides	Agricultural and silvicultural control of weed species or damage-causing insects
	Human intrusion	Disruption and disturbance due to the presence of humans on the landscape	Recreational activities, industrial exploration activities, fire suppression / ignition
Air	Emissions	Air pollution, including toxic emissions, smoke, smog, greenhouse gases, and particulate matter	Industrial facilities, power plants, vehicle and machinery emissions
	Noise	Unnatural sources of noise above natural levels; acute and prolonged sources	Construction activities, industrial machinery, compressor stations, traffic noise, industrial and urban noise pollution
	Light	Unnatural sources of light above natural levels; diffuse and point sources	Lights on building and structures, general light pollution from industrial and urban sources
	Dust	Unnatural sources of dust above natural levels; diffuse and point sources	Road construction, use of unpaved roads, construction activities
Land	Soil disturbance	Erosion of soil material due to modification of stabilizing elements or alteration of hydrologic processes	Tillage of agricultural fields, compaction by industrial and agricultural machinery
	Soil contamination	Release and persistence of toxic chemicals into the soil	Hydrocarbons, heavy metals, dioxins
	Linear infrastructure	Anthropogenic structures with linear footprint	Power lines, above-ground pipelines
	Structures	Anthropogenic structures with polygonal or linear footprints	Industrial and urban buildings, communication towers, other structures
	Traffic	Vehicular traffic along transportation routes	Car and truck traffic, rail traffic
	Solid waste	Solid waste entering the landscape	Landfills, illegal dumping, tailings
Water	Water management	Withdrawals, diversions or changes in the timing of flow. No distinction is made between direct manipulation (e.g., dams) and indirect manipulation (e.g., oilsands development).	Dams and reservoirs, water withdrawal and/or diversion for oilsands processing, wetland drainage, withdrawal for urban water use
	Water pollution	Water-borne pollution of various sources and origins	Direct contamination from industrial and urban sources, direct contamination from pesticides, leaching from solid waste, collection from surface runoff, deposition of air-borne particulate matter or acid rain

Table A1.4. Alignment of development sectors with stressors affecting landscapes of the study area originating from major (●) and minor / conditional sources (○).

Stressor Grouping	Stressor	Development Sectors								
		Mining	Forestry	Agriculture	Oil Sands	Convent'l Oil and Gas	Urban-ization	Human Use	Transport-ation	Distant Industry
Biological	Patch clearing	○	●	○	○	○	○			
	Linear clearing	○	○		●	●		○	●	
	Conversion			●			●			
	Biomass extraction		●	●				●		
	Introductions			●			●	●	●	
	Pesticides		●	●			○			
	Human intrusion	●	●		●	●	●	●		
Air	Emissions	●		○	●	●	●		●	●
	Noise	●			●	●	●		●	
	Light				●	●	●		●	
	Dust	●	●	○	●	●		○	●	
Land	Soil disturbance	●	●	●	●	●	●	○	●	
	Soil contamination	●	○	●	●	●	○			
	Linear infrastructure	●	●	○	●	●	●		●	○
	Structures				●	●	●			
	Traffic	●	●	○	●	●	●	○	●	
	Solid waste	●			●		●			
Water	Water management			●	●	●	●			○
	Water pollution	●		●	●	●	●			

Bird guild models

Development of the two bird guild models was based on several reports summarizing impacts on boreal forest birds (Blancher 2003; Schneider and Dyer 2006; Wells and others 2008; ABMI 2009b; Cheskey and others 2011; PEG 2011; Environment Canada 2012), as well as other research papers on specific elements within each of the guild models (e.g., see citations in Table A1.5).

A simplified version of the guild model is provided in Fig. A1.5 and follows the broad form of the landscape-level population model (Fig. A1.4). The forest (Fig. A1.6) and wetland-dependent (Fig. A1.7) bird models elaborate on this simplified model. These guilds also align with the upland/forest and lowland/wetland habitat states at the landscape level (Fig. A1.3). The pathways-of-effect were organized somewhat differently across guilds to test equally credible alternative structures. For both guild models, pathways are grouped according to impacts on habitat and impacts on health (activity or condition) and survival. The wetland-dependent bird model explicitly considers impacts on nesting success, where the forest bird model does not.

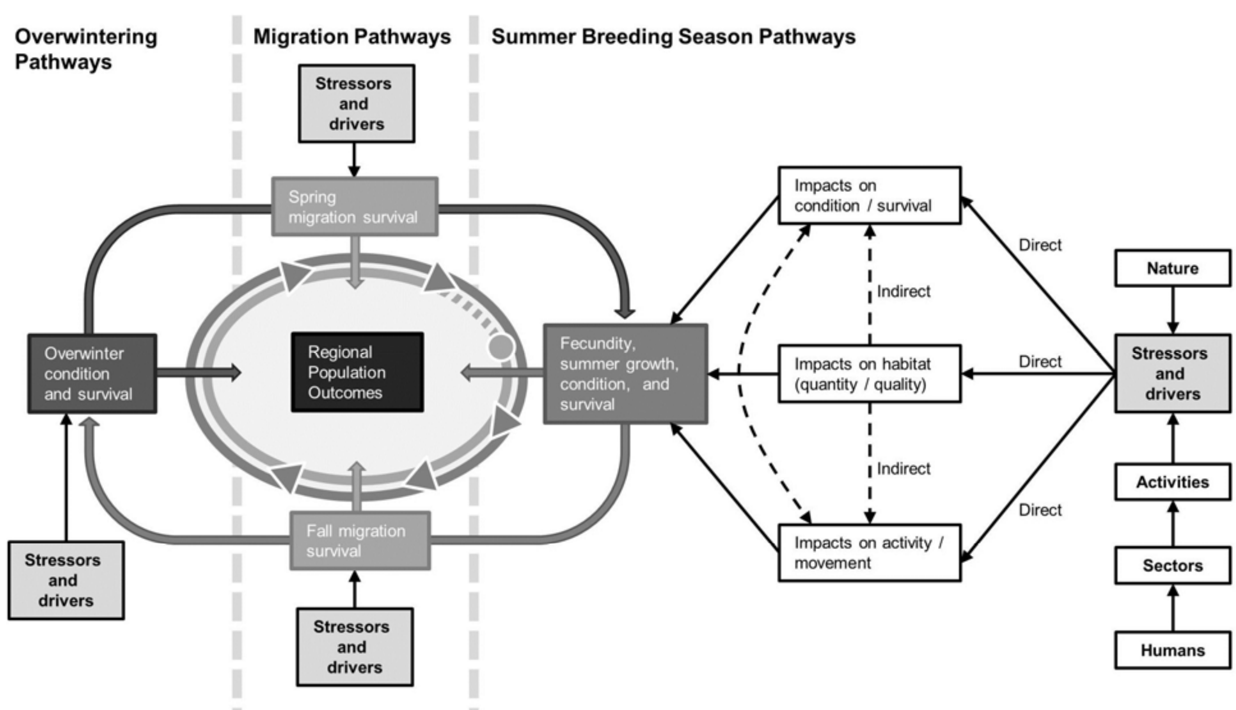

Fig. A1.5. Simplified model illustrating the core components and pathways in the forest and wetland-dependent bird guild models. Of particular importance is that only the ‘Summer Breeding Season Pathways’ are influenced by the oil sands region, with what are likely significant influences on regional population outcomes during both migration and wintering portions of the lifecycle (Sillet and Holmes 2002; Rockwell and others 2012; Hostetler and others 2015).

