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L'HABITAT DE LA SAUVAGINE EN PÉRIODE DE NIDIFICATION
DANS LE QUÉBEC FORESTIER

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AVANT-PROPOS

Conformément aux exigences du programme de maîtrise en biologie, ce mémoire comprend deux articles rédigés en langue anglaise ainsi qu'une introduction et une conclusion générales. Le premier article est prêt à soumettre au périodique scientifique *The Journal of Wildlife Management*. Le second article a quant à lui été accepté pour publication dans le périodique scientifique *Avian Conservation and Ecology*, dans une section spéciale ayant pour thème la résilience des oiseaux boréaux face aux perturbations. Je suis l'auteur principal de ces articles et j'ai procédé à toutes les étapes du traitement et de l'analyse des données. Louis Imbeau, Marcel Darveau et Daniel Bordage en sont les co-auteurs.

Je désire adresser de sincères remerciements à mon directeur de travaux, Louis Imbeau, professeur à l'UQAT, ainsi qu'à mon co-directeur, Marcel Darveau, chef de la conservation boréale chez Canards Illimités Canada et professeur associé à l'Université Laval, pour leur soutien et leur disponibilité durant le projet. Je remercie Daniel Bordage, du Service canadien de la faune, région du Québec, pour ses multiples collaborations aux différentes étapes de mon projet de maîtrise, de même qu'André Desrochers, professeur à l'Université Laval, d'avoir siégé au comité d'orientation. Je suis également reconnaissant envers les membres externes du comité d'évaluation, soit François Fournier et Eric Reed.

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RÉSUMÉ

Les milieux humides des régions forestières abritent de nombreuses espèces de sauvagine, lesquelles totalisent, au Québec, plus de 350 000 couples nicheurs. Le présent mémoire de maîtrise vise à explorer les relations entre ces espèces et leurs habitats de nidification en milieu forestier. Cette étude est basée sur les données récoltées lors de l'inventaire aérien du Plan conjoint sur le Canard noir et du Service canadien de la faune. Il s'agit d'un inventaire effectué en hélicoptère et qui échantillonne un territoire de 540 000 km² en 156 quadrats de 25 km² chacun. Les données relatives à l'habitat proviennent des cartes écoforestières numériques (1:20 000). Les localisations de couples nicheurs des espèces observées ont été mises en relation avec les principaux types d'habitats, dans une analyse de l'utilisation et de la sélection de l'habitat. Plus de 32 000 observations de couples nicheurs ont été distribuées parmi sept grands types de milieux humides et aquatiques, et six types de milieux riverains. Cela a révélé l'importance des petites étendues d'eau et des ruisseaux pour la reproduction de la sauvagine. L'effet local et à court terme (environ 4 ans) des coupes forestières sur les populations de canards cavicoles et d'espèces nichant au sol a également été évalué. Aucun effet négatif n'a été détecté chez les espèces cavicoles, alors qu'un effet positif semble avoir eu lieu chez la Bernache du Canada et la Sarcelle d'hiver, deux espèces nichant au sol. Cette étude dresse donc un portrait des relations entre les espèces et les principaux types d'habitat, confirme l'efficacité de la carte écoforestière pour la caractérisation des milieux humides, et appuie l'hypothèse de la résilience des espèces de sauvagine face à un certain niveau de perturbation résultant de la récolte forestière au Québec.

Mots clés : coupe forestière, forêt boréale, Québec, sauvagine, sélection de l'habitat.

INTRODUCTION GÉNÉRALE

La sauvagine dans les forêts du Québec

Les forêts du Québec représentent un vaste habitat de nidification pour plus de 20 espèces de sauvagine. On estime à plus de 350 000 le nombre de couples d'oies et de canards qui reviennent nicher annuellement dans les forêts de la province après avoir hiverné dans des contrées plus chaudes du continent (Bordage et al. 2003a). Les populations de ce cortège d'oiseaux nicheurs appartiennent à des espèces dont l'aire de nidification s'étend bien au-delà du Québec forestier, que ce soit dans les forêts tempérées au sud, vers les plaines du centre du continent et au-delà des Rocheuses, dans les zones plus nordiques de la toundra, et même en Europe et en Asie (Bellrose 1976, Cramp et Simmons 1977). Les espèces de sauvagine constituent par ailleurs une ressource internationale et font l'objet d'une importante récolte de la part des chasseurs sportifs (Dupuis et al. 1996). Ainsi, en tant que groupe faunique hautement convoité et largement répandu, les espèces de sauvagine ont reçu beaucoup d'attention, mais bien souvent dans des milieux passablement différents des habitats québécois (Baldassarre et Bolen 2006).

L'habitat en période de nidification

L'habitat de nidification des espèces de sauvagine doit répondre aux multiples besoins vitaux rencontrés durant cette période. Il comprend essentiellement l'environnement du nid, des corridors de déplacement et des sites d'alimentation pour les deux membres du couple, et ce, depuis la ponte jusqu'à ce que les jeunes quittent le nid, peu après l'éclosion.

Tout d'abord, l'habitat de nidification doit receler un site de nidification préférablement isolé des prédateurs et des rigueurs du climat. Pour établir leur nid, les espèces de sauvagine recherchent pour la plupart un couvert végétal dense, exception faite de la Bernache du Canada (*Branta canadensis*), qui utilise fréquemment des sites offrant une bonne visibilité (Mowbray et al. 2002), et des canards cavicoles, qui requièrent des cavités d'arbres de grande dimension (Prince 1968, Peterson et Gauthier 1985).

La période couvrant la ponte et l'incubation est physiologiquement très exigeante pour la femelle d'espèce nidifuge (Drobney 1980, Hohman 1985, Gauthier 1993). Celle-ci doit

optimiser le moment et la taille de sa ponte en fonction de ses propres ressources énergétiques pour maximiser son succès reproducteur. L'habitat de nidification doit donc aussi être suffisamment productif pour permettre à la femelle de subvenir aux exigences alimentaires de la vitellogénèse de même qu'à sa propre régulation pendant la durée de l'incubation (Drobney 1982). Pour certaines espèces, cela peut signifier un habitat aux eaux claires et poissonneuses ou, pour d'autres, un habitat riche en invertébrés benthiques.

La proximité d'un site d'élevage de qualité pour les jeunes est un autre facteur susceptible d'influencer l'utilisation d'un habitat durant la nidification (Staicer et al. 1994). En étudiant la race eurasienne de la Sarcelle d'hiver (*Anas crecca caroliniensis*), Elmberg et al. (2005) ont constaté que les femelles nichant le plus hâtivement utilisaient les meilleurs lacs et obtenaient les meilleurs taux de reproduction. Bien que le déplacement de couvées soit un comportement couramment rapporté (Wayland et McNicol 1994, Maisonneuve et al. 2000), une abondance immédiate de nourriture pour les canetons ne peut toutefois qu'être favorable à leur survie (Toft et al. 1982, Staicer et al. 1994, Gunnarsson et al. 2004).

Tout environnement local s'inscrit à la fois dans un contexte biogéographique régional (Brown et al. 1996). Ainsi, l'aire géographique de répartition des espèces est un élément important à considérer lorsque de vastes territoires sont étudiés ou lorsque des résultats observés en certaines localités sont extrapolés. Alors que les gradients environnementaux, tels le climat et la disponibilité de nourriture à l'échelle continentale, déterminent la possibilité pour une espèce de se perpétuer dans un territoire, d'autres facteurs, tels la compétition interspécifique, conditionnent la probabilité pour l'espèce d'occuper le territoire. Ceux-ci expliqueraient par exemple le fait que le Canard noir soit absent de la région des cuvettes des prairies, un habitat où il se serait probablement très bien établi n'eût été de la présence d'autres espèces de sauvagine.

La nidification dans le cycle vital

Pour bien comprendre les mécanismes qui déterminent les relations entre l'habitat de nidification et les espèces de sauvagine, il importe également de situer l'importance de ce stade de la reproduction par rapport au cycle de vie complet. Les populations de sauvagine sont en effet susceptibles de se voir réguler à plusieurs étapes de leur cycle de vie. Dans une revue exhaustive des facteurs influençant les niveaux de population de Canard noir, figuraient

aux côtés de la qualité de l'habitat de reproduction la qualité de l'habitat d'hiver, la récolte par la chasse, la compétition interspécifique (avec le Canard colvert), les maladies et les parasites (Conroy et al. 2002). Ces facteurs sont représentatifs de ceux qui régissent l'ensemble des espèces de sauvagine. L'habitat de nidification, qui fait partie de l'habitat de reproduction, constitue donc un facteur important parmi d'autres, et tous sont impliqués de façon complexe dans la détermination des niveaux des populations. Il demeure toutefois largement reconnu qu'un habitat de nidification de qualité est primordial pour la sauvagine (Baldassarre et Bolen 2006).

Les études sur la sauvagine au Québec

On dénombre au Québec environ une vingtaine de publications scientifiques issues d'inventaires spécifiques et qui ont permis d'approfondir les connaissances sur divers aspects de la reproduction de la sauvagine dans les écosystèmes de forêt continue (p. ex.: Bouvier 1974, Courcelles et Bédard 1979, DesGranges et Darveau 1985, DesGranges et Rodrigue 1986, DesGranges et Darveau 1988, Reed et al. 1994, Carrière et Titman 1998, Robert et al. 2002, Sénéchal 2003, Maisonneuve 2004, Savard et Robert 2007). Le territoire forestier du Québec est vaste et peu accessible, ce qui, à chaque fois, rend laborieux le travail d'acquisition de données sur les espèces qui y nichent. De plus, on y observe une densité généralement inférieure à 1 couple nicheur/km² de territoire (Lemelin et al. 2004), laquelle une fois répartie entre les multiples espèces présentes, ajoute à la difficulté. Des travaux de recherche à grande échelle exigent la réalisation de coûteux inventaires. Au Québec, il existe des banques de données contenant de l'information sur les oiseaux nicheurs, comme par exemple le Relevé des oiseaux nicheurs, les données d'Étude des populations d'oiseaux du Québec et celles de l'Atlas des oiseaux nicheurs du Québec (Gauthier et Aubry 1995). Toutefois, celles-ci ne visent principalement qu'à confirmer la présence et la nidification de l'ensemble des espèces aviaires et voient leur effort d'échantillonnage réduit dans les grandes zones forestières. Enfin, la sauvagine bénéficie d'un inventaire dédié : l'inventaire aérien du Plan conjoint sur le Canard noir (PCCN)–Service canadien de la faune (SCF). Cet inventaire est réalisé annuellement depuis 1990 et a généré une importante base de données, exploitée principalement pour estimer les niveaux des populations servant à l'établissement des quotas de chasse, puis, de façon secondaire, pour cartographier la répartition géographique des

espèces (Bordage et Grenier 1995, Robert et al. 2000, Lemelin et al. 2004). La méthode d'inventaire a été mise point après plusieurs années de travaux préliminaires (Bordage 1987, 1988a, 1988b) ayant également permis de produire quelques rapports et articles sur la sauvagine et ses habitats (Grenier et al. 1993, Grenier et al. 1994, Robert et al. 2000, Bordage et al. 2002). C'est précisément à partir de cette base de données qu'ont été explorées les questions abordées par ce projet.

Objectifs de l'étude

L'objectif général de la présente étude est d'explorer et de documenter les relations entre les espèces de sauvagine (incluant par extension le Plongeon huard [*Gavia immer*]) et leur habitat en période de nidification dans les écosystèmes forestiers du Québec. Elle vise par le fait même à tirer profit de l'importante somme de données recueillies lors de l'inventaire aérien du PCCN–SCF et s'articule en deux articles indépendants. Dans les deux cas cependant, les informations concernant l'habitat ont été tirées des cartes écoforestières numériques (1:20 000) du Ministère des Ressources naturelles et de la Faune du Québec.