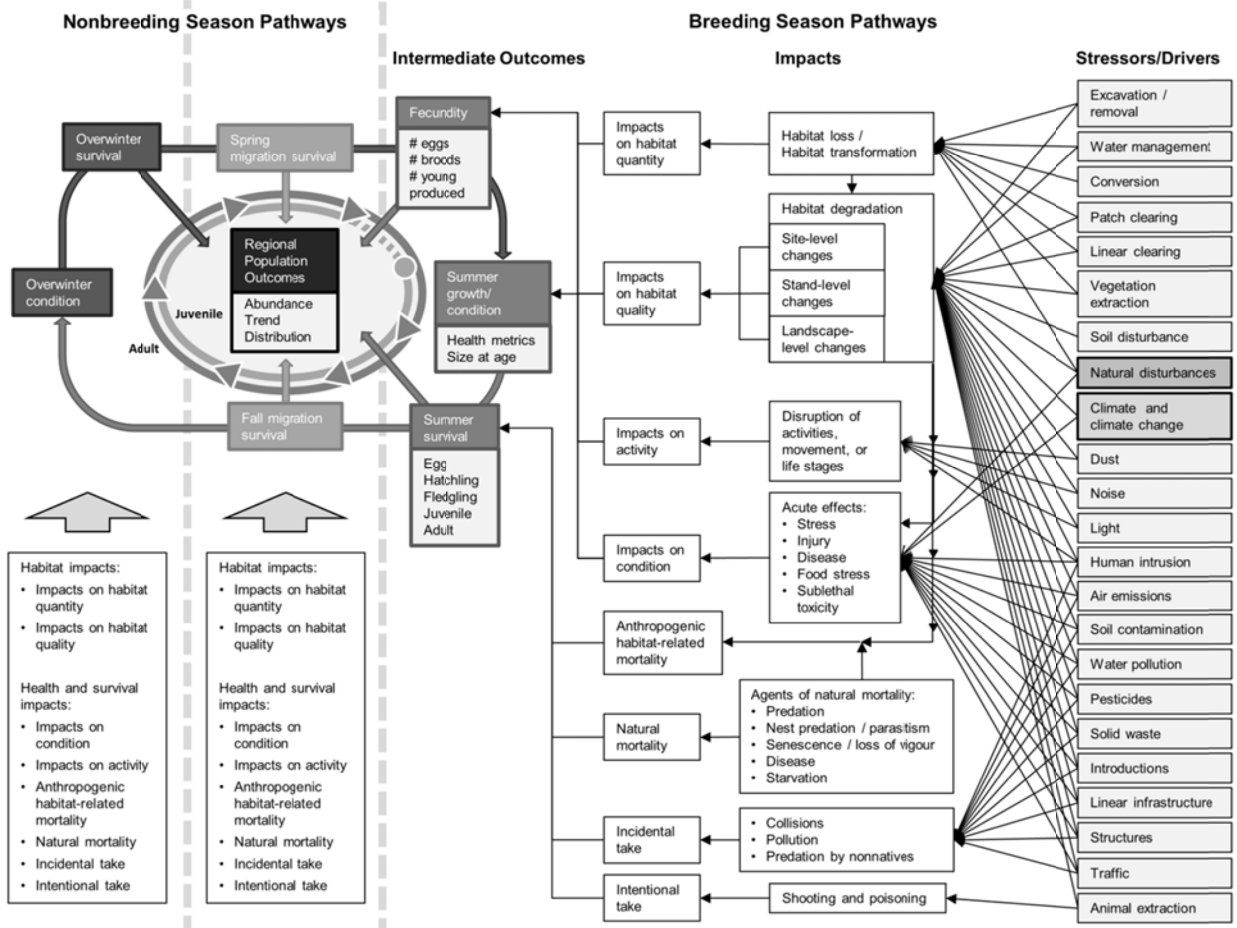

Fig. A1.6. Conceptual model representing relationships among human stressors / natural drivers, impacts, life stages, and population responses for all **forest birds** occupying the study area.

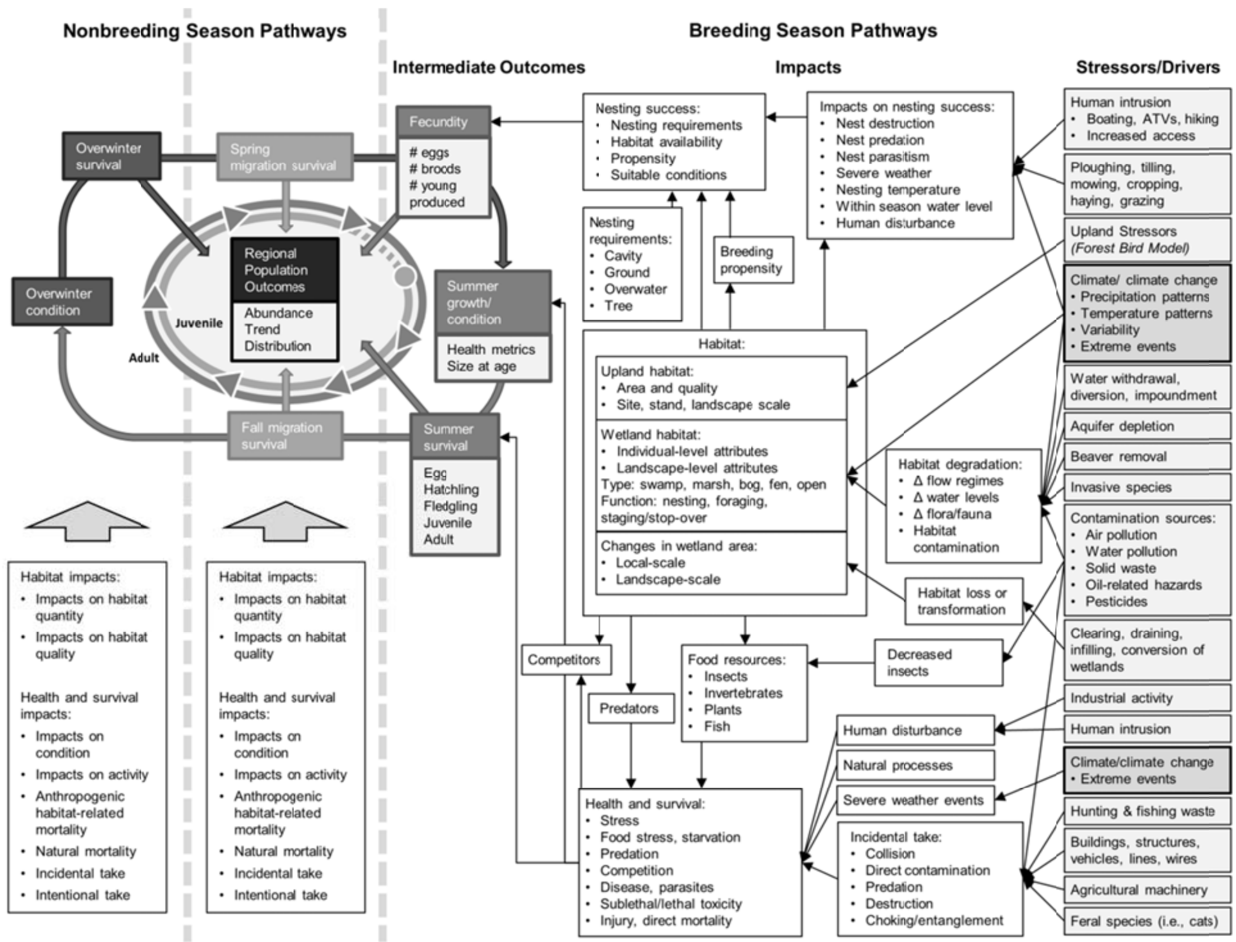

Fig. A1.7. Conceptual model representing relationships among human stressors / natural drivers, impacts, life stages, and population responses for all **wetland-dependent birds** occupying the study area

The left part of the models shows an annual life cycle separated into key life stages: breeding, fall migration, overwintering, and spring migration. At the centre are outcomes related to migratory bird populations which represent the most important, relevant, and measurable outcomes for the monitoring program. Regional population measures are the core consideration, as opposed to continental population measures, because many of the species of interest have wide summer breeding ranges that will be subject to different sets of stressors. An inner ring represents juveniles or “hatch year” for the first year of life, though species with delayed maturity would continue to be considered juvenile until they start breeding (represented by thatching of inner circle). An outer ring represents subsequent adult years of life with seven distinct influences: fecundity, summer growth/condition, summer survival, fall migration survival, overwinter condition, overwinter survival, and spring migration survival. Survival and fecundity are direct impacts on populations (arrows to the centre), whereas changes in condition have indirect impacts on populations through their effect on subsequent life stages (arrows to other life stages). For instance, summer growth/condition affects summer survival, fall migration survival and ultimately overwinter condition (denoted by arrow from summer growth to overwinter condition). Alternatively, fecundity is influenced both by the condition that birds are in when they return to the breeding ground from their overwintering grounds (overwinter condition) and the conditions on the breeding grounds themselves.

Stressors and drivers are shown to have potential impacts on summer breeding, migration, and overwintering stages in the middle and left part of the model. For the summer breeding season, stressors and drivers are elaborated upon and shown to be natural (e.g., wildfire or drought) or anthropogenic. Each of the stressors and individual pathways do not necessarily apply to all species, but rather represent drivers of pathways that are relevant to at least a subset of species. These forcings can have direct and indirect impacts on habitats and/or individuals, which ultimately affect migratory bird populations based on a sequence of linkages represented in the models by pathways-of-effect in the breading season (middle portion of model). As noted above, breeding season pathways can be grouped according to their: (1) impact on habitat, (2) impact on health (activity and condition) and survival, and (3) impact on nesting success. Nonbreeding season pathways are not explicitly represented in these models given the geographic focus of the monitoring program, though are expected to result in similar kinds of impacts across migratory and overwintering ranges.