Le premier article a pour sujet l'utilisation et la sélection par les espèces de sauvagine des types d'habitats humides (ruisseaux, étangs, lacs, marécages, etc.). Il s'agit d'une analyse visant à (1) quantifier et évaluer l'importance des types d'habitat pour chaque espèce; à (2) dresser un portrait écologique comparatif des espèces; et à (3) tester l'utilité de la carte écoforestière numérique en tant qu'outil de base pour classifier et cartographier les habitats humides et aquatiques d'un groupe faunique tel que la sauvagine.

Le second article s'attarde à évaluer l'effet de la coupe forestière sur les populations de canards cavicoles et nichant au sol. Plus précisément, les objectifs sont de (1) détecter la présence d'effets locaux et à court terme sur les communautés de sauvagine et (2) d'en évaluer l'importance sur les populations nicheuses.

Ces deux articles sont suivis de la conclusion générale du projet de maîtrise, dans laquelle seront abordés le degré d'atteinte de ses objectifs, sa contribution au savoir collectif, ainsi que quelques perspectives pour la recherche future.

ARTICLE I

Forest Wetlands Use and Selection by Breeding Waterfowl in Quebec

FOREST WETLANDS USE AND SELECTION BY BREEDING WATERFOWL IN QUEBEC

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Abstract. Wetlands of remote forest landscapes support numerous species of breeding waterfowl yet species-habitat associations remain little documented. From 1990 to 2005, Black Duck Joint Venture – Canadian Wildlife Service aerial survey systematically covered a 540,000-km² area located in the vast forests of southern Quebec. This annual helicopter survey yielded a major database of spatially recorded observations of waterfowl. We used these data to investigate local habitat use and selection by waterfowl, based on a newly developed wetland classification system that we elaborated from numerical forestry maps. For 18 waterfowl species and the common loon (*Gavia immer*), we present detailed indicated breeding pairs (IBP) distribution across broad aquatic, wetland, and shoreline habitat types, and estimated selection ratios within the groups of similar habitat types. Connected ponds (<8 ha) were highly used and highly selected by all dabbling duck species and by ring-necked duck (*Aythya collaris*), hooded merganser (*Lophodytes cucullatus*), common (*Bucephala clangula*), and Barrow's goldeneyes (*B. islandica*). Isolated ponds were primarily selected by many species, but their use remained negligible. Dabbling duck species and Canada goose (*Branta canadensis*) made extensive use of streams (25–41% of all IBP). Half of the species preferentially used shorelines of waterbodies <8 ha, whereas all three piscivorous species preferred shorelines of larger waterbodies. Our results raise the question of the ecological relevance of systematically prioritizing large connected wetlands in protection guidelines over large jurisdictions such as in Quebec.

Résumé. Bien que les milieux humides des paysages forestiers supportent de nombreuses espèces de sauvagine en période de nidification, les associations espèces-habitat y demeurent peu documentées. De 1990 à 2005, l'inventaire aérien du Plan conjoint sur le Canard noir – Service canadien de la faune a systématiquement échantillonné un territoire de 540 000 km² situé dans les vastes forêts du Québec méridional. Cet inventaire, effectué annuellement par hélicoptère, a généré une importante base de données d'observations localisées d'oiseaux aquatiques. Nous avons utilisé ces données pour étudier l'utilisation et la sélection par les oiseaux aquatiques parmi les classes d'habitat local d'un système de classification des milieux humides que nous avons élaboré à partir des cartes forestières numériques. Pour 18 espèces

d'oiseaux aquatiques et le plongeon huard (*Gavia immer*), nous présentons la distribution des équivalents-couples nicheurs (ÉCN) à travers les classes d'habitat aquatique, de milieux humides et de rivage, et rapportons les ratios de sélection à l'intérieur des groupes d'habitats similaires. Les étangs reliés ont été hautement utilisés et sélectionnés par toutes les espèces de canards barboteurs et par le fuligule à collier (*Aythya collaris*), le harle couronné (*Lophodytes cucullatus*), le garrot à œil d'or (*Bucephala clangula*) et le garrot d'Islande (*B. islandica*). Les étangs isolés ont été sélectionnés par de nombreuses espèces, mais leur utilisation est demeurée négligeable. Les espèces de canards barboteurs et la bernache du Canada (*Branta canadensis*) ont fait une utilisation importante des ruisseaux (25–41% des ÉCN). La moitié des espèces a utilisé préférentiellement les rivages des étendues d'eau de superficie <8 ha, tandis les espèces piscivores ont toutes trois préféré les rivages d'étendues d'eau >8 ha. Nos résultats soulèvent la question de la pertinence de prioriser systématiquement les milieux humides de grande superficie qui sont reliés au réseau hydrographique dans les démarches de protection des milieux humides sur de vastes territoires tel que le Québec.

Key words. Aerial survey, boreal, breeding, forest, habitat selection, habitat use, Quebec, waterfowl, wetlands.

INTRODUCTION

Waterfowl species breed in wide variety of environments, ranging from prairie potholes to hilly forest regions, from lush hardwood to open tundra landscapes (Bellrose 1976). However, habitat requirements of populations distributed at low density in remote areas are often less documented. Such is the case of waterfowl populations that breed in forested landscapes of Quebec, an area over 500,000 km² with an estimated average of over 350,000 breeding pairs (Bordage et al. 2003). The vast forest landscapes of Quebec nevertheless harbour the core of the breeding ranges of the American black duck (*Anas rubripes*) (Longcore et al. 2000) as well as the eastern population of the Barrow's goldeneye (*Bucephala islandica*) in North America (Robert et al. 2000), a population currently designated as special concern (COSEWIC 2007). Some 18 other species of waterfowl and the common loon (*Gavia immer*) also breed in Quebec forests.

Relating breeding pairs distribution across the classes of a wetland habitat classification system is an effective way of analyzing the importance of broad habitat types for waterfowl species. For example, in the states of Maine and New York, Ringelman et al. (1982) and Dwyer and Baldassarre (1994) linked American black duck and mallard (*Anas platyrhynchos*) to Cowardin et al's (1979) habitat classification system. In the boreal Claybelt of Ontario, Rempel et al. (1997) have analyzed the distribution of 14 waterfowl species according to a habitat classification system applicable from aerial photography. In portions of the boreal forest of Quebec, Bordage (1987, 1988) examined pair distribution of American black duck and common merganser (*Mergus merganser*) across open water classes elaborated from 1:50,000 topographic maps. Also, both McNicol et al. (1987) in northern Ontario, and Nummi and Pöysä (1995) in Finland, compared, for the most abundant species present, the densities of pairs per km of shoreline among several lake-size classes.

Along with site attribute studies and controlled experiments, assessments of habitat use and habitat selection in natural areas provide basic ways of enhancing knowledge about species ecology (Garshelis 2000). In wildlife studies, habitat use is commonly referred to as the proportion of a population that uses a certain habitat component, whereas habitat selection is defined as the comparison of use vs. availability of that component (Manly et al. 2002). Habitat use and habitat selection are in fact two different parameters that may help in

assessing the importance of a specific habitat type for a given species. Maximum use by a species directly relates to the greatest number of individuals, whereas maximum selection refers to the habitat components occupied at the highest density.

Including multiple related species in a habitat use and selection study may provide additional grounds for results interpretation. When compared to the Prairie Pothole region, the boreal forest is a rather stable environment where interspecific competition may play a determinant role in community organization (Nudds 1983). Simultaneously studying habitat requirements of a group of species such as waterfowl may help understanding the causes and mechanisms related to fluctuations in population size. Examples of this can be found in the hypotheses of a causal relationship between population abundance of mallard vs. American black duck (Ankney et al. 1987; Conroy et al. 1989; Merendino et al. 1993), as well as of common goldeneye (*Bucephala clangula*) vs. Barrow's goldeneye (Savard and Robert 2007).

In this paper, we relate our use of two existing data sets to explore habitat associations between 18 species of breeding waterfowl and the common loon, and forest wetlands of Quebec. More specifically, we investigated 16 years of Black Duck Joint Venture (BDJV) – Canadian Wildlife Service (CWS) aerial survey data in relation to an original wetlands classification based on Quebec numerical forestry maps. Our aim was to quantify habitat use and selection by waterfowl species across broad and ecologically meaningful habitat types using a classification system that is readily available for a vast region.

STUDY AREA

Our study area was the area covered by the BDJV – CWS aerial survey in Quebec, corresponding to the forest-dominated landscapes of Quebec (Figure 1). This 540,000-km² area was located south of 51°15'N, but excluded the St. Lawrence and Lake St. Jean lowlands and the part of the Appalachians located south of 47° N. It extended northward from northern temperate deciduous forest to the boreal coniferous forest zone. According to the National Ecological Framework for Canada (Marshall and Schut 1999), the study area is mainly distributed among 6 ecoregions : Southern Laurentians (31%), Central Laurentians (27%), Abitibi Plains (13%), Rupert River Plateau (11%), Mecatina Plateau (10%), and

Appalachians (8%). The hydrographical network of this area is generally highly developed and includes numerous lakes, ponds, rivers and streams. Open water and wetlands with tree cover <25% altogether encompass nearly 18% of the total area (Ménard et al. 2006). Beaver (*Castor canadensis*) was ubiquitous within the study area, although its abundance was higher in the western part of the region (Lafond and Pilon 2004).

METHODS

Waterfowl surveys

We used data from the first 16 years (1990-2005) of the BDJV – CWS waterfowl aerial survey in Quebec. The survey design has been modified over the years. From 1990 to 1992, 82 square plots (10 × 10 km), systematically distributed along 100-km intervals, were surveyed. The number of plots was reduced to 43 in 1993–1994, and to 35 in 1995. From 1996 to 2005, plot size was reduced to 5 × 5 km with 50-km spacing between plots, and the number of plots was increased to 156; half of the plots being surveyed once annually in a rotating scheme (Bordage et al. 2003).

Surveys were done by experienced observers in a helicopter (Bell 206L with bubble side-windows) that flew over every waterbody, watercourse and wetland within the plot. Depending on habitat and topography, flight altitude was 15–50 m above ground level and speed varied from 60–100 km/h. Although the survey was primarily designed to produce population size estimates of American black duck, all waterfowl species as well as many other bird species (including common loon) were also noted. Observations were recorded during the survey on topographic maps (scale 1:50,000) with a 100-m precision, thus allowing possibility for high-resolution spatial analyses. Surveys we timed to occur at the end of egg-laying and the beginning of incubation period of the American black duck, an early nesting species, on average from 6–30 May. In all analyses we used breeding pair observations, which were determined following indicated breeding pair (IBP) criteria of the BDJV in eastern Canada (Bordage et al. 2003).

Wetland classification

The forest landscapes in Quebec are a vast and remote area, and no extensive wetland classification and inventory was available for this region. Thus we extracted wetland data from the Quebec Ministry of Natural Resources and Wildlife numerical 1:20,000 forestry maps and we elaborated a habitat classification system adapted to waterfowl. Minimum mapping area for open water and wetland areal features was set to 1 ha (Létourneau 1999), although numerous smaller islands and ponds were mapped. Streams, defined as watercourses < 6-m wide, were mapped as linear features. Maps were available for 73 (out of 82) 10 × 10-km waterfowl survey plots and 143 (out of 156) 5 × 5-km plots, that were located in the portion of Quebec primarily managed for timber harvest.

We retained the following areal habitat classes directly from the maps: open water areas, open wetlands (vegetated wetlands with less than 25% tree cover, including for example meadow marshes, emergent marshes, riparian fens, and bogs), shrub swamps (mostly *Alnus rugosa* stands), and flooded swamps (dominated by dead standing trees). Remaining areas were mostly forest land and forest swamps. Within open water areas, we further defined lakes as all waterbodies >8 ha and ponds as waterbodies <8 ha, based on one of the criteria used by Cowardin et al. (1979) to separate lacustrine from palustrine waters. We distinguished lake shores from offshore zones with a boundary set 100 m in-water from shorelines. In the absence of available bathymetric data, this zone criterion (as opposed to "basin" criteria used by Stewart and Kantrud [1971]) yields classes that are akin to the lacustrine littoral and limnetic subclasses of Cowardin et al.'s (1979) classification. We distinguished connected from isolated ponds based on the presence of a surface hydrological link (stream or river). This distinction may be useful as the two habitats may be ecologically different and addressed differently by some legislations (Leibowitz 2003). Rivers were identified as such on the maps and were directly transferred into our classification. Shoreline vegetation may also be a significant predictor of waterfowl use (Nummi et al. 1994). Based on the polygons adjacent to water on the maps, we thus classified shorelines of open water and streams among the 5 following types: open wetland, shrub swamp, flooded swamp, small island (<20 ha) and forest (mainly upland forest, forest swamps, and islands >20 ha). We grouped the 3

components of the forest shoreline type because our preliminary analyses showed similar selection by waterfowl species.

Pair-habitat association

We superimposed IBP locations and habitat data within a geographic information system and associated IBP to habitat types following a simple algorithm. According to the precision of location mapping, we searched within a 100-m radius for probable aquatic or wetland habitat types. In a first step, we associated each IBP to the closest open water habitat type. When no such habitat was present, we alternatively associated IBP to the closest stream habitat, and, when no stream was present, to the closest wetland habitat type (saturated open wetland, shrub swamp, or flooded swamp). All IBP previously associated to an open water habitat type or a stream were also associated to the closest shoreline type.

Statistical analyses

We evaluated habitat use and selection by successively analyzing IBP distributions into the classes of categorical habitat variables. In our study, habitat use was simply defined as the percent of observed IBP associated to a given habitat type over the total number of IBP detected in all habitats (Manly et al. 2002). For each observed value of habitat use, we computed a confidence interval with the large-sample 95% confidence interval formula (Manly et al. 2002:53).

We derived expected percentages of habitat use based on relative availability distribution of habitat types following Neu et al. (1974). However, habitat availability assessment had to account for continental breeding range boundaries encountered by many species within the study area. Because we aimed at studying selection of site-scale habitat features within species geographic range, we considered as available only the survey plots where ≥ 1 IBP of a given species has been observed over the years. We cumulated areas of plots available to each species over the total number of years that the plot was surveyed. We then expressed habitat selection with a simple estimator corresponding to the ratio of observed : expected use for a given habitat type (Manly et al. 2002). This selection ratio reflects the number of times a habitat is used comparatively to its availability. Unlike chi-square values, selection ratios vary on a fixed-scale and are largely independent of sample size.

We analyzed habitat use among open water habitat types, open wetlands, and streams, and habitat use and selection within open water habitat types. We analyzed shoreline type use and selection within open water habitat types and streams. We also estimated and tested for preferences between waterbodies < vs. > 8 ha by comparing observed IBP numbers with those expected according to shoreline length. Because difference in shoreline type availability alone could lead to an apparent preference for one or the other class of waterbody size – an effect known as Simpson's paradox (Agresti 1996) –, we controlled for shoreline type availability by computing Mantel-Haenszel (MH) odds ratios. Thus, we estimated the strength of the preference (with 95% confidence intervals) for either class of waterbody size after controlling for the effect of shoreline type (Agresti 1996) and removing offshore zones. We excluded all IBP mapped further than 100 m from any open water, open wetland or stream (2.6% of all IBP) as they were probably moving between habitats when detected.

In order to synthesize community structure and to identify relationships between species and habitat types, we performed a correspondence analysis (CA) on the two-way contingency table of IBP frequencies computed for species by all combinations of aquatic vs. shoreline habitat types and wetland habitat types (Legendre and Legendre 1998). This multivariate analysis differs from our species by species analyses in that it considers all species simultaneously and that it uses broken combinations of all habitat types. We performed geographic procedures with ArcGIS Version 9.1 (2005), MH odds ratio tests with SAS Version 9.1 (2002), and correspondence analysis with CANOCO Version 4.5 (2002).

RESULTS

From 1990 to 2005, we used 31,508 IBP locations from 18 waterfowl species (17 after having pooled greater and lesser scaups [*Aythya marila* and *A. affinis*]) and the common loon in habitat association analyses. All species had most of their IBP associated to open water areas, but the 6 species of dabbling ducks and the Canada goose (*Branta canadensis*) all used streams in higher proportions than the 10 species of diving ducks and the common loon, with 24.6–41.4% of IBP located in streams (Table 1). In the latter group, the lowest use of open water areas was observed in hooded merganser (*Lophodytes cucullatus*, 77.8%), followed by ring-necked duck (*Aythya collaris*, 87.0%).

Among open water areas, lake offshore zones were generally used less than expected based on areal coverage with estimated selection ratios ≤ 0.2 for 15 of the 18 species (Table 1). Connected ponds received the highest use from all dabbling duck species, Canada goose, ring-necked duck, hooded merganser, and common and Barrow's goldeneyes, with lake shore zones used in second place. The reverse was true for all other species. However, all duck species and Canada goose tended to prefer ponds over lake shore zones, as shown by estimated selection ratios ($\hat{S}$) all ≥ 1.5. Common loon was the only species to select lake shore zones first ($\hat{S} = 1.5$). Isolated ponds were primarily selected by many species, but the maximum use of these habitats only reached 3.8% IBP, in Canada goose. Rivers were preferred over lake shore zones by most dabbling species, but to a lesser extent than connected ponds.

Among open water shoreline types, most species used forest shorelines the most frequently, except for Canada goose, blue-winged teal (*Anas discors*) and green-winged teal (*A. crecca*), which made comparable use of open wetland shorelines, and scaups, which mainly used open wetland shorelines (Table 2). Open wetland shorelines were used more than expected by the highest number of species (13/18). Flooded swamp shorelines were used in higher proportion than available by all species of dabbling ducks, ring-necked duck, and hooded merganser, with selection ratios consistently > 2.2 and significant at the 5% confidence level. Small island shorelines were used more than expected by only 3 species: common loon, Barrow's goldeneye, and black scoter (*Melanitta nigra*).

In stream shorelines, some diving species were observed too infrequently to be included in our analyses (Table 3). Among the more abundant species, highest use was shared between forest (wood duck [*Aix sponsa*], mallard, common goldeneye, and common and hooded mergansers) and open wetland shorelines (Canada goose, ring-necked duck, and American black duck). Duck species frequenting streams generally prioritized flooded swamp over shrub swamp, and shrub swamp over open wetland shorelines.

Controlling for shoreline type availability in waterbodies, we found that 9 species had more chance of selecting a given shoreline type when located in waterbodies <8 ha (Table 4). Common loon, red-breasted merganser (*Mergus serrator*), and common merganser, which are the 3 main fish-eating species, preferred shorelines of larger waterbodies.

The two first axes of the CA respectively explained 56% and 20% of the percentage of variance in species-habitat relations, totalling 76% (Figure 2). Axis I, i.e. the most discriminating gradient, ordered the habitats in a sequence of increasing water openness, and axis II expressed increasing water movement.

DISCUSSION

Wetlands importance

Black Duck Joint Venture – CWS aerial survey provided a large dataset, enabling the exploration of waterfowl-habitat associations. With spatially recorded observations, made possible by low pair density and the use of helicopter, we back-located IBP in their local habitat types, obtaining information that may be partially validated with or that may add to prior knowledge of wetlands importance to each species in comparable environments (Table 5).

From the waterfowl community standpoint, interpretation of our ordination bi-plot highlighted water openness as being the most significant gradient and water movement as the best complementary gradient to explain species variation in pair habitat use. These habitat gradients are similar to those found in the study of Rempel et al. (1997), which is also based on a wetland habitat classification derived from remote-sensed data.

There have been few attempts to relate breeding waterfowl density to waterbody size in forested areas. From the data presented in Bordage (1987, 1988), it can be drawn that both American black duck and common merganser pair densities, calculated over an areal basis, were higher in lakes <10 ha and decreased with increasing lake size. According to our results, this relationship had to be expected since zones located >100-m offshore proved to be largely unused by all species. Shoreline length, which is also routinely used to report waterfowl densities (e.g. Toft et al. 1982, Gauthier and Smith 1987, Elmberg et al. 2003), is thus susceptible to reduce variability of density measures. This has been tested in Finland by Nummi and Pöysä (1995), who compared pair densities per km of shoreline among several lake size classes. They found in all abundant species (mallard, European green-winged teal (*Anas crecca crecca*), and common goldeneye) that density decreased in lakes >10 ha. In a

similar analysis from northern Ontario lakes, McNicol et al. (1987) observed that this relationship held for insectivores (hooded merganser and common goldeneye) and generalist feeders (mallard, American black duck, and ring-necked duck) but was reversed in species that are mostly piscivorous (common merganser and common loon). Our results add to the body of evidence (see also DesGranges and Darveau 1985) that larger waterbodies are preferred by piscivores (Table 4), and also highlight the importance of ponds for most other species: many species not only showed a clear preference for waterbodies < vs. > 8 ha both on a water area and a shoreline length basis, but also used these wetlands in higher absolute numbers (Table 1). Smaller size reduces wetland exposure to wind and wave action (Cowardin et al. 1979). Influence of beaver, presence of macrophytes (Longcore et al. 2006), and absence of fish (Mallory et al. 1994, Marklund et al. 2002), which are all more likely to occur in small wetlands, are other positive factors that may also contribute to explain their importance.

Studies of habitat use and selection by breeding waterfowl often relate pair distribution to pond or lake descriptors, leaving stream habitats unaddressed (e.g. Nummi et al. 1994, Paquette and Ankney 1996, Gabor et al. 2002). Whereas this approach may be appropriate for many regions and species, ignoring small streams for evaluating habitat importance would not come without a certain cost in territories that are comparable on this point to forest landscapes of Quebec. We found that streams mapped as linear features were used consistently by all dabbling duck species (25–41% of IBP observations), Canada goose (33%), and hooded merganser (21%), clearly demonstrating the significant importance of small streams in our study area (Table 1). Thus, neglecting the contribution of streams to overall habitat may have incidence on applications such as predictive distribution models, as well as on general understanding of waterfowl breeding ecology. Once streams are taken into account, discriminating upon adjacent habitat type may help in refining species-streams relationships (Table 3). In our case, maps included numerous high-gradient and intermittent streams, which explains why all stream types running through wetland patches were highly selected on a segment length availability basis.

In other forested regions of north-eastern North America, beaver ponds have been recognized as important waterfowl breeding habitats, being used by all dabbling ducks, hooded

merganser and ring-necked duck (Renouf 1972, Brown and Parsons 1979, Rempel et al. 1997, Longcore et al. 2006). This would perfectly fit our results if we rely on flooded swamps as indicators of beaver ponds. Indeed, the same species assemblage selected for flooded swamps as open water shorelines (Table 2). Moreover, even though flooded swamps only bordered a fraction of all beaver ponds present in our survey plots, flooded swamp shorelines supported considerable proportions of total IBP of American widgeon (*Anas americana*, 22%), wood duck (14%), mallard (10%), and blue-winged teal (10%). This confirms that beaver management practices and trapping effort (often related to fur value) have the potential to impact waterfowl populations that breed in the forest wetlands of Quebec.