Impacts on habitat include loss, transformation, and degradation. Loss refers to the complete elimination of habitats. Habitat transformation refers to the alteration from an existing state to an alternative that leads to a change in species composition. For example, the conversion from a forest to a pasture may eliminate occupancy by warblers but increase habitat use by savannah sparrows. Habitat degradation refers to a more subtle, though broader, range of impacts that decrease the quality and suitability of habitats. For instance, selective harvesting has been shown to decrease abundance of ovenbirds likely due to changes in the quality of both the canopy and shrub-layer in harvested stands (Bourque and Villard 2001; Jobes and others 2004). The three impacts to habitat also create complex interactions that are not represented in these models. Similarly, interdependencies among stressors are also not captured to avoid an unnecessarily complex model (e.g., air emissions can lead to water pollution, aquifer depletion may be driven by water withdrawal, diversion and a changing climate). Links from the habitat boxes indicate that changes in habitat quantity and quality can lead to other impacts. As an example, studies have found higher rates of nest predation in forested patches suggesting a possible relationship between forest fragmentation and predation (e.g., Darveau and others 1997; Manolis and others 2002).

Impacts on health include stressors that disrupt or interfere with a species' ability to conduct its normal activities, especially foraging and movement among habitats, or may cause stress, injury, disease, malnutrition, and toxicity, which have an effect on an individual's condition. For instance, disruption of foraging-related activities may result in reduced summer growth/condition as illustrated by discussion in the literature on the importance of high quality wildlife habitats (Thompson 2004). Impacts on health may also be due to changes in habitat caused by other stressors (e.g., changes in habitat that affect food availability which leads to food stress).

Impacts on survival include different sources of natural mortality: predation, senescence/loss of vigour, disease and starvation. Though natural, they can also be substantially altered by human-induced changes in habitat. This group of impacts includes incidental take – human-induced mortality that is direct and unintentional (e.g., birds killed by colliding with telecommunication towers or cars, see Calvert and others 2013), and intentional take – killing which is deliberate, as in hunting of waterfowl or upland game birds.

Impacts on nesting success are influenced by the availability of appropriate nesting habitat and processes that interfere with successful nesting despite the availability of sites. Interfering processes include predation or parasitism of nests, destruction of nests by human actions or severe weather, detrimental changes in habitat conditions, or disturbance from human intrusion. These impacts are important since the disruption of breeding-related activities or disturbance of birds on their nests may lead to reduced fecundity or abandonment. This phenomenon has been observed for a wide variety of species including Bald Eagle (Therres and others 1993), Great Blue Heron (Vennesland 2010), and White-throated Sparrow (Hannah and others 2008).

Due to their breadth, the forest and wetland-dependent bird models lacked the level of specificity necessary for the expert weighting process. Distinct and embedded pathways-of-effect and causal mechanisms affecting life stage and population level responses were pulled from the diagrams and elaborated upon. Eight distinct habitat pathways were identified. Given the geographic scope and emphasis of the monitoring program, pathways leading to human induced mortality (incidental and intentional take) and pathways-of-effect at other life stages, were not included. Table A1.5 provides a summary of each pathway disaggregated according to the drivers, linkages, and outcomes of relevance to migratory birds for which new visualizations were made to present to experts (see example of a single pathway diagrammed in Fig. A1.8). Pathways were distinguished according to their spatial scale of effect (stand vs. landscape level), type of habitat impact (quantity vs. quality) and form of habitat disturbance based on the sector of origin (habitat loss vs. habitat transformation). From the guild models, eleven causal mechanisms were also identified to explicitly recognize the underlying and driving influences that affect the proximate (growth, survival, and fecundity) and ultimate (abundance, trend, distribution) outcomes of interest. Table 2 in the main manuscript lists these causal mechanisms. These pathways and causal mechanisms were the subjects in the prioritization exercise summarized in the main manuscript.

Table A1.5. Core pathways-of-effect influencing migratory bird habitats across the study area.

Pathways-of-Effect	Drivers[a]		Linkages		Outcomes		
	Sectors	Stressors	Impacts	Impact Classes[b]	Intermediate	Ultimate[c]	Examples
(A) Stand-level disturbances to forests due to urbanization, industrial development, and transportation leading to habitat losses and potential decreases in regional populations.	OGO MIN TRP URB	VE	Such changes reduce habitats for forest birds, leading to displacement, competition, and changes in predation.	HQN AHM CON	Absence of forest birds and local emigration	–	All obligate forest birds
(B) Landscape level disturbances to forests due to urbanization, industrial development, and transportation leading to losses and fragmentation of habitats and potential for negative influences on regional populations.	OGO MIN TRP URB	VE	Conversion / fragmentation of forest reduces habitat for birds and changes in connectivity / continuity. Landscape-level impacts are related in a nonlinear way to the extent of harvesting.	HQN HQL AHM	Landscape-level emigration and reduced landscape-level populations	–	All obligate forest birds
(C) A broad range of human activities leading to localized impacts on habitat quality which have the potential for landscape level and cumulative impacts on habitats and adverse effects on regional populations.	OGO MIN TRP URB FOR AGR	All of Table A1.3	Habitat quality is degraded through stressors which alter the capacity of habitats, leading to loss of key site-level requirements (nesting structures, perches, cover vegetation).	HQL	Decreased productive capacity and reduced condition	–	Several species of birds are less abundant in noisy environments in the oil sands including white-throated sparrow, yellow-rumped warbler, and red-eyed vireo (Bayne and others 2008)
(D) Stand level transformations of forests due to agricultural conversion leading to potential losses / gains and either negative or positive influences on regional populations (depending on habitat preferences).	AGR	CO	Conversion from forested to nonforested habitats alters the abundance of food and habitat attributes leading to fewer forest-dwelling species and more species able to use forest edges.	HQN HQL	Reduced productivity, emigration, and lower density with habitat decreases	–	All obligate forest birds
					Increased productivity, immigration, and higher density with habitat increases	+	American robin associate positively with forest edges (Hawrot and Niemi 1996)
(E) Landscape-level transformations of forests due to agricultural conversion leading to fragmentation and losses / gains of habitats with either negative or positive influences on regional populations (depending on habitat preferences).	AGR	CO	Conversion from forested to nonforested areas lead to variable landscape, leading to changes in habitat connectivity, as well as less habitat for forest-dwelling species and more habitat for generalist species.	HQN HQL	Landscape-level emigration and reduced landscape-level populations for birds with decreases in habitat	–	All obligate forest birds
					Landscape-level immigration and increases in landscape-level populations for birds with increases in habitat	+	Corvid density may increase in fragmented forest (Andrén 1992)
(F) Stand-level transformations from older to young regenerating forest due to harvesting leading to either negative or positive influences on regional populations (depending on habitat preferences).	OGO[d] FOR	PC LC	Shift to regenerating forests alters abundance of food and habitat attributes leading to less habitat for some species specialists (mature forests, conifer-dominated uplands) and more habitat for other species (early seral, nonforested habitats)	HQN HQL	Reduced productivity, local emigration and reduced local density for birds with decreases in habitat	–	Red-breasted nuthatches prefer large old conifers and would be adversely affected (Steeger and Hitchcock 1998)
					Increased productivity, local immigration, and increased local density for birds with increases in habitat	+	Early seral species such as song sparrow are more abundant in young forests (Lance and Phinney 2001)

Pathways-of-Effect	Drivers[a]		Linkages		Outcomes		
	Sectors	Stressors	Impacts	Impact Classes[b]	Intermediate	Ultimate[c]	Examples
(G) Landscape-level transformations from older to young regenerating forest due to harvesting leading to fragmentation and either negative or positive influences on regional populations (depending on habitat preferences).	OGO[d] FOR	PC	Shift to regenerating forests leading to less habitat for some specialists (preferring contiguous, large interior forests) and more habitat for generalists (preferring fragmented, disturbed, highly variable landscapes).	HQN HQL	Landscape-level emigration and reduced landscape-level populations for birds with decreases in habitat Landscape-level immigration and increases in landscape-level populations for birds with increases in habitat	– +	Ovenbird abundance has been shown to be related to landscape characteristics (Betts and others 2006) Corvid density may increase in fragmented forests (Andrén 1992)
(H) Transformations of habitats from old to young regenerating forest due to changes in forest fire dynamics (i.e., wildfire, human caused fires, fire suppression) leading to stand and landscape level changes with potential negative or positive influences on regional populations (depending on habitat preferences).	FOR URB HUM	ND HI WC	Alteration in habitats leading to fewer habitats for some (mature forest species) and more habitats for others (early seral species). Fire suppression may reduce, while climate change will increase fires, creating changes in natural dynamics on landscape.	HQN HQL	Decreased density for species which use intact, old forest, increased density and fecundity for species which use burned forest, immigration or emigration depending on species preferences (both positive and negative effects)	– +	A number of species are more abundant in unburned than burned forests (e.g., Northern waterthrush, red-eyed vireo, see Morissette and others2002) Black-backed and three-toed woodpeckers would immigrate as they prefer burned habitats (Hoyt and Hannon 2002)

Footnotes:

[a] Note use of the following abbreviations: AGR (agriculture), FOR (forestry), HUM (human use), MIN (mining), OGO (oil sands, conventional oil and gas), TRP (transportation), URB (urban), VE (vegetation extraction), CO (conversion), LC (linear clearing), HI (human intrusion), PC (patch clearing), WC (weather and climate), ND (natural disturbance).