Wetland classification

The use of numerical forestry maps provided a straightforward scheme to analyze patterns of habitat use and selection of waterfowl over a large forest territory. Even though wetland coverage may now be derived through satellite imagery, the detection of linear streams, which are important waterfowl habitats in Quebec forests, still necessitates the use of photointerpretation (Ozesmi and Bauer 2002). Other important habitats such as narrow fringes of emergent plants on shorelines, emergent rocks, or small bog ponds may have been overlooked due to minimum estimated mapping area (1 ha). However, on the maps of our survey plots, islands smaller than 0.1 ha accounted for 59% of the 2,251 small islands, whereas ponds smaller than 0.4 ha accounted for 71% of the 321 isolated ponds and for 43% of the 5,781 connected ponds. Probably more important are wetland dynamics induced by beaver activity, which produced changes between the time of the photography and the waterfowl surveys. At frequencies and locations that we could not record, impoundments appeared where small streams ran through open wetlands, streams became river-wide, and waterbody shorelines were redefined. Another potential weakness in the habitat classification we used lied in the definition of the open wetland class, which did not allow dissociating shorelines of floating riparian fens from marshes with emergent plant cover. Although it could be considered somewhat coarse, our wetland classification relied on existing numerical data, which made it cost effective. Forestry maps are also widely used by forest stakeholders

and therefore constitute an excellent planning tool on which decision making regarding habitat management can be based.

Potential biases

Errors undoubtedly occurred in the different steps of this species/habitat analysis. Apart from wetland identification and mapping, uncertainty may stem from survey timing, breeding pairs detection and location. To survey all species within the appropriate survey window – after migrants have passed through and before mates desertion – in a single survey is a challenging task. Our results must therefore be interpreted with caution, especially those of late breeding species such as scaups, surf scoter (*Melanitta perspicillata*), black scoter and red-breasted merganser (Bordage et al. 2003) because these species might still not be established in their nesting habitat yet. Regarding differential detectability rates among habitats, it should be reminded that breeding pair surveys occur before leafing and that birds do not tend to hide on aircraft approach, leading to relatively high breeding pair detectability in surveys run from a helicopter, compared to other survey methods (Ross 1985). Also, with the IBP criteria, females concealed or on a nest could be inferred by the presence of a lone male. Finally, one may logically assume that detection probability was lower in small and structurally complex wetlands and for small and secretive species when interpreting the results. Regarding IBP location, the more important bias may have occurred in the pair/habitat association algorithm, due to mapping precision (±100 m). However, we developed the algorithm to reduce bias as much as possible, thus ordering possible positive biases in a sequence that is conservative according to waterfowl (open water areas > streams > non-forested wetland areas > forested areas). Despite this sequence, we do not consider that our results on habitat selection are severely affected by the mapping imprecision or by our pair/habitat association algorithm. For example, our data regarding use rates of streams relative to open water areas is amongst the highest reported in the scientific literature. Finally, because identifying greater and lesser scaups to the species taxonomical level is difficult from aerial surveys, we had to group the two species under scaups.

MANAGEMENT IMPLICATIONS

One could see in habitat use a basis for broad-scale management decisions and in habitat selection a basis for population or habitat restoration. Most selected habitats may constitute judicious habitats where to concentrate local conservation or restoration efforts, whereas most used habitats deserve consideration when planning at a broad regional scale.

Recently, the Quebec government adopted a provincial guideline concerning evaluation mechanisms used for development projects in wetlands. This guideline entails a protection level that is higher for peatlands and large-sized wetlands (>10 ha) that are hydrologically connected (MDDEPQ 2007). This leaves wetlands that are small-sized (<10 ha) and isolated with a lower protection level. Our results show that small wetlands containing open water are used preferentially by several waterfowl species. Also, far from diminishing their ecological value, the absence of a surface hydrological link may even be an additional factor responsible for their high selection by waterfowl. These two points lead us to question the ecological relevance of size and connectivity criteria as a basis for wetlands protection guidelines. Furthermore, small isolated water areas only account for < 0.2% of the total open water area of the forest landscapes of Quebec but they are used by 1.4% of total waterfowl, and elementary precaution, such as in a conservation approach based on the coarse-filter principle, rather pleads for their preservation (Lemelin and Darveau 2006).

ACKNOWLEDGMENTS

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Table 1. Habitat use (%) and estimated selection ratios (Ŝ) of indicated breeding pairs (IBP) of 18 waterfowl species and the common loon across wetland habitat types in forest landscapes of Quebec, Canada, 1990–2005. Significant estimated selection ratios (with 95% CI excluding 1.0) are respectively italicized (lower preference) or highlighted in bold (higher preference) whether < or > 1.0.

Habitat type		CaGo[a]	WoDu	AmWi	BwTe	GwTe	ABDu	Mall	RnDu	Scau	CoGo	BaGo	Buff	SuSc	BlSc	CoMe	HoMe	RbMe	CoLo
Open water																			
Lake – offshore zone																			
Obs	x[b]	1.7	0.0	13.4	0.0	2.9	2.0	2.9	1.0	4.2	2.8	0.9	6.2	6.1	13.0	5.1	0.6	12.3	21.9
	a	0.7	0.0	8.2	0.0	1.0	0.3	1.3	0.3	2.4	0.5	1.8	2.9	2.4	7.5	0.7	0.5	7.2	2.1
Exp		41.1	41.4	52.8	38.0	39.1	39.2	35.3	39.2	33.3	39.2	31.0	38.5	39.8	33.2	39.3	39.4	55.9	39.2
Ŝ		*0.0*	*0.0*	*0.3*	*0.0*	*0.1*	*0.1*	*0.1*	*0.0*	*0.1*	*0.1*	*0.0*	*0.2*	*0.2*	*0.4*	*0.1*	*0.0*	*0.2*	*0.6*
Lake – shore zone																			
Obs	x	30.1	25.2	32.8	21.1	23.3	33.7	30.7	27.7	47.1	35.5	32.1	43.2	55.7	61.0	58.3	26.5	61.7	67.2
	a	2.6	6.7	11.2	13.0	2.7	1.1	3.6	1.3	6.0	1.5	8.9	6.0	5.0	10.9	1.7	2.7	10.6	2.4
Exp		43.9	44.9	35.5	43.6	45.2	45.3	48.5	45.2	47.6	45.3	50.9	46.6	45.7	48.5	45.3	43.8	32.6	45.5
Ŝ		*0.7*	*0.6*	*0.9*	*0.5*	*0.5*	*0.7*	*0.6*	*0.6*	1.0	*0.8*	*0.6*	0.9	**1.2**	**1.3**	**1.3**	*0.6*	**1.9**	**1.5**
Pond – connected																			
Obs	x	54.9	67.5	43.3	52.6	59.2	53.6	50.2	65.5	40.3	54.5	64.2	41.3	33.2	13.0	23.9	65.5	13.6	7.5
	a	2.8	7.2	11.9	15.9	3.1	1.2	3.9	1.4	5.9	1.6	9.1	6.0	4.8	7.5	1.4	2.9	7.5	1.3
Exp		9.3	9.0	4.9	10.4	9.6	9.7	9.7	9.6	9.3	9.7	15.3	8.5	10.0	8.8	9.6	10.2	5.7	9.6
Ŝ		**5.9**	**7.5**	**8.8**	**5.0**	**6.1**	**5.5**	**5.2**	**6.8**	4.3	**5.6**	4.2	**4.9**	3.3	1.5	**2.5**	**6.4**	2.4	0.8
Pond – isolated																			
Obs	x	3.8	1.2	0.0	2.6	1.6	1.7	1.0	1.7	3.4	0.9	0.0	2.7	1.1	1.3	0.4	2.6	0.0	0.1
	a	1.1	1.7	0.0	5.1	0.8	0.3	0.8	0.4	2.2	0.3	0.0	2.0	1.0	2.5	0.2	1.0	0.0	0.2
Exp		0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.2	0.3	0.5	0.2	0.2	0.2	0.2
Ŝ		**19.2**	5.4	*0.0*	**11.8**	8.6	9.0	4.4	**9.0**	10.8	**4.6**	*0.0*	11.3	4.0	2.7	**2.2**	**13.1**	*0.0*	0.7
River																			
Obs	x	9.5	6.1	10.4	23.7	13.0	9.0	15.3	4.1	4.9	6.4	2.8	6.6	4.0	11.7	12.3	4.8	12.3	3.3
	a	1.7	3.7	7.3	13.5	2.1	0.7	2.8	0.6	2.6	0.8	3.2	3.0	2.0	7.2	1.1	1.3	7.2	0.9
Exp		5.5	4.4	6.6	7.8	5.9	5.7	6.3	5.7	9.5	5.7	2.7	6.2	4.2	9.0	5.7	6.4	5.5	5.5
Ŝ		**1.7**	1.4	1.6	**3.0**	**2.2**	**1.6**	**2.4**	*0.7*	*0.5*	1.1	1.1	**1.1**	0.9	1.3	**2.2**	*0.7*	**2.2**	*0.6*
Total open water																			
Obs	x	62.6	67.4	64.4	54.3	59.9	74.1	57.1	87.0	93.9	91.7	93.0	91.2	98.4	100.0	89.6	77.5	98.8	98.9
	a	2.2	5.9	9.2	11.7	2.4	0.9	2.9	0.9	2.8	0.8	4.7	3.3	1.2	0.0	1.0	2.2	2.4	0.5
	IBP	1,209	163	67	38	977	6,883	629	4,456	263	3,759	106	259	377	77	3,387	1,060	81	1,524
Stream																			
Obs	x	32.9	31.8	33.7	41.4	37.7	24.6	39.9	11.7	5.4	7.8	5.3	7.0	1.6	0.0	9.9	21.0	1.2	1.0
	a	2.1	5.9	9.1	11.5	2.4	0.9	2.9	0.9	2.6	0.8	4.1	3.0	1.2	0.0	1.0	2.2	2.4	0.5
	IBP	635	77	35	29	615	2,283	439	601	15	321	6	20	6	0	376	287	1	15
Open wetland																			
Obs	x	4.6	0.8	1.9	4.3	2.5	1.4	3.0	1.3	0.7	0.5	1.8	1.8	0.0	0.0	0.4	1.5	0.0	0.1
	a	0.9	1.1	2.6	4.7	0.8	0.2	1.0	0.3	1.0	0.2	2.4	1.5	0.0	0.0	0.2	0.7	0.0	0.2
	IBP	88	2	2	3	40	129	33	65	2	21	2	5	0	0	17	21	0	2
n	IBP	1,932	242	104	70	1,632	9,295	1,101	5,122	280	4,101	114	284	383	77	3,780	1,368	82	1,541

[a] CaGo = Canada goose, WoDu = wood duck, AmWi = American widgeon, BwTe = blue-winged teal, GwTe = green-winged teal, ABDu = American black duck, Mall = mallard, RnDu = ring-necked duck, Scau = greater scaup and lesser scaup, CoGo = common goldeneye, BaGo = Barrow's goldeneye, Buff = bufflehead, SuSc = surf scoter, BlSc = black scoter, CoMe = common merganser, HoMe = hooded merganser, RbMe = red-breasted merganser, and CoLo = common loon.

[b] Confidence intervals of use percentages are given in the form x ± a (%) and were computed with the proportion large-sample CI formula (Manly et al. 2002).

Table 2. Habitat use (%) and estimated selection ratios (Ŝ) of indicated breeding pairs (IBP) of 18 waterfowl species and the common loon across shoreline types of open water habitat types in forest landscapes of Quebec, Canada, 1990–2005. Significant estimated selection ratios (with 95% CI excluding 1.0) are respectively italicized (lower preference) or highlighted in bold (higher preference) whether < or > 1.0.

Shoreline type		CaGo[a]	WoDu	AmWi	BwTe	GwTe	ABDu	Mall	RnDu	Scau	CoGo	BaGo	Buff	SuSc	BlSc	CoMe	HoMe	RbMe	CoLo
Open wetland																			
Obs	x[b]	42.8	21.5	20.7	34.2	40.8	31.9	30.3	36.2	52.0	20.7	13.3	31.8	16.4	17.9	15.0	27.4	31.4	10.5
	a	2.8	6.3	9.7	15.1	3.1	1.1	3.6	1.4	6.0	1.3	6.5	5.7	3.7	8.6	1.2	2.7	10.1	1.5
Exp		13.9	14.9	16.2	18.8	13.6	13.6	14.4	13.6	16.9	13.6	10.8	15.4	13.8	17.1	13.4	14.0	15.6	13.5
Ŝ		**3.1**	**1.4**	1.3	**1.8**	**3.0**	**2.4**	**2.1**	**2.7**	**3.1**	**1.5**	1.2	**2.1**	1.2	1.0	**1.1**	**2.0**	**2.0**	*0.8*
Shrub swamp																			
Obs	x	6.2	8.6	12.1	18.4	13.3	6.9	16.2	4.7	5.2	2.8	1.0	5.9	2.8	4.5	4.2	4.8	2.9	1.7
	a	1.4	4.3	7.8	12.3	2.1	0.6	2.9	0.6	2.7	0.5	1.8	2.9	1.7	4.6	0.7	1.3	3.6	0.6
Exp		4.4	5.9	7.7	8.1	4.5	4.5	5.0	4.5	6.3	4.4	1.7	5.4	3.7	4.6	4.4	5.1	4.5	4.2
Ŝ		**1.4**	1.5	1.6	2.3	**3.0**	1.5	**3.3**	1.0	0.8	*0.7*	0.6	1.1	0.8	1.0	0.9	0.9	0.6	*0.4*
Flooded swamp																			
Obs	x	1.9	14.7	34.5	15.8	5.2	4.4	12.1	6.8	0.0	1.3	0.0	5.4	0.0	0.0	1.3	8.3	2.9	1.0
	a	0.8	5.4	11.4	11.6	1.4	0.5	2.6	0.7	0.0	0.4	0.0	2.8	0.0	0.0	0.4	1.7	3.6	0.5
Exp		1.8	3.1	2.6	4.1	2.0	2.0	2.5	2.0	1.8	2.0	1.0	2.9	0.5	0.4	2.0	2.3	0.9	2.0
Ŝ		1.1	**4.8**	**13.4**	**3.9**	**2.6**	**2.2**	**4.9**	**3.4**	*0.0*	0.7	*0.0*	1.9	*0.0*	*0.0*	*0.6*	**3.5**	3.1	*0.5*
Small island																			
Obs	x	6.2	3.1	1.7	0.0	3.6	3.3	3.8	2.9	4.8	4.5	9.5	2.9	5.4	14.9	7.6	2.4	4.3	13.9
	a	1.4	2.6	3.1	0.0	1.2	0.4	1.5	0.5	2.6	0.7	5.6	2.1	2.3	8.0	0.9	0.9	4.4	1.7
Exp		5.1	5.4	8.2	3.5	5.0	4.9	5.1	4.9	5.8	4.9	3.4	5.7	5.0	5.6	5.0	4.9	5.4	5.0
Ŝ		1.2	0.6	*0.2*	*0.0*	*0.7*	*0.7*	0.7	*0.6*	0.8	0.9	**2.8**	*0.5*	1.1	**2.7**	**1.5**	*0.5*	0.8	**2.8**
Forest[c]																			
Obs	x	42.8	52.1	31.0	31.6	37.2	53.4	37.5	49.4	38.1	70.5	76.2	54.0	75.4	62.7	71.9	57.1	58.6	72.8
	a	2.8	7.7	11.1	14.8	3.0	1.2	3.8	1.5	5.9	1.5	8.1	6.1	4.3	10.8	1.5	3.0	10.7	2.2
Exp		74.8	70.8	65.4	65.6	74.8	75.0	73.0	74.9	69.2	75.1	83.1	70.7	77.1	72.4	75.2	73.7	73.5	75.3
Ŝ		*0.6*	*0.7*	*0.5*	*0.5*	*0.5*	*0.7*	*0.5*	*0.7*	*0.6*	*0.9*	0.9	*0.8*	1.0	0.9	*1.0*	*0.8*	*0.8*	*1.0*
n	IBP	1,185	163	58	38	947	6,733	610	4,403	252	3,650	105	239	354	67	3,210	1,052	70	1,185

[a] CaGo = Canada goose, WoDu = wood duck, AmWi = American widgeon, BwTe = blue-winged teal, GwTe = green-winged teal, ABDu = American black duck, Mall = mallard, RnDu = ring-necked duck, Scau = greater scaup and lesser scaup, CoGo = common goldeneye, BaGo = Barrow's goldeneye, Buff = bufflehead, SuSc = surf scoter, BlSc = black scoter, CoMe = common merganser, HoMe = hooded merganser, RbMe = red-breasted merganser, and CoLo = common loon.

[b] Confidence intervals of use percentages are given in the form x ± a (%) and were computed with the proportion large-sample CI formula (Manly et al. 2002).

[c] Forest shoreline type mainly includes upland forest, forest swamps, and islands > 20 ha.

Table 3. Habitat use (%) and estimated selection ratios (Ŝ) of indicated breeding pairs (IBP) of 18 waterfowl species and the common loon across shoreline types of streams in forest landscapes of Quebec, Canada, 1990–2005. Significant estimated selection ratios (with 95% CI excluding 1.0) are respectively italicized (lower preference) or highlighted in bold (higher preference) whether < or > 1.0.

Shoreline type		CaGo[a]	WoDu	AmWi	BwTe	GwTe	ABDu	Mall	RnDu	Scau	CoGo	BaGo	Buff	SuSc	BlSc	CoMe	HoMe	RbMe	CoLo
Open wetland																			
Obs	x	58.1	24.7	20.0	31.0	35.8	37.3	24.8	46.1		30.2		30.0			33.5	30.0		
	a	3.8	9.6	13.3	16.8	3.8	2.0	4.0	4.0		5.0		20.1			4.8	5.3		
Exp		13.5	12.2	20.7	14.7	12.7	12.6	13.8	12.7		12.7		14.5			12.7	12.4		
Ŝ		**4.3**	**2.0**	1.0	**2.1**	**2.8**	**3.0**	**1.8**	**3.6**		**2.4**		2.1			**2.6**	**2.4**		
Shrub swamp																			
Obs	x	19.5	15.6	37.1	24.1	23.9	22.6	26.2	15.6		25.9		25.0			15.7	16.4		
	a	3.1	8.1	16.0	15.6	3.4	1.7	4.1	2.9		4.8		19.0			3.7	4.3		
Exp		6.1	7.1	8.8	10.2	6.2	6.1	7.5	6.2		6.1		8.1			6.0	6.9		
Ŝ		**3.2**	**2.2**	**4.2**	**2.4**	**3.8**	**3.7**	**3.5**	**2.5**		**4.3**		3.1			**2.6**	**2.4**		
Flooded swamp																			
Obs	x	0.9	14.3	8.6	3.4	4.7	5.8	9.3	12.8		4.0		10.0			4.8	11.5		
	a	0.8	7.8	9.3	6.6	1.7	1.0	2.7	2.7		2.2		13.1			2.2	3.7		
Exp		0.7	1.5	1.0	1.1	0.8	0.8	1.0	0.8		0.8		1.2			0.8	1.0		
Ŝ		1.3	**9.5**	8.7	3.0	**5.9**	**7.0**	**8.9**	**15.3**		**4.9**		8.0			**5.7**	**12.0**		
Forest[c]																			
Obs	x	21.4	45.5	34.3	41.4	35.6	34.3	39.6	25.5		39.9		35.0			46.0	42.2		
	a	3.2	11.1	15.7	17.9	3.8	1.9	4.6	3.5		5.4		20.9			5.0	5.7		
Exp		79.7	79.2	69.5	74.0	80.3	80.5	77.6	80.3		80.4		76.1			80.5	79.7		
Ŝ		*0.3*	*0.6*	*0.5*	*0.6*	*0.4*	*0.4*	*0.5*	*0.3*		*0.5*		*0.5*			*0.6*	*0.5*		
n	IBP	635	77	35	29	615	2,283	439	601	15	321	6	20	6	0	376	287	1	15

[a] CaGo = Canada goose, WoDu = wood duck, AmWi = American widgeon, BwTe = blue-winged teal, GwTe = green-winged teal, ABDu = American black duck, Mall = mallard, RnDu = ring-necked duck, Scau = greater scaup and lesser scaup, CoGo = common goldeneye, BaGo = Barrow's goldeneye, Buff = bufflehead, SuSc = surf scoter, BlSc = black scoter, CoMe = common merganser, HoMe = hooded merganser, RbMe = red-breasted merganser, and CoLo = common loon.

[b] Confidence intervals of use percentages are given in the form x ± a (%) and were computed with the proportion large-sample CI formula (Manly et al. 2002).

[c] Forest shoreline type mainly includes upland forest, forest swamps, and islands > 20 ha.

Table 4. Preference of indicated breeding pairs (IBP) of 18 waterfowl species and the common loon for waterbodies < vs. > 8 ha, in forest landscapes of Quebec, Canada, 1990–2005. Expected values were derived from shoreline length distribution with shoreline type as control variable. Mantel-Haenszel (MH) odds ratio estimate is a measure of the strength of the preference. *P* values are that of the associated Cochran-Mantel-Haenszel statistic (1 df).

Water body size preference	Species	*n* observed (IBP)	MH Odds ratio	MH 95% CI	*P*
<8 ha	Wood duck	153	3.3	2.0–5.5	< 0.001
	Hooded merganser	1,002	3.1	2.5–3.7	< 0.001
	Barrow's goldeneye	102	2.9	1.6–5.2	< 0.001
	Ring-necked duck	4,223	2.8	2.5–3.0	< 0.001
	Green-winged teal	822	2.7	2.1–3.3	< 0.001
	Common goldeneye	3,414	2.5	2.3–2.8	< 0.001
	Canada goose	1,073	2.4	2.0–2.8	< 0.001
	American black duck	6,122	2.0	1.9–2.2	< 0.001
	Mallard	514	1.6	1.2–2.1	< 0.001
	Blue-winged teal	29	1.6	0.5–4.6	0.402
	Bufflehead	223	1.3	0.9–1.9	0.148
	American widgeon	51	1.3	0.5–3.1	0.574
	Scaup spp.	239	1.1	0.7–1.5	0.696
	Surf scoter	339	1.0	0.7–1.4	0.913
>8 ha	Common loon	1,139	4.8	3.8–6.1	< 0.001
	Red-breasted merganser	61	3.3	1.4–7.6	0.006
	Black scoter	58	2.3	0.9–5.6	0.069
	Common merganser	2,795	1.5	1.3–1.6	< 0.001

Table 5. Summarized associations of indicated breeding pairs of 18 waterfowl species and the common loon for broad aquatic, wetland, and shoreline habitat types, in forest landscapes of Quebec, Canada, 1990–2005.

Species	Habitat associations
Canada goose	Our study brings original information from southern range of northern races breeding in Quebec (*Branta canadensis interior* and *B. c. canadensis*). Mostly relied on ponds and streams with open wetland margins, but also used lake shore zones and forested shorelines.
Wood duck	Mostly used connected ponds and streams. Although preferred shorelines with wetland vegetation development, mostly located nearby forest shorelines.
American widgeon	Did not discriminate upon waterbody size when using open water shorelines, and used ponds and lakes equally. Used and selected for connected ponds, and also relied on the slow-moving streams and rivers of Abitibi Plains, where it was mostly distributed. Mostly selected for shores of flooded swamp, but also of open wetland and shrub swamp.
Blue-winged teal	More than half of IBP observed on either a stream or a river, the rest having been located on connected ponds and lake shore zones. Selected for flooded swamp shorelines but mostly relied on open wetland, forest, and shrub swamp shorelines.
Green-winged teal	Made high use of ponds and streams with either forest or open wetland margins. Had a clear preference for waterbodies <8 ha with wetland margins.
American black duck	The most abundant species in the area. Mainly used ponds, whereas lakes and streams were used equally. Preferred small waterbodies with developed wetland margins.
Mallard	Made high use of flowing waters, but also of ponds and lakes with a weak preference for pond shorelines. Selected for shorelines inversely to use, from the most preferred to the least: flooded swamp, shrub swamp, open wetland, and forest shorelines.