[b] Note use of the following abbreviations: AHM (anthropogenic habitat-related mortality), CON (condition), HQL (habitat quality), and HQN (habitat quantity).

[c] – and + symbols denote the potential for negative and/or positive influences on regional populations.

[d] Primarily related to seismic lines

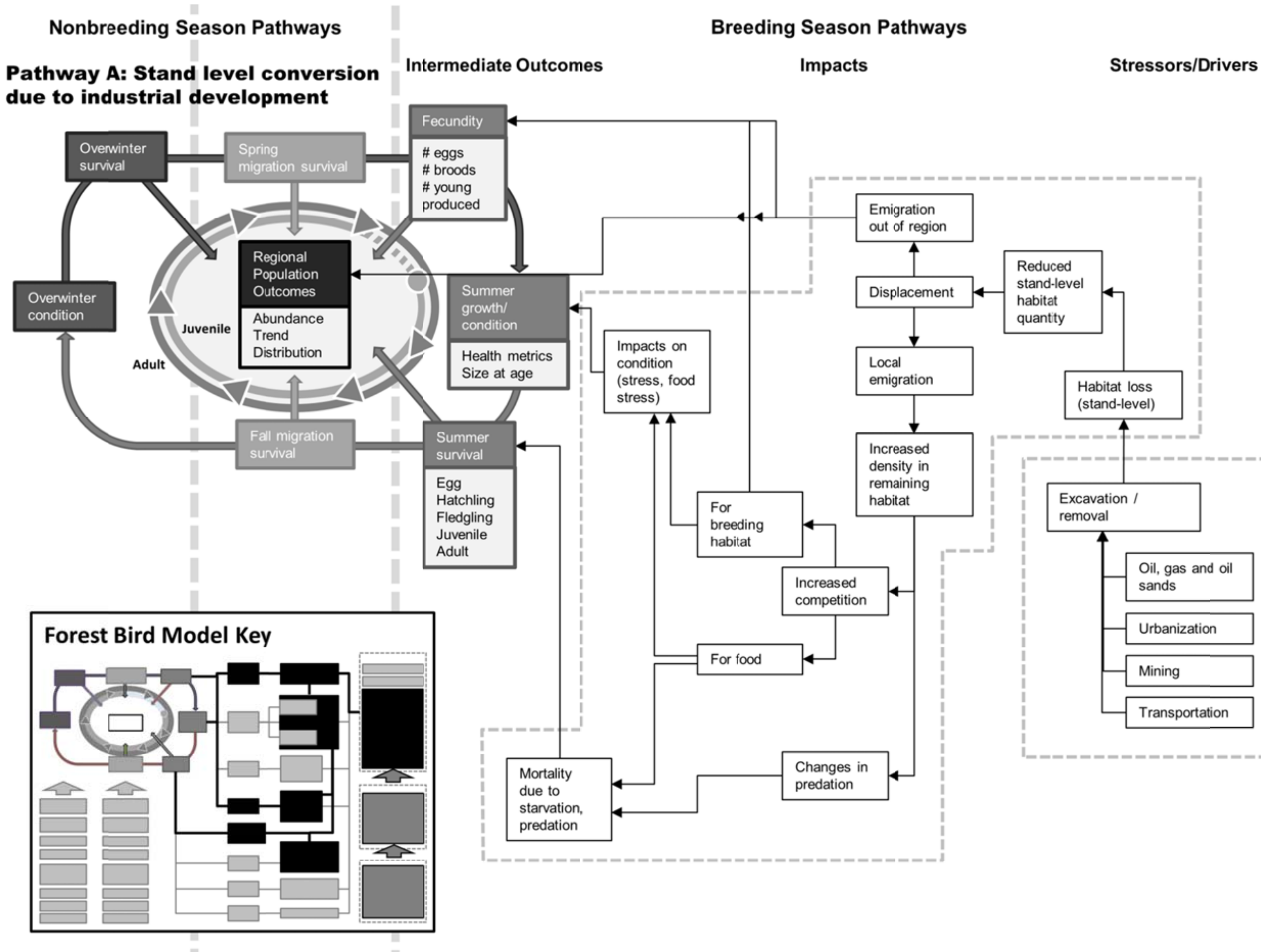

Fig. A1.8. Conceptual model representing habitat pathway A in Table A1.5 for all forest birds across the study area (i.e., stand level conversion due to industrial development). Inset diagram represents the core pathways-of-effect of relevance (in black) from the forest bird model in Fig. A1.6.

Species models

Species models were made for Canada Warbler (*Cardellina canadensis*), Horned Grebe (*Podiceps auritus*), Swamp Sparrow (*Melospiza georgiana*), Barn Swallow (*Hirundo rustica*), Common Nighthawk (*Chordeiles minor*), Olive-sided Flycatcher (*Contopos cooperi*), Rusty Blackbird (*Euphagus carolinus*), Whooping Crane (*Grus americana*), and Yellow Rail (*Coturnicops noveboracensis*). This mix of species was selected to illustrate the range of potential effects of human development on bird populations within the study area, especially on Species At Risk. These models were based on COSEWIC Assessment Reports (e.g., Government of Canada 2013b), Alberta Breeding Bird Atlas (FAN 2007), and Birds of North America Online (Cornell Lab of Ornithology 2013), primary literature and expert judgements. Conceptual models for Canada Warbler and Horned Grebe are provided here. Pathways are numbered to correspond with the full suite of hypotheses that have been identified as having an influence on abundance, trend, or distribution of relevant species (see Tables A1.6, A1.7). Details are only presented here for the first two species, but similar information was prepared for the remainder. The conceptual models (diagrams and supporting text) for the latter species are available from the authors or through Research Gate (https://www.researchgate.net/publication/281112203_Conceptual_models_of_migratory_birds_and_human_development_as_relevant_to_the_oil_sands_of_Canada).

A dramatic decline in abundance of Canada Warbler since the late-1960s has intensified in recent decades leading to its listing as a "*Threatened*" species (COSEWIC 2008). Though the underlying causes of the decline are not known (Venier and others 2012), Fig. A1.9 summarizes the full range of pathways that are known to influence Canada Warbler populations. Direct habitat loss (**HL**), habitat transformation (**HT**), and habitat degradation through landscape level alterations (**LC**), changes in the shrub layer (**SL**) and increases in noise (**NS**) are identified as disturbances to breeding habitats that will ultimately affect fecundity and growth / condition of individuals. These disturbances originate from human development activities (e.g., forestry, agriculture, oil and gas exploration, urbanization) that remove, clear, and/or convert the forested landscape. Moreover, the associated changes in breeding habitats may alter insect abundance (**IA**) or affect rates of nest parasitism (**NP**) which can have direct effects on summer survival. Lastly, mortality along migratory flyways from various human sources (**MH**) and widespread loss and transformation of habitat in its wintering range (**OH**) as a result of intensive human development in the mountain rainforests of northwestern South America are noted as additional pathways that have direct effects on survival during these life stages.

A persistent decline since the mid-1960s, with rapid declines noted more recently, have led to western population of Horned Grebe being listed as a species of "*Special Concern*" (COSEWIC 2009). Fig. A1.10 illustrates the pathways-of-effect and interactions among the potential causal mechanisms that are known to influence Horned Grebe populations. Core pathways include habitat losses through permanent (**PW**) and temporary (**TW**) disturbances to wetlands, as well as the degradation of nesting sites through eutrophication of wetlands due to application of fertilizers (**DW**) and flooding of nesting sites due to extreme weather during the breeding season (**WX**). Habitat alterations from human activities also have the potential to affect the abundance of other species which can lead to increases in predation (**IP**) on all breeding stages (nest, juvenile, and adults) and displacement of adults by competitors (**DC**). Release of contaminants into waterways from human sources can have toxic effects (**TX**) and ongoing changes in the incidence of disease (**DS**) can have impacts on summer survival. During migration additional mortality due to fishing gear entanglement (**FG**), disease (**DS**) and extreme weather (**WX**) can have adverse population level effects. Finally, Horned Grebe is also vulnerable to marine oil spills (**MS**) and changes in marine prey (**MP**) in its wintering range.

Table A1.6. Summary of core pathways-of-effect hypothesized as affecting population level status of Canada Warbler (CAWA) in the study area. Letters refer to notations of pathways in Fig. A1.9.