Ring-necked duck and hooded merganser	These two species showed high similarity in both habitat use and selection, with similar use and selection of connected ponds, lakes, and rivers. Both were mainly found on connected ponds and had a clear preference for the shorelines of waterbodies < 8 ha. When using streams, both highly selected for flooded swamps. One notable difference was the higher preference of open wetland shorelines in ring-necked duck, which was counterbalanced in forest shorelines in hooded merganser, consistent with nest sites.
Scaup	Although individuals detected were probably migrants, used almost exclusively open wetland shorelines of lakes and ponds.
Common and Barrow's goldeneyes	Mostly used and selected connected ponds with forest shorelines.
Bufflehead	Equally used lakes and connected ponds, mostly along forest shorelines but with a preference for open wetland shorelines.
Surf scoter and black scoter	Both species were largely found on lakes and ponds but surf scoter estimated selection ratios suggest a preference for slightly smaller waterbodies.
Common merganser	Preferred lakes, but also frequented connected ponds, rivers, and streams. Largely found along forest shorelines.
Red-breasted merganser	Exclusive use of open water areas, mostly lakes but also connected ponds and rivers, often bordered with open wetlands. Preferred waterbodies >8 ha based on shoreline density.
Common loon	Almost exclusively used lakes >8 ha, and was highly attracted by small islands.

Figure 1. Study area (540,000 km²) and design of the Black Duck Joint Venture-Canadian Wildlife Service aerial survey in Quebec. Only survey plots used in the analyses are shown. Larger squares, representing 10 × 10-km plots, each overlap one 5 × 5-km plot.
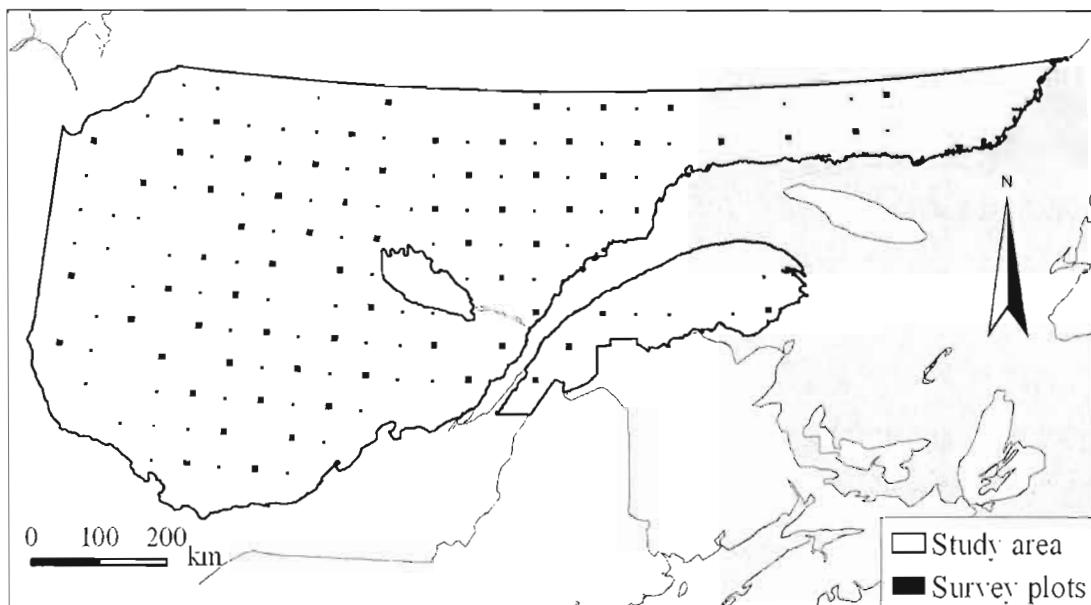
Figure 2. Correspondence analysis (CA) ordination diagram (bi-plot) of waterfowl and common loon habitat associations, in forest landscapes of Quebec, Canada, 1990–2005. CA was performed on indicated breeding pair two-way contingency table computed for i) species by ii) all combinations of aquatic vs. shoreline habitat types and wetland habitat types. Axis I corresponds to an amount of open water gradient and axis II to a water movement gradient. The two first character positions of the habitat classes are aquatic and wetland habitat types and the two last, where applicable, are shoreline habitat types. Habitat codes are: Lo = lake offshore zone, Ls = lake shore zone, Ri = river, Cp = connected pond, Ip = isolated pond, St = stream, Ow = open wetland, Ss = shrub swamp, Sf = flooded swamp, Is = island, and Fo = forest. Species codes are: CaGo = Canada goose, WoDu = wood duck, AmWi = American widgeon, BwTe = blue-winged teal, GwTe = green-winged teal, ABDu = American black duck, Mall = mallard, RnDu = ring-necked duck, Scau = greater scaup and lesser scaup, CoGo = common goldeneye, BaGo = Barrow's goldeneye, Buff = bufflehead, SuSc = surf scoter, BlSc = black scoter, CoMe = common merganser, HoMe = hooded merganser, RbMe = red-breasted merganser, and CoLo = common loon.
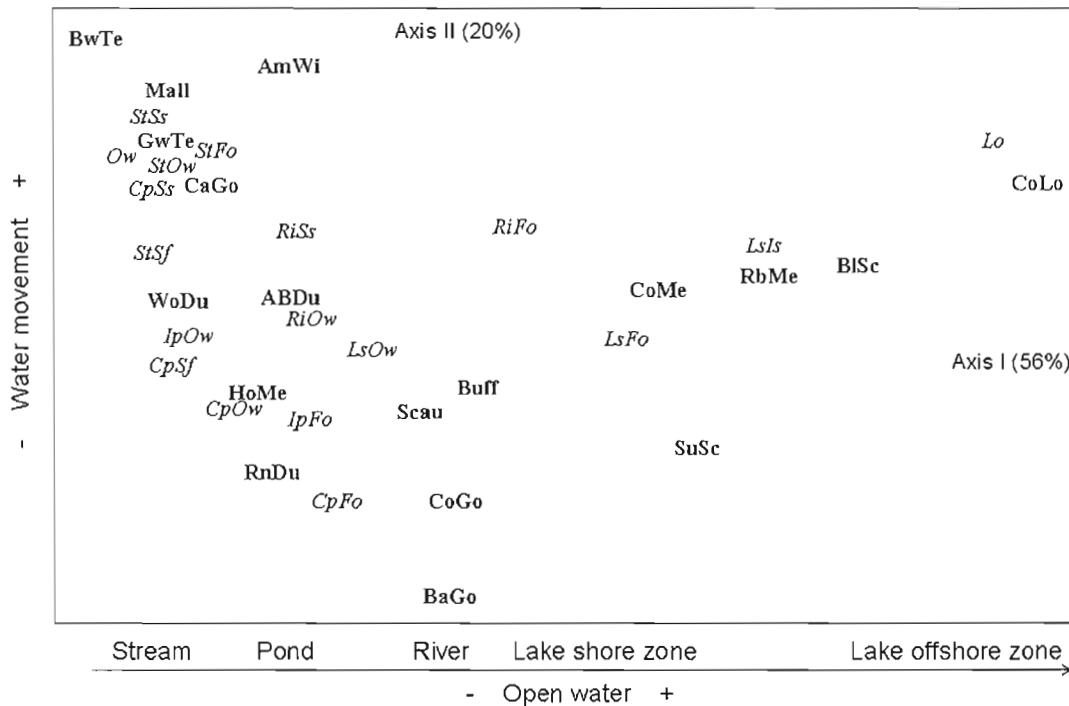
ARTICLE II

Local, Short-term Effects of Forest Harvesting on Breeding Waterfowl and Common
Loon in Forest-dominated Landscapes of Quebec

LOCAL, SHORT-TERM EFFECTS OF FOREST HARVESTING ON BREEDING WATERFOWL AND COMMON LOON IN FOREST-DOMINATED LANDSCAPES OF QUEBEC

EFFETS LOCAUX ET À COURT TERME DE LA RÉCOLTE FORESTIÈRE SUR LA SAUVAGINE ET LE PLONGEON HUARD EN PÉRIODE DE NIDIFICATION DANS LE QUÉBEC FORESTIER

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ABSTRACT. Northern forests are major breeding habitats for several waterfowl and other waterbird species. In Quebec, as in many other areas within the boreal region, clear-cut logging is an important human activity, and it is likely to affect ground- and cavity-nesting species differently. We used Black Duck Joint Venture/Canadian Wildlife Service aerial survey data, together with Quebec digital forest maps, to investigate local, i.e., within 2 km of clear-cut areas, short-term (~ 4 yr) effects of forest harvesting on waterfowl and Common Loon. Our predictions were that clear-cut logging would not affect ground nesters, but would negatively affect pair settling patterns in cavity nesters through nesting habitat disturbance. Our study spanned a 540,000-km² territory in which we considered over 30,000 ha of clear-cut areas that were dispersed into 42 different locations. We controlled for interannual variation in population size by comparing the pre- and post-harvest percentages of potentially hospitable nesting cover disturbed by timber harvesting within a 1-km radius of indicated breeding pairs. Our results suggest that timber harvesting positively influenced local populations of Canada Goose and American Green-winged Teal. No other ground-nesting species showed a significant response. For the cavity-nesting guild and species, we detected no local, short-term effect of clear-cutting. This result was unexpected because many previous studies of nest-box provisioning reported increased breeding pair densities, indicating that availability of natural holes may limit cavity-nesting duck populations. Moreover, because cavity-nesting ducks are considered among the most vulnerable bird species to forest management, our results are consistent with the hypothesis that boreal bird populations exhibit some resilience to disturbance. This conclusion follows from a study in landscapes where forests were mostly first-growth. It is not evident that it will remain valid following subsequent clear-cutting episodes and long-term forestry.

RÉSUMÉ. Les forêts nordiques sont des habitats essentiels pour plusieurs espèces de sauvagine et d'autres d'oiseaux aquatiques. Au Québec comme dans beaucoup d'autres territoires forestiers boréaux, l'exploitation forestière est une activité humaine importante et elle est susceptible d'influencer les espèces de sauvagine nichant au sol différemment de celles nichant en cavité. À partir des données de l'inventaire aérien du Plan conjoint sur le canard noir / Service canadien de la faune et des cartes écoforestières numériques du Québec, nous avons étudié les effets locaux (à moins de 2 km des aires de coupe) et à court terme (environ 4 ans) de la récolte forestière sur les populations de sauvagine et de Plongeon huard en période de nidification. Nos prédictions étaient que la récolte n'influencerait pas le patron de distribution des couples d'espèces nichant au sol, mais affecterait négativement celui des nicheurs de cavité par une altération de l'habitat de nidification. Notre étude s'est étendue sur un territoire de 540 000 km², dans lequel nous avons considéré plus de 30 000 ha d'aires de coupe réparties en 42 localités différentes. Nous avons tenu compte des variations interannuelles des niveaux de population en comparant les pourcentages d'habitat de nidification potentiel récolté à l'intérieur d'un rayon de 1 km des localisations d'équivalents-couples nicheurs, avant et après coupe forestière. Nos résultats indiquent que la coupe forestière a influencé positivement les populations locales de Bernache du Canada et de Sarcelle d'hiver. Aucune autre espèce nichant au sol n'a montré de réponse significative à la coupe totale. Dans la guilde et les espèces nichant en cavité, nous n'avons détecté aucun effet significatif local et à court terme des coupes totales. Ce résultat était inattendu puisque plusieurs expériences précédentes d'ajout de nichoirs ont résulté en une augmentation de la densité de couples nicheurs, indiquant que les populations de canards nichant en cavités pourraient être limitées par la disponibilité de sites de nidification. De plus, puisque les canards nichant en cavité sont considérés comme étant les espèces d'oiseaux les plus vulnérables face aux activités d'aménagement forestier, nos résultats supportent l'hypothèse d'une certaine résilience des populations boréales d'oiseaux face aux perturbations. Cette conclusion découle d'une étude réalisée dans des paysages où les peuplements forestiers étaient principalement de première venue. Il n'est pas évident qu'elle demeurera valide après des épisodes répétés de coupe à blanc et d'autres interventions forestières.