<u>(HL) Habitat Loss:</u> Urbanization, transportation, and oil & gas developments contribute to the loss of habitats through the removal of vegetation. In western Canada, forests have been significantly removed due to oil and gas activities (Cooper and others 1997; Senate Subcommittee on the Boreal Forest 1999; Hobson and others 2002; South Peace Bird Atlas Society 2006). The resulting changes can impact fecundity through loss of breeding areas and summer growth/condition through loss of foraging areas. Stand-level changes will also have cumulative effects at the landscape-level.
<u>(HT) Habitat Transformation:</u> Conversion from expanding agriculture and urbanization result in transformation of deciduous and mixedwood forests to other habitats unsuitable for CAWA (Senate Subcommittee on the Boreal Forest 1999; Hobson and others 2002). Patch clearing from forestry and linear clearing from oil and gas exploration can further alter the successional stage of forests, decreasing the amount of mid- or late-seral stages (Senate Subcommittee on the Boreal Forest 1999; Schneider and others 2003). For instance, industrial development in northern Alberta may eliminate old-growth softwood stands within 20 years and old-growth hardwood stands within 65 years (Schneider and others 2003). The resulting decrease in stand-level habitats can have impacts on fecundity and summer growth/condition as well as lead to cumulative effects at the landscape-level (e.g., fragmentation of habitats and increases in forest edges).
<u>(LC) Landscape-Level Changes:</u> As discussed above, changes in stand-level habitat will lead to cumulative effects at the landscape-level. Such habitat fragmentation will also occur due to linear clearing from oil and gas exploration. These changes may increase the shrub layer, but also increase opportunities for nest parasitism. CAWA is relatively tolerant of habitat discontinuity associated with forestry (Schmiegelow and others 1997), but relatively intolerant when associated with agriculture (Robbins and others 1989; Hobson and Bayne 2000). Other research has shown that the occurrence of CAWA is negatively affected by the proximity and length of paved roads within its breeding habitat (Miller 1999). These changes may influence population status as road development is expected to increase substantially in the boreal mixedwood forests of northern Alberta over the coming years (Schneider and others 2003).
<u>(NS) Noise:</u> Although COSEWIC (2008) does not describe noise as a disturbance to CAWA, it is a plausible stressor based on research for other boreal passerines in Alberta (Habib and others 2007; Bayne and others 2008) and other boreal birds in Ontario (Summers and others 2011). Noise may result from numerous activities associated with urbanization, transportation, and oil and gas development (e.g., construction, road traffic, compressor stations). Noise can affect fecundity or summer growth/condition through a direct disruption of normal breeding and foraging activities. For instance, Habib and others (2007) found that ovenbird pairing success was lower near compressor stations than noise-less wellpads. They hypothesized that compressor noise interfered with females' ability to hear males' songs over longer distances or distorted the song so females incorrectly perceived males to be of lower quality.
<u>(SL) Shrub Layer:</u> Naturally forming canopy gaps due to natural disturbance or regenerating forests following harvesting contribute to development of the shrub layer. This habitat is critical for CAWA foraging. In western Canada, local concentrations of suitable habitat were associated with old growth deciduous forests, particularly near small, incised streams at the local scale, and a deciduous forest matrix at the landscape scale (Ball and others 2013). Though increases in forest edges due to harvesting may increase shrub habitats, some silvicultural practices can limit shrub development (Askins and Philbrick 1987; Gauthier and Aubry 1996; Cooper and others 1997; Norton and Hannon 1997; Schieck and others 2000; Tittler and others 2001). As well, grazing by ungulates can reduce the shrub layer and affect habitat quality for CAWA (Conway 1999).
<u>(IA) Insect Abundance:</u> Decreases in insect abundance may impact summer survival, fecundity and growth/condition due to a decrease in food resources. As well, insect abundance depends on a well-developed shrub layer and is further affected by periodic, natural insect outbreaks. CAWA feed primarily on flying insects and spiders in the shrub layer (Conway 1999). Canada Warbler may feed heavily on spruce budworm during outbreaks though they are not considered a spruce budworm specialist (Crawford and Jennings 1989; Patten and Burger 1998; Conway 1999; Sleep and others 2009). It has been suggested that decline of CAWA may be associated with the coinciding decline in spruce budworm outbreaks (Sleep and others 2009), but more recent research indicates little evidence of such a relationship (Venier and others 2012).
<u>(NP) Nest Parasitism:</u> Habitat fragmentation and creation of forest edges tend to increase opportunities for nest parasitism, resulting in decreased summer survival of young CAWA as young cowbirds outcompete them for food brought to the nest. Although CAWA is a common cowbird host its significance is unknown in Alberta (Reitsma and others 2010).
<u>(MH) Migratory Habitat:</u> COSEWIC (2008) does not discuss threats to CAWA during its migration, but it is plausible that it may be vulnerable to impacts on habitats along its migration. Migratory habitats in Central America are similar to its overwintering habitats in South America and expected to be exposed to similar human development pressures.
<u>(OH) Overwintering Habitat:</u> Extensive human development has led to substantial impacts on CAWA's overwintering habitat in South America. Overwintering grounds in the northern Andes include the most threatened forests in the world (Davis and others 1997). Since the 1970s, 90% of rainforests and 95% of cloud forests have been lost, while remaining forests are heavily disturbed (Henderson and others 1991). Such impacts will affect overwinter condition and survival.

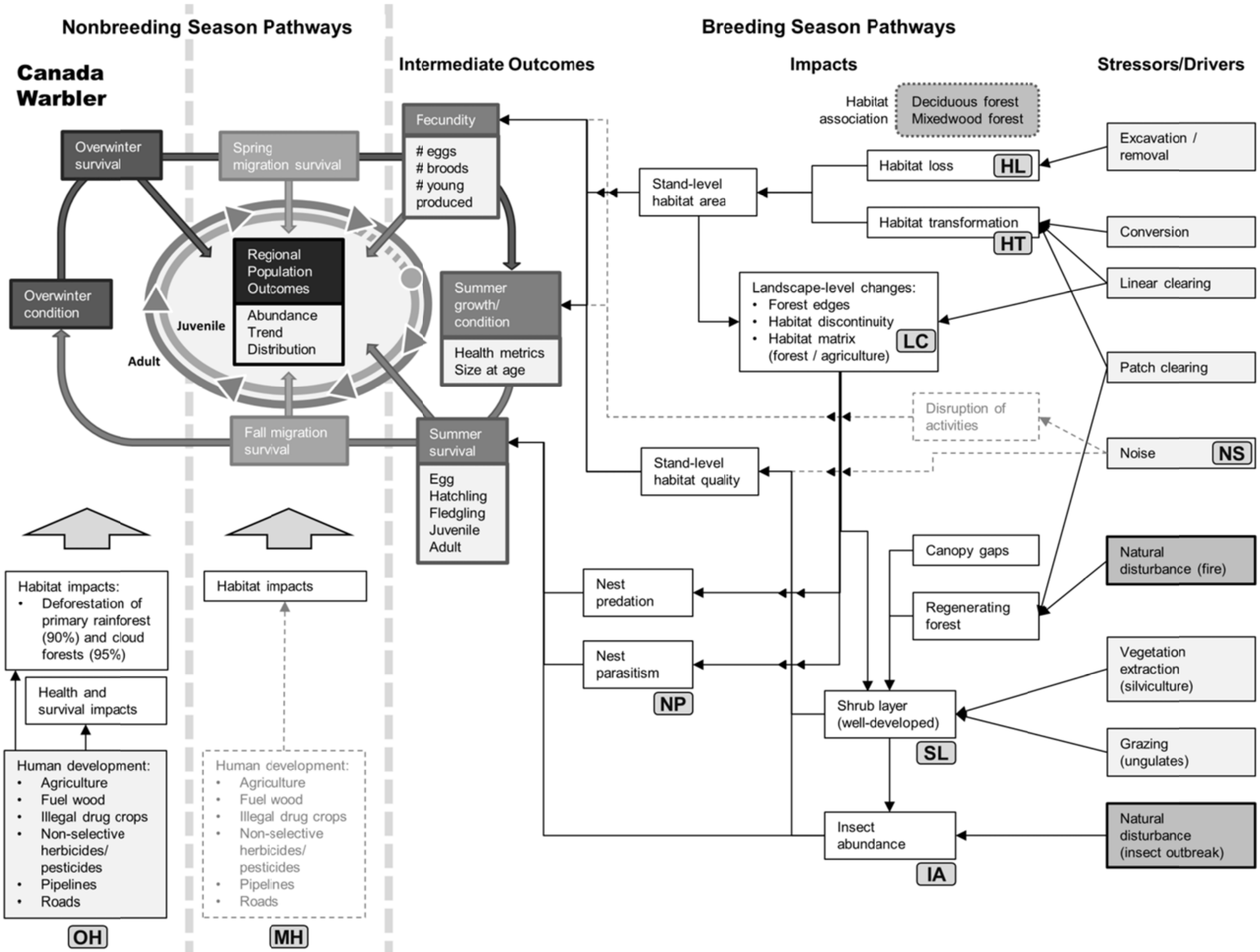

Fig. A1.9. Conceptual model representing the pathways-of-effect influencing population status of Canada Warbler. Letter notations correspond to pathways described in Table A1.6. See Table A1.4 for alignment of stressors presented here with development sectors from study area.

Table A1.7. Summary of core pathways-of-effect hypothesized as affecting population level status of Horned Grebe (HOGR) in the study area. Letters refer to notations of pathways in Fig. A1.10.

<u>(IP) Increased Predation:</u> A major expansion in range and/or increase in abundance of some predators may be threatening HOGR. Raccoon, Common Raven, Black-billed Magpie, and various gull species take eggs; Northern Pike and gulls can prey on chicks; and minks and possibly foxes prey on adults (Ferguson 1977; Fournier and Hines 1999; Stedman 2000). Raccoons are believed to be spreading into northeastern Alberta (Latham 2008). Breeding Bird Survey observations indicate the abundance of Common Raven has increased substantially in Alberta and across Canada over the past several decades (CWS 2014) with increases in relative abundance also being detected in the study area (FAN 2007).

<u>(PW) Permanent Loss of Wetlands:</u> The clearing, draining, infilling, and conversion of wetlands for human development (e.g., agricultural, rural, industrial, and urban activities) results in the permanent loss of wetlands, thus eliminating the productive potential of such habitats. The cumulative loss of wetlands at a landscape scale may result in a disproportionately greater loss of avian productivity resulting from decreases in nesting density (Andrén 1994).

<u>(TW) Temporary Loss of Wetlands:</u> Drought can lead to the temporary loss of breeding ponds. Although drought is a natural part of climate cycles, the frequency, intensity and duration is expected to increase with climate change. Moreover, HOGR may be additionally sensitive to these losses when combined with permanent losses across the landscape.

<u>(DS) Disease:</u> Type E Botulism may be a significant source of mortality for population exposed to outbreaks. HOGR were among the most affected species in several outbreaks in the Great Lakes (USGS 2007; USGS 2008).

<u>(DW) Eutrophication and Degradation of Wetlands:</u> The accumulation of fertilizers from agricultural activities can lead to eutrophication, contamination and an overall degradation of wetlands (COSEWIC 2009).

<u>(TX) Toxicity:</u> HOGR are vulnerable to contaminant releases, especially through bioaccumulation since they are at a high tropic level in the food chain. Elevated levels of DDE, PCBs, dioxins, and furans have been detected in HOGR (Vermeer and others 1993; Forsyth and others 1994).

<u>(DC) Displacement by Competitors:</u> HOGR may be displaced from breeding ponds by both Pied-billed Grebes and Red-necked Grebes (COSEWIC 2009). Pied-billed Grebes have been increasing in western Canada over the past two decades, with substantial increases in Alberta during last decade (CWS 2014), though decreases in their relative abundance in the study area have also been detected (FAN 2007).

<u>(MP) Changes in Marine Prey:</u> Due to shifts in ocean regimes and changes in human stresses, populations of forage fish and other marine prey species along the coast have changed considerably in recent decades (e.g., Anderson et al 2009; Therriault et al 2009). Changes in marine prey in the wintering range may affect overwinter survival and movement.

<u>(MS) Marine Oil Spills:</u> During overwintering, HOGR spend the majority of its time on the water and is therefore vulnerable to marine oil spills. Mortalities due to oil spills have been document in numerous cases (COSEWIC 2009). Hundreds or thousands have been killed in individual oil spills, sometimes representing substantial portions of all species oiled (del Hoyo and others 1992; Stedman 2000; COSEWIC 2009). Though HOGR are likely vulnerable to oil spills across the entire northern hemispheric range, their expansive overwintering range may offer some protection against catastrophic losses from individual events (Stedman 2000).

<u>(FG) Entanglement in Commercial Fishing Gear:</u> HOGR can get entangled in fishing nets and drown (Harrison and Robins 1992), particularly on large lakes during migration (Riske 1976; Piersma 1988; Ulfvens 1989). Although there are documented cases of HOGR in marine bycatch, there is little evidence of fishing net mortality in North American marine environments during the winter (COSEWIC 2009).

<u>(WX) Severe Weather:</u> The combination of increased rainfall and wind during storm events can result in flooding of floating nests in the breeding season (Shaffer and Laporte 2003). Severe storms have also occasionally been documented to have detrimental impacts during their migration (COSEWIC 2009).

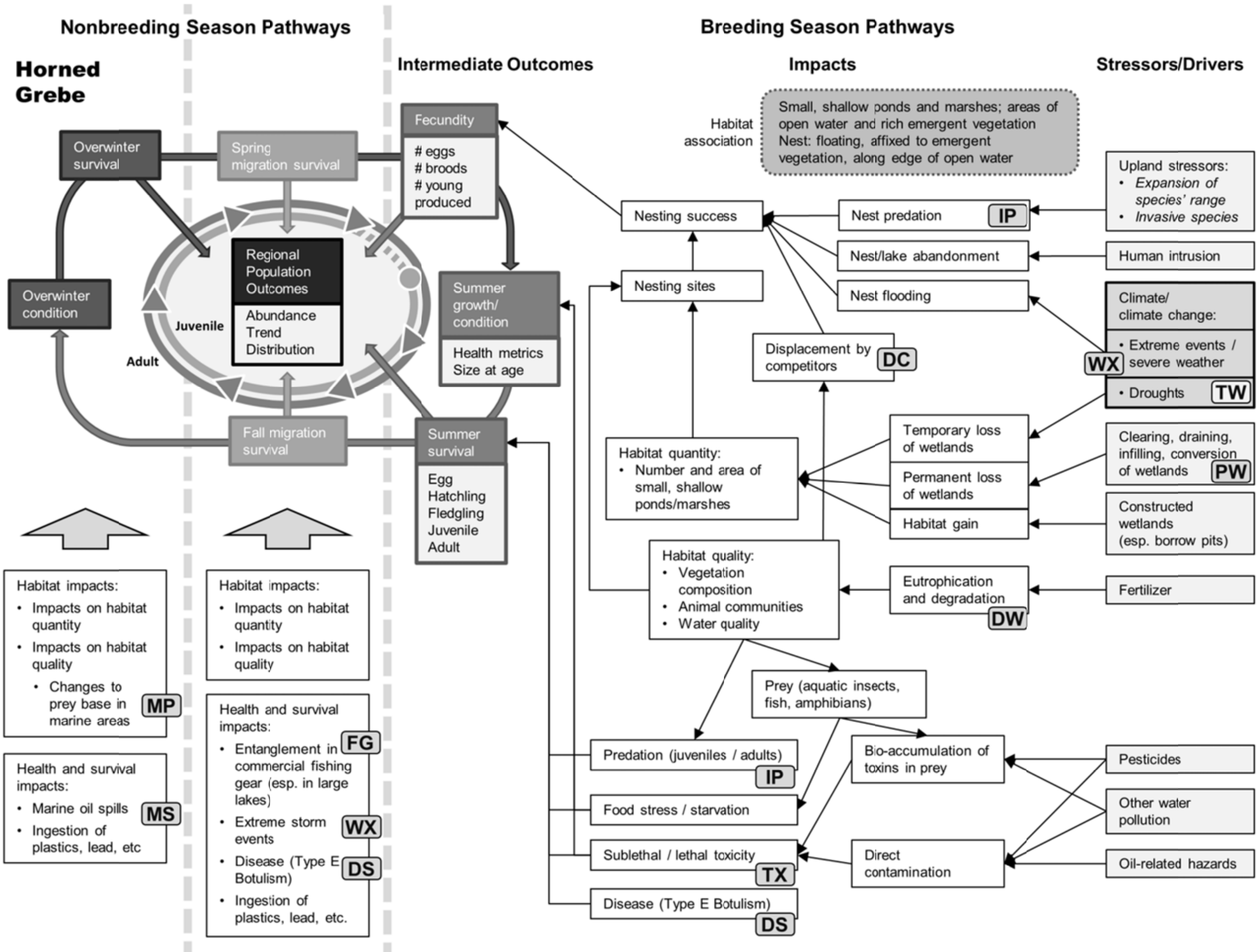

Fig. A1.10. Conceptual model representing the pathways-of-effect influencing population status of Horned Grebe. Letter notations correspond to pathways described in Table A1.7. See Table A1.4 for alignment of stressors presented here with development sectors from study area.

LITERATURE CITED

Alberta Biodiversity Monitoring Institute [ABMI] (2009a) ABMI's habitat pyramid: Definitions and element lists. (20039), Version 2009-04-20. Edmonton, AB

Alberta Biodiversity Monitoring Institute [ABMI] (2009b) ABMI species pyramid: Guild definitions and species lists, Version 2009-12-22. Edmonton, AB

Alberta Biodiversity Monitoring Institute [ABMI] (2010) Human disturbance footprint map. Version 1.1. http://www.abmi.ca/home/data/gis-data/human-footprint-download.html?scroll=true Accessed 20 March 2015, but v1.1 has been updated.