KEY WORDS. Boreal; breeding; cavity nesters; clear-cut; forest harvesting; ground nesters; nest site; population size; Quebec; waterfowl.

INTRODUCTION

More than 20 *Anatidae* and 1 *Gaviidae* species breed in forest-dominated landscapes of the eastern Canadian boreal forest, with annual numbers averaging over 350,000 breeding pairs in Quebec alone. Moreover, Quebec forests constitute the core of the breeding range of the American Black Duck (*Anas rubripes*) (Longcore et al. 2000), as well as partial ranges of 14 other ground-nesting and 6 cavity-nesting species. This region may contain the core of the breeding area of Barrow's Goldeneye (*Bucephala islandica*) in eastern North America (Robert et al. 2000), a population of special concern. Because many of the waterfowl populations that breed in Quebec are hunted throughout the Atlantic flyway, biological knowledge regarding the factors responsible for variation in population size is of prime interest for both hunting and conservation purposes (NAWMP Plan Committee 2004).

Quality of breeding habitat may be seen as one of the main factors affecting waterfowl populations (Conroy et al. 2002), and forest harvesting has been regularly pointed out as having a potential influence on breeding habitats (e.g., Rusch et al. 1989, Robert et al. 1999). Impacts of timber harvesting on forest landscapes are long lasting, as several decades may be necessary for initial tree cover and large trees to grow again. Effects of forest harvesting on breeding waterfowl and Common Loon (*Gavia immer*) population sizes or dynamics have never been specifically addressed within the eastern Canadian boreal forest and have also received little attention in other forested ecosystems.

During the breeding season, nesting can be seen as the most "terrestrial" part in the lifecycle of aquatic birds, and thus the most likely to be affected by forest management activities. One striking difference in nesting characteristics among waterfowl species is that some build their nests on the ground while others rely on existing tree cavities.

Ground nesters display some variability in nest site preferences, notably in terms of distance from water and vegetation cover. Although many species usually build their nests within a few meters from the edge of water, e.g., Ring-necked Duck (*Aythya collaris*) (Mendall 1958), Common Loon (McIntyre 1983), and Lesser Scaup (*A. affinis*) (Corcoran 2005), others frequently select nest sites at greater distances from water, e.g., American Black Duck (Stotts and Davis 1960, Ringelman et al. 1982), Mallard (*Anas platyrhynchos*) (Gilmer et al. 1975), American Widgeon (*Anas americana*) (Mowbray 1999), American Green-winged Teal (*Anas*

crecca carolinensis) (Johnson 1995), and Surf Scoter (*Melanitta perspicillata*) (Savard et al. 1998). Even though preferences in vegetation physiognomy may vary among ground-nesting species and habitat types, species within this group generally seek the concealment of dense low cover for nest establishment (Bellrose 1976, McIntyre and Barr 1997). The only exception to this rule is the Canada Goose (*Branta canadensis*), which prefers nest sites with good visibility (Mowbray et al. 2002). In forested habitats, there is no evidence that availability of nest sites is a limiting factor for ground-nesting populations of waterbirds. However, more comprehensive knowledge on the overall effects of forest harvesting on breeding habitats is still needed, as other mechanisms may be involved in determining reproductive success.

Cavity-nesting ducks use large secondary cavities (Darveau and Desrochers 2001), which are provided by large woodpeckers or which are created in physically damaged trees (Pöysä and Pöysä 2002). Six of these species are known to breed in Quebec (Gauthier and Aubry 1995). The Wood Duck (*Aix sponsa*) nests in hollow branches or trunks of deciduous trees or, less frequently, in Pileated Woodpecker (*Dryocopus pileatus*) holes (Godfrey 1967, Prince 1968, Hepp and Bellrose 1992). Common Goldeneye (*Bucephala clangula*) usually nests in cavities and readily uses chimney-type cavities (Prince 1968), although other microsites may be used (Eadie et al. 1995, Bordage 1996). Barrow's Goldeneye has only be recently confirmed to nest in the eastern forests of North America (Robert et al. 2000) and its nest site preferences remain unknown. It has been associated in western Canada with Pileated Woodpecker holes (Evans et al. 2002), but this latter species is scarce in the Barrow's eastern breeding range. The needs of Bufflehead (*Bucephala albeola*) have also been studied mostly in western Canada, where it is associated with Northern Flicker (*Colaptes auratus*) holes (Gauthier 1993). Although it is present all across the boreal biome (Alvo 1995), Common Merganser (*Mergus merganser*) has received relatively little attention compared to other waterfowl species. It is generally considered to nest in tree cavities and readily uses nest-boxes (Cramp and Simmons 1977), but the Common Merganser also uses other types of sites, such as holes in shore banks or bushes (Godfrey 1967, Bellrose 1976). The scientific literature is also scarce on the nest site preferences of the Hooded Merganser (*Lophodytes cucullatus*), but it is known to nest in tree cavities (Bellrose 1976, Dugger et al. 1994, Maisonneuve et al. 2002). Overall, although these species regularly use bucket-type structures instead of typical

enclosed, lateral tree holes (Prince 1968, Maisonneuve et al. 2002), nesting in natural forested habitats rarely occurs in non-tree cavities (Bellrose 1976).

Clear-cutting is considered harmful to breeding populations for which cavity density is a limiting resource (Newton 1994). In waterfowl, many nest-box experiments have shown an increase in breeding pair densities relative to pre-treatment (Haramis and Thompson 1985, Savard 1988, but see Gauthier and Smith 1987), suggesting that nest sites could limit population sizes in some cases. However, increases in breeding pairs were not always sustainable (Johnson 1967), proportional to density of nest-box additions (Eriksson 1982, Fredga and Dow 1984), or accompanied by a proportional increase in broods or fledged birds (Pöysä and Pöysä 2002, Savard and Robert 2007), suggesting that other resources such as space or food may play a role in the determination of population sizes. Also, cavity characteristics other than density, such as accessibility (Prince 1968, Peterson and Gauthier 1985), location (Pierre et al. 2001, Evans et al. 2002), or their physical attributes (Robb and Bookhout 1995), may be important for the assessment of forest logging effects on cavity-nesting ducks. On the whole, factors that limit populations of cavity-nesting ducks appear to be the result of a region-specific balance among many factors (Pöysä and Pöysä 2002), but previous research suggests that negative impacts of forest harvesting are more likely to occur than positive ones (Imbeau et al. 2001).

In this paper we used Black Duck Joint Venture (BDJV)/Canadian Wildlife Service (CWS) aerial survey data, together with digital forest maps, to investigate the local, short-term effects of timber harvesting on waterfowl and Common Loon in forest-dominated landscapes of Quebec. Effects were measured by the percentage of nesting habitat disturbed by timber harvest within a 1-km radius of breeding pair locations, in a pre- vs. post-harvest comparison. We report evidence for possible positive effects in a few ground-nesting species and limited effects in cavity-nesting species for the period and the area under study. This study provides an evaluation of the stability and resilience of waterfowl and Common Loon to timber harvesting, with stability being defined as the probability of all populations persisting (Walker 1995), and resilience being the capacity of populations to absorb disturbance (Walker et al. 2004).

METHODS

Study area

Our study was carried out in forest-dominated landscapes of Quebec, located south of 51°15'N, but excluding the St. Lawrence and Lake St. Jean lowlands and the southernmost part of the Appalachians (Fig. 1). This 540,000-km² area roughly corresponds to the public forest lands in Quebec, and extends northward from temperate deciduous forest to the boreal coniferous forest zone. Open water and wetlands with tree cover less than 25% cover nearly 18% of the total area (Ménard et al. 2006). Beavers (*Castor canadensis*) are ubiquitous within the study area, although their abundance is higher in the western part of the region (Lafond and Pilon 2004).

Human activities in Quebec's forests are mostly directed toward extraction of natural resources. Timber production was the most visible activity over the duration of our study with more than 3000 km² clear-cut annually, being equivalent to 0.51% of total public forest lands and to 1.0% of the productive, accessible public lands allocated for timber harvest (MRNQ 2002). Forest harvesting has substantially affected the forest over the last decades, inducing stand rejuvenation and simplification of forest composition and structure (Crête and Marzell 2006). The timber industry has also severely altered the hydrographical network by maintaining numerous water reservoirs and dams for timber floating, which was prevalent until the end of the 1980s. Other sources of human alteration include mining, hydroelectric power generation, acid rain, and recreational resorts (Lee 2004).

Waterfowl surveys

We obtained waterfowl data from the Black Duck Joint Venture and Canadian Wildlife Service (BDJV/CWS) aerial survey of Quebec. This survey was implemented in 1990 and was designed to produce accurate population size estimates of American Black Duck and other waterfowl species in forest-dominated landscapes. From 1990 to 1992, 82 systematically distributed square plots (10 x 10 km) were surveyed. Because of budgetary restrictions, the number of plots was dropped to 43 in 1993–1994, and to 35 in 1995. Since 1996, plot size was reduced to 5 x 5 km and the number of plots increased to 156; half of the plots are surveyed once annually in a rotating scheme (Bordage et al. 2003). All survey years

from 1990 to 2003 were considered for potential use in the analyses. Surveys were done using a helicopter (Bell 206L with bubble side-windows) that flew over every body of water, watercourse, and wetland within the plot. Flight altitude was 15–50 m above ground and speed varied from 60–100 km/h. All waterfowl seen by three observers were noted on topographic maps (scale 1:50,000) with a 100-m precision and were later transferred to a geographic information system. Surveys were done during egg laying or at the beginning of the incubation period of the American Black Duck, on average from 6–30 May. Breeding pair observations, which were used in the analyses, were determined following indicated breeding pair (IBP) criteria of the BDJV in eastern Canada (Bordage et al. 2003). For all duck species and the Common Loon that were detected from 1990 to 2003 in the BDJV/CWS aerial surveys, 82% of the birds detected positively entered the indicated breeding pair (IBP) criteria and 71% of the birds were observed in groups of two birds or less, indicating good survey timing not only for the American Black Duck but also for most other species. As examples, direct breeding evidence within our study area suggests that BDJV/CWS surveys were also conducted during the egg-laying or incubation period of the Common Goldeneye and Hooded Merganser (Sénéchal 2003). For Canada Goose, which breeds extensively in the northern third of Quebec (Malecki and Trost 1990), regular observations of active nests and eggs in 46 plots also substantiated breeding evidence and the adequacy of BDJV/CWS survey timing (Lemelin et al. 2004).