Alberta Sustainable Resource Development [ASRD] (2002) Fort McMurray-Athabasca oil sands: Subregional integrated resource plan. Government of Alberta, Edmonton, AB

Anderson EM, Bower JL, Nysewander DR, Evenson JR, Lovvorn JR (2009) Changes in avifaunal abundance in a heavily used wintering and migration site in Puget Sound, Washington, during 1966–2007. Mar Ornithol 37: 19-27

Andrén H (1992) Corvid density and nest predation in relation to forest fragmentation: A landscape perspective. Ecol 73: 794-804

Andrén H (1994) Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: A review. Oikos 71(3): 355-366

Askins RA, Philbrick MJ (1987) Effect of changes in regional forest abundance on the decline and recovery of a forest bird community. Wilson Bull 99: 7-21

Ball JR, Solymos P, Bayne EM, Habib T, Stepnisky D, Mahon CL, Schmiegelow F, Song S, Cumming S. (2013) Determination of Habitat associations and Development of Best Management Practices for Canada Warblers in Mixed-Wood Boreal Forests in Alberta. Technical report. Habitat Stewardship Program for species at Risk. Government of Canada.

Bayne EM, Habib L, Boutin S (2008) Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. Conserv Biol 22 (5):1186-1193

Betts MG, Forbes GJ, Diamond AW, Taylor PD (2006) Independent effects of fragmentation on forest songbirds: An organism-based approach. Ecol Appl 16:1076-1089

Blancher P (2003) The importance of Canada's boreal forest to landbirds. Canadian Boreal Initiative and the Boreal Songbird Initiative

Bourque J, Villard MA (2001). Effects of selection cutting and landscape-scale harvesting on the reproductive success of two Neotropical migrant bird species. Conservation Biology 15:184-195.

Britten M, Schweiger EW, Frakes B, Manier D, Pillmore D (2007) Rocky Mountain network vital signs monitoring plan. Natural Resource Report NPS/ROMN/NRR-2007/010. National Park Service, Fort Collins, Colorado

Calvert AM, Bishop CA, Elliot RD, Krebs EA, Kydd TM, Machtans CS, Robertson GJ (2013) A synthesis of human-related avian mortality in Canada. Avian Conserv and Ecol 8(2):11.

Canadian Wildlife Service [CWS] (2014) Migratory birds conservation, monitoring and reporting. http://www.ec.gc.ca/ron-bbs/P001/A001/?lang=e Accessed 20 March 2015

Cheskey E, Wells J, Casey-Lefkowitz S (2011) Birds at risk: The importance of Canada's boreal wetlands and waterways. Natural Resources Defense Council, New York, NY

Ciborowski JJH, Kang M, Grgicak-Mannion A, Raab D, Bayley SE, Foot AL (2013) Synthesis: Applying the reference condition approach for monitoring reclamation areas in the Athabasca oil sands region. Report 2010-0025 prepared for the Cumulative Environmental Management Association. Wood Buffalo, AB

Committee on the Status of Endangered Wildlife in Canada [COSEWIC] (2008) COSEWIC assessment and status report on the Canada Warbler *Wilsonia Canadensis* in Canada. Ottawa, ON. http://www.registrelep-sararegistry.gc.ca/default_e.cfm Accessed 20 March 2015

Committee on the Status of Endangered Wildlife in Canada [COSEWIC] (2009) COSEWIC assessment and status report on the Horned Grebe *Podiceps auritus*, Western population and Magdalen Islands population, in Canada. Ottawa, ON. http://www.sararegistry.gc.ca/document/default_e.cfm?documentID=1804 Accessed 20 March 2015

Conway CJ (1999) Canada Warbler (*Wilsonia canadensis*) In: Poole A, Gill F (eds.) The Birds of North America, No. 421. The Birds of North America, Inc., Philadelphia, PA

Cooper JM, Enns KA, Shepard MG (1997) Status of the Canada Warbler in British Columbia. Wildlife Working Report No. WR-81. Ministry of Environment, Land and Parks, Wildlife Branch, Victoria, BC

Cornell Lab of Ornithology (2013) The Birds of North America Online. Cornell Lab of Ornithology and the American Ornithology Union. http://bna.birds.cornell.edu/bna Accessed 20 March 2015

Crawford HS, Jennings DT (1989) Predation by birds on spruce budworm *Choristoneura fumiferana*: Functional, numerical and total responses. Ecol 70: 152-163

Cumulative Environmental Management Association [CEMA] (2008) Terrestrial ecosystem management framework for the Regional Municipality of Wood Buffalo. Sustainable Ecosystem Working Group, Fort McMurray, AB

Darveau M, Bélanger L, Huot J, Mélançon É, DeBellefeuille S (1997) Forestry practices and the risk of bird nest predation in a boreal coniferous forest. Ecological Applications 7:572-580.

Davis SD, Heywood VH, Herrera-MacBryde O, Villa-Lobos J, Hamilton A (1997) Centres of plant diversity: A guide and strategy for their conservation, Volume 3: The Americas. IUCN Publications Unit, Cambridge, England.

del Hoyo J, Elliot A, Sargatal J (1992) Handbook of the birds of the world. Volume 1: Ostrich to ducks. Lynx Edicions, Barcelona

Demarchi DA (2010) Boreal plains ecoprovince. Version 2.2. February 2010

Environment Canada (2011) Integrated monitoring plan for the oil sands, terrestrial biodiversity component. Government of Canada, Ottawa, ON. Cat. No. En14-48/2011E-PDF

Environment Canada (2012) Bird conservation strategy for Bird Conservation Region 6, Prairie and Northern Region: Boreal taiga plains. DRAFT: 24 September 2012 version. Government of Canada

Federation of Alberta Naturalists [FAN] (2007) The atlas of breeding birds of Alberta: A second look. Federation of Alberta Naturalists. Edmonton, AB

Ferguson RS (1977) Adaptations of the Horned Grebe for breeding in Prairie Pothole marshes. Master's Thesis, University of Manitoba, Winnipeg.

Fischenich JC (2008) The application of conceptual models to ecosystem restoration. Ecosystem Management and Restoration Research Program. Technical Note: ERDC/EBA TN-08-1.

Forsyth DJ, Martin PA, De Smet KD, Riske ME (1994) Organochlorine contaminants and eggshell thinning in grebes from prairie Canada. Environ Pollut 85: 51-58

Fournier MA, Hines JE (1999) Breeding ecology of the Horned Grebe *Podiceps auritus* in subarctic wetlands. Occasional Paper No. 99. Canadian Wildlife Service.

Frid L, Daniel C (2012) Development of a state-and-transition model in support of reclamation planning. Report 2012-005 prepared for the Cumulative Environmental Management Association. Wood Buffalo, AB

Gauthier J, Aubry Y (1996) Les oiseaux nicheurs du Québec: Atlas des oiseaux nicheurs du Québec méridional. Association québécoise des groups d'ornithologues, Société québécoise de protection des oiseaux, Service Canadien de la faune, Environnement Canada, Montréal, PQ

Government of Alberta (2011) Draft lower Athabasca regional plan 2011-2021. Government of Alberta, Edmonton, AB

Government of Alberta (2013) Canada/Alberta implementation plan for oil sands monitoring: The implementation plan, progress report 2012-2013. Edmonton, AB

Government of Canada (2013b) Committee on the Status of Endangered Wildlife in Canada (COSEWIC). http://www.cosewic.gc.ca/eng/sct5/index_e.cfm Accessed 20 March 2015

Grant WE, Pedersen EK, Marin SL (1997) Ecology and natural resource management: Systems analysis and simulation. John Wiley & Sons. New York, NY

Habib L, Bayne EM, Boutin S (2007) Chronic industrial noise affects pairing success and age structure of ovenbirds Seiurus aurocapilla. J Appl Ecol 44 (1): 176-184

Halsey LA, Vitt DH, Beilman D, Crow S, Mehelcic S, Wells R (2004) Alberta Wetland Inventory Classification System, Version 2.0. Alberta Sustainable Resource Development, Government of Alberta, Edmonton, AB

Hannah, KC, Schmiegelow FKA, Aitken KEH (2008) White-throated Sparrow response to forest harvesting in north-central Alberta: Results not so clear-cut? Avian Conserv and Ecol 3(1):6

Harrison N, Robins M (1992) The threat from nets to seabirds. RSPB Conserv Rev 6: 51-56

Hawrot RY, Niemi GJ (1996) Effects of edge type and patch shape on avian communities in a mixed conifer-hardwood forest. The Auk 113(3):586-598

Henderson A, Churchill SP, Luteyn JL (1991) Neotropical plant diversity. Nature 351: 21-22

Hobson KA, Bayne E (2000) Effects of forest fragmentation by agriculture on avian communities in the southern boreal mixedwoods of western Canada. Wilson Bull 112: 373-387

Hobson KA, Bayne E, Van Wilgenburg SL (2002) Large-scale conversion of forest to agriculture in the boreal plains of Saskatchewan. Conserv Biol 16: 1530-1541

Hobson KA, Schieck J (1999) Changes in bird communities in boreal mixedwood forest: Harvest and wildfire effects over 30 years. Ecol Appl 9: 849-863

Hoyt JS, Hannon SJ (2002) Habitat associations of black-backed and Three-toed Woodpeckers in the boreal forests of Alberta. Can J For Res 32: 1881-1888

Jobes AP, Nol E, Voigt DR (2004) Effects of selection cutting on bird communities in contiguous eastern hardwood forests. J Wildl Manag 68(1): 51-60

Jorgensen SE (1988) Fundamentals of ecological modelling. Elsevier Publishers

Lance AN, Phinney M (2001) Bird responses to partial retention timber harvesting in central interior British Columbia. For Ecol Manag 142 (1–3): 267-280

Latham ADM (2008) Evidence of raccoon, *procyon lotor*, range extension in northern Alberta. Can Field-Natur 122(2): 176-178

Manolis J, Andersen DE, Cuthbert FJ (2002) Edge effect on nesting success of ground nesting birds near regenerating clearcuts in a forest-dominated landscape. The Auk 119(4): 955-970

Hostetler JA, Sillet TS, Marra PP (2015). Full-annual-cycle population models for migratory birds. The Auk, Ornithological Advances 132:433-449.

Miller NA (1999) Landscape and habitat predictors of Canada Warbler (*Wilsonia canadensis*) and Northern Waterthrush (*Seiurus noveboracensis*) occurrence in Rhode Island swamps (Masters thesis). University of Rhode Island, Kingston, RI

Morissette JL, Cobb TP, Brigham RM, James PC (2002) The response of boreal forest songbird communities to fire and post-fire harvesting. Can J For Res 32: 2169-2183

Natural Regions Committee (2006) Natural regions and subregions of Alberta. Compiled by Downing DJ and Pettapiece WW. Government of Alberta, Edmonton, AB

Noon BR (2002) Conceptual issues in monitoring ecological resources. In: Busch DE and Trexler JC. Monitoring Ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, USA

Norton MR, Hannon SJ (1997) Songbird response to partial-cut logging in the boreal mixedwood forest of Alberta. Can J For Res 27:44-53

Patten MA, Burger JC (1998) Spruce budworm outbreaks and the incidence of vagrancy in eastern North American wood-warblers. Can J Zool 76:433-439

Pew Environment Group [PEG] (2011) A forest of blue: Canada's boreal. Pew Environment Group, Seattle, WA http://www.pewenvironment.org/news-room/reports/a-forest-of-blue-canadas-boreal-328843 Accessed 20 March 2015

Piersma T (1988) Body size, nutrient reserves and diet of Red-necked and Slavonian Grebes *Podiceps grisegena* and *P. auritus* on Lake Ijsselmeer, the Netherlands. Bird Study 35: 13-24

Reitsma, L, Goodnow M, Hallworth MT, Conway CJ (2010) Canada Warbler (*Cardellina canadensis*) In: Poole A (ed) The birds of North America online Ithaca: Cornell Lab of Ornithology. http://bna.birds.cornell.edu/bna/species/421/articles/introduction Accessed 20 March 2015

Riske ME (1976) Environmental impact upon grebes breeding in Alberta and British Columbia. PhD Thesis, University of Calgary, Calgary, AB

Robbins CS, Dawson DK, Dowell BA (1989) Habitat area requirements of breeding forest birds of the middle Atlantic states. Wildl Monogr 103: 1-34

Rockwell SM, Bocetti CI, Marra PP (2012) Carry-over effects of winter climate on spring arrival date and reproductive success in an endangered migratory bird, Kirtland's Warbler (*Setophaga kirtlandii*). The Auk 129: 744-752

Salafsky N, Salzer S, Stattersfield AJ, Hilton-Taylor C, Neugarten R, Butchart SHM, Collen B, Cox N, Master LL, O'Connor S, Wilkie D (2008) A standard lexicon for biodiversity conservation: Unified classifications of threats and actions. Conserv Biol 22(4): 897-911

Schieck J, Hobson KA (2000) Bird communities associated with live residual tree patches within cut blocks and burned habitat in mixedwood boreal forests. Can J For Res 30: 1281-1295

Schieck J, Stuart-Smith K, Norton MR (2000) Bird communities are affected by amount and dispersion of vegetation retained in mixedwood boreal forest harvest areas. For Ecol Manag. 126: 239-254

Schmiegelow FKA, Machtans CS, Hannon SJ (1997) Are boreal birds resilient to forest fragmentation? An experimental study of short-term community responses. Ecol 78: 1914-1932

Schneider R, Dyer S (2006) Death by a thousand cuts: Impacts of in situ oil sands development on Alberta's boreal forest. The Pembina Institute, Drayton Valley, AB

Schneider RJ, Stelfox BJ, Boutin S, Wasel S (2003) Managing the cumulative impacts of land-uses in the western Canadian sedimentary basin: A modeling approach. Conserv Ecol 7(1) http://www.ecologyandsociety.org/vol7/iss1/art8/ Accessed 20 March 2015

Senate Subcommittee on the Boreal Forest (1999) Competing realities: The boreal forest at risk. Senate of Canada, Ottawa, ON. http://www.parl.gc.ca/content/sen/committee/361/bore/rep/rep09jun99-e.htm Accessed 20 March 2015

Shaffer F, Laporte P (2003) Le Grèbe esclavon (*Podiceps auritus*) aux Îles-de-la- Madeleine: Population, nidification et habitat. Canadian Wildlife Service, Environmental Conservation Branch, Environment Canada, Québec, Quebec

Shell Canada Limited (2007) Application for approval of the Jackpine mine expansion project and Pierre river mine project, environmental assessment. Volume 5: Terrestrial resources and human environment. http://www.ceaa-acee.gc.ca/050/documents_staticpost/59539/46923/volume_5.pdf Accessed 20 March 2015

Sillett TS, Holmes RT (2002) Variation in survivorship of a migratory songbird throughout its annual cycle. J Anim Ecol 71: 296-308

Sleep DJH, Drever MC, Szuba KJ (2009) Potential role of spruce budworm in range-wide decline of Canada Warbler. J Wildl Manag 73(4): 546-555

South Peace Bird Atlas Society (2006) Canada Warbler (*Wilsonia canadensis*). http://www.pris.bc.ca/spbas/index.htm Accessed 20 March 2015

Stedman SJ (2000) Horned Grebe (*Podiceps auritus*) In: Poole A (ed) The birds of North America online Ithaca: Cornell Lab of Ornithology. http://bna.birds.cornell.edu/bna/species/505/ Accessed 20 March 2015

Steeger C, Hitchcock CL (1998) Influence of forest structure and diseases on nest-site selection by Red-breasted Nuthatches. J Wildl Manag 62(4): 1349-1358

Summers PD, Cunnington GM, Fahrig L (2011) Are the negative effects of roads on breeding birds caused by traffic noise? J Appl Ecol 48(6)

Therres GD, Byrd MA, Bradshaw DS (1993) Effects of development on nesting bald eagles: Case studies from Chesapeake Bay. Trans N Am Wildl Nat Resour Conf 58: 62-69

Therriault TW, Hay DE, Schweigert JF (2009) Biologic overview and trends in pelagic forage fish abundance in the Salish Sea (Strait of Georgia, British Columbia). Mar Ornithol 37: 3-8

Thompson ID (2004) The importance of superior-quality wildlife habitats. The For Chron 80(1): 75-81

Tittler R, Hannon SJ, Norton MR (2001) Residual tree retention ameliorates short-term effects of clear-cutting on some boreal songbirds. Ecol Appl 11: 1656-1666

Ulfvens J (1989) Clutch size, productivity and population changes in a population of the Horned Grebe *Podiceps auritus* in an exposed habitat. Ornis Fennica 66(2): 75-77

United States Geological Survey [USGS] (2007) USGS national wildlife health center, quarterly wildlife mortality report July 2006 to September 2006. http://www.nwhc.usgs.gov/publications/quarterly_reports/2006_qtr_3.jsp Accessed 20 March 2015

United States Geological Survey [USGS] (2008) National wildlife health center, quarterly wildlife mortality report October 2007 to December 2007. http://www.nwhc.usgs.gov/publications/quarterly_reports/2007_qtr_4.jsp Accessed 20 March 2015

Venier LA, Holmes SB, Pearce JL, Fournier RE (2012) Misleading correlations: The case of the Canada Warbler and spruce budworm. J Wildl Manag 76(2): 294-298

Vennesland RG (2010) Risk perception of nesting Great Blue Herons: Experimental evidence of habituation. Can J Zool 88: 81-89

Vermeer K, Cretney WJ, Elliott JE, Norstrom RJ, Whitehead PE (1993) Elevated polychlorinated dibenzodioxin and dibenzofuran concentrations in grebes, ducks, and their prey near Port Alberni, British Columbia, Canada. Mar Pollut Bull 26: 431-435

Wells J, Casey-Lefkowitz S, Chavarria G, Dyer S (2008) Danger in the nursery – Impact of birds of tar sands oil development in Canada's boreal forest. Natural Resources Defense Council, New York, NY