Detectability biases are important characteristics of surveys that can be categorized into visibility bias and availability bias. In these surveys, visibility bias, i.e., birds potentially visible from the helicopter, but missed by the observers, was estimated with sight-resighting data, a technique that is analogous to mark-recapture, in which front and rear observers are independent. For several sources of variability, including habitat type, group size, date, and distance from the helicopter, visibility bias was considered negligible for most species tested (N. Plante and D. Bordage, Canadian Wildlife Service, *unpublished report*). Availability bias, i.e., for concealed birds not visible from the helicopter was not assessed, but was partly controlled for through the indicated breeding pair calculations. Overall, it is unlikely that forest harvesting could have modified detectability rates because shorelines were surveyed from the water side, and individuals that were detected were usually flushed from open water. In addition, a mandatory 20-m wide forested buffer strip separated all wetlands and

permanent streams from clear-cuts and the same experienced observers were in place throughout most of the survey period.

Timber harvesting and nesting cover information

Temporal evolution of landscapes with regard to timber harvesting was reconstructed using digitized ecoforestry maps of the Quebec Ministry of Natural Resources and Fauna. Maps had information on years and boundaries of clear-cuts that occurred before the 2003 bird survey. Maps were queried to locate blocks harvested in the plots and conducted between two waterfowl-survey years. Cutting operations that spanned more than one year in a single plot were considered as a single clear-cut for pre/post comparisons. Clear-cut areas located outside the survey plots up to 2 km were included in the analyses.

Timber harvest regulations during the sample period generally prescribed logging of all merchantable stems over 9.0 cm in diameter at breast height. Clear-cut blocks, i.e., contiguous cut areas, exceeding 150 ha were normally not authorized, and had to be separated by 100-m wide forest strips (60-m strips for 100-ha blocks). Forested buffer strips 20-m wide were mandatory around lakes, rivers, wetlands, and all permanent streams (Gouvernement du Québec 1988, 1996). During the study period, first-growth stands occupied the northern third of the study areas, whereas second-growth forests that had been harvested once or twice grew on the southern part (Crête and Marzell 2006). Clear-cut blocks that were used in our analyses totalled 33,886 ha and were spread across 42 survey plots (Fig.1). Thirty-two of the plots were 25 km² and had a median cut area of 263 ha (range: 3 to 1463 ha), and 10 were 100 km² with a median cut area of 447 ha (range: 13 to 2676 ha). Cut hectare distribution followed a negative exponential function, with 25% were in cut blocks < 33 ha, 50% in cut blocks < 60 ha, and 75% in cut blocks < 114 ha. Eighteen percent of cut hectares were in cut areas exceeding 150 ha all in one block. Considering the total area located within the plots and no further than 2000 m away from the cut areas, 70% of the productive forests were originally mature stands (> 60 yr of age) and 22% of the productive forest area has been clear-cut between pre- and post-treatment waterfowl surveys.

Nesting habitat information in uncut land patches was also extracted from the ecoforestry maps to assess potentially hospitable nesting areas for both ground and cavity nesters. Nesting habitat for ground-nesting species included forest stands of all ages, saturated open

wetlands, shrub swamps, and rock barrens with less than 25% tree cover, whereas open water areas, dead flooded swamps, and areas with land uses more disruptive than timber production were excluded. Nesting habitat for cavity nesters, i.e., land patches likely to support cavity trees, only included forest stands of all ages (Courteau et al. 1997) and dead flooded swamps.

Statistical analyses

According to the BDJV/CWS aerial survey, waterfowl breeding population sizes varied during the 1990–2003 period (Fig 2). When analyzing effects of habitat changes on species, one has to account for coarser-scale temporal fluctuations in population sizes that are not caused by the treatment (Pierre and Paszkowski 2000). Since the survey plots were systematically separated by 45 km intervals and because they were not large enough to randomly select control sites, they were not appropriate for paired treatment/control samples. Hence, we compared survey data in each plot before and after harvest in a pre/post retroduction approach (Nichols 1991).

To measure the local, short-term effects of forest harvesting on breeding waterfowl and Common Loon, we measured the percentage of undisturbed nesting habitat within a 1-km radius of each IBP location, considering the same cut areas for pre- and post-treatment years. The 1-km radius (314-ha circle area) was chosen because it is in the same order of magnitude than known home-range sizes of waterfowl species in forest habitats (Ringelman et al. 1982, Kirby et al. 1985). Considering all IBP of a population within 2 km from clear-cut areas, the distribution of this percentage was expected to vary only if clear-cuts induced a biologically significant change to the breeding habitat of pairs, regardless of fluctuations in population size between years (Fig. 3). A negative difference indicated a lower undisturbed nesting habitat (higher % of clear-cut) after treatment than before, and vice-versa. We justify the inclusion of IBP until 2 km from clear-cuts for several reasons: (1) the buffered area beside clear-cuts had to be large enough to track potential change in distribution of pairs avoiding clear-cuts, which should include a greater proportion of undisturbed nesting habitat at the scale of their home range post treatment, (2) the buffered area also had to be restricted enough to ensure that IBP disturbed by harvest according to our selected radius were adequately represented in the pre-treatment sample. Furthermore, the 2 km distance was also chosen under the constraint of our minimal plot size (25 km²): it was the threshold distance

above which the number of logged plots still containing IBP data at such distant area would have dropped below 30.

Due to low waterfowl density, which is generally less than 1.0 IBP/km², plots and years were pooled. We used the maximum available number of waterfowl survey years per period and per plot as long as they were equal in pre-treatment and post-treatment periods. Thus, survey years occurring between two harvest years were excluded. For example, if in a given plot we had five available survey years before the treatment but only two afterwards, we used the last two years before and used the two years after. When the number of available survey years was smaller before than after, we kept the last years of the post-treatment period to allow maximum time for populations to adjust their local distributions following the habitat change. We tested for differences of undisturbed nesting habitat in pre- vs. post-harvest periods with the nonparametric Mann-Whitney U-test. This test was performed on all species total, on both ground and cavity nesters guilds, as well as on the nine most abundant species, i.e., Canada Goose, American Black Duck, Mallard, American Green-winged Teal, Ring-necked Duck, Common Loon, Common Goldeneye, Common Merganser, and Hooded Merganser. Tests were two-tailed and differences were considered significant at $P \leq 0.05$. All statistical tests were performed in SAS (Version 9.1, SAS Institute Inc. 2002).

RESULTS

Waterfowl surveys allowed the detection and use of 2061 indicated breeding pair (IBP) for 18 species. Twelve species were ground nesters, arranged from most to least abundant as follows: American Black Duck, Ring-necked Duck, Canada Goose, Common Loon, American Green-winged Teal, Mallard, Surf Scoter, Black Scoter (*Melanitta nigra*), Lesser Scaup, Red-breasted Merganser (*Mergus serrator*), American Widgeon, and Blue-winged Teal (*Anas discors.*) The latter six species each had less than 20 IBP. There were six species of cavity-nesting ducks: Common Goldeneye, Common Merganser, Hooded Merganser, Bufflehead, Wood Duck, and Barrow's Goldeneye; each of the latter three had no more than 20 IBP.

The mean number (± SD) of waterfowl survey years used per period for each plot and the average delay of the response measure, i.e., the time gap between harvest and post-harvest IBP surveys, were estimated to 2.5 ± 1.4 yr and 4.0 ± 2.3 yr, respectively.

Canada Goose (P = 0.026) and American Green-winged Teal (P = 0.024) were the only species to present a significant post-harvest decrease in percentage of undisturbed nesting habitat in their 1-km surroundings (Table 1). The guild of ground nesters also showed a decrease (P = 0.031). For all other species and guilds tested, no statistically significant differences were detected. Raw data used in the analyses, in the form of cumulative distributions of counts and percentages, are graphically presented on Fig. 4 for ground nesters, Canada Goose, American Green-winged Teal, cavity nesters, and all species combined. Intensity of harvesting may be indicated by the percentage of nesting habitat that was subsequently disturbed by clear-cut for the 5th IBP percentile during the pre-harvest reference period. This value was 37% and 35% for ground nesters and cavity nesters, respectively (Fig. 4).

DISCUSSION

Ground nesters

The relationship between ground-nesting waterfowl and logging has received little attention (Rusch et al. 1989). Currently, there is no evidence that availability of nest sites is a limiting factor for ground-nesting populations of aquatic birds in forested habitats. Our study brings evidence that breeding pairs of ground-nesting species are not negatively affected, in their settling pattern, by timber harvesting of a part of their 1-km surrounding area in the short term. This agrees with our initial prediction and would indicate that forest landscapes, even following actual clear-cut logging, offer enough suitable nest sites to meet the requirements of ground nesters. We also found that breeding pair numbers within 2-km of clear-cut areas increased in all species after timber harvest (Table 1). However, because of the aerial survey design constraints, we could not rigorously separate these local increases from the broadscale, general increases observed in most species (Fig. 2).

Mechanisms other than nest site availability may be involved in determining local population sizes and are susceptible to be influenced by logging. Such dynamics may be involved in the positive responses that we observed after clear-cutting for Canada Goose and American Green-winged Teal. In both species, more pairs were located within 2 km of clear-cut areas (Fig. 4), and those pairs had lower percentage of undisturbed nesting habitat in their 1-km surroundings after clear-cutting (Table 1). While preference for open nesting habitat with good visibility in Canada Goose may explain part of the results, it does not apply to American Green-winged Teal, whose nests are relatively well concealed compared to other ground-nesting ducks (Johnson 1995). Because the breeding biology of American Green-winged Teal is poorly known (Paquette and Ankney 1996), and because we did not collect more data than that of the BDJV/CWS aerial survey, further studies are needed to better understand these results and validate their biological significance.

Cavity nesters

The role of nest site limitations in cavity-nesting ducks has mostly been studied through the provision of nest-boxes for *Bucephala* species in small areas (Fredga and Dow 1984, Gauthier and Smith 1987, Savard 1988, Pöysä and Pöysä 2002, Savard and Robert 2007). However, forest management can act as a natural-cavity removal agent and thus conclusions derived from nest-box provision studies might be difficult to link to our study.

We detected no significant local, short-term effect of forest harvesting on cavity-nesting ducks based on the pre- vs. post-harvest distributions of percentages of undisturbed nesting habitat (Table 1). Our results were consistently nonsignificant for all species tested, despite differences in cavity characteristic preferences among species (Prince 1968, Bellrose 1976, Maisonneuve et al. 2002). Moreover, Common Goldeneye, Common Merganser, and Hooded Merganser had higher pair numbers after logging (Table 1), but again these increases could not be rigorously dissociated from coarser-scale population trends over our study area. These slight IBP increases do support the conclusion that forest harvesting induced no negative local, short-term effect on cavity-nesting ducks.

One way to analyze the relationship between cavities and cavity nesting ducks is to consider the following characteristics of cavities: density, detectability, and accessibility. If timber harvesting unavoidably reduces cavity density, then a number of cavities could remain after

at least one episode of forest harvesting and consequently, they could become more easily detectable and accessible to ducks. This hypothesis is especially relevant in coniferous-dominated stands where deciduous trees remain unharvested (Courteau et al. 1997), but also applies to cavity trees located near cut-block edges. Other potential effects of forest logging operating through nest sites include changes in predation rates (Pierre et al. 2001), the consequences of nest parasitism, and nest-site competition. On the whole, factors such as cavities can become limiting with shifts in the balance in relative density among available resources, such as open water, food, nest sites, competitors, and predators. The complexity of this equation coupled with our lack of fitness data precludes inferences regarding which biological processes could have operated. Based on these considerations and on the high degree of resemblance between our pre- and post-harvest counts and percentage curves (Fig. 4), a simple and reasonable explanation for our results lies in either (1) cavities having not been limiting; or (2) cavity resources having not been significantly depleted after what is likely the case in most of our study area, a first episode of forest harvesting. We also acknowledge that the level of clear-cutting in our study plots, i.e., approximately 22% of forest loss, despite its representativeness of the harvest operations conducted within our general study area, may yet be considered below a potential critical threshold (*sensu* Andrén 1994) of mature forest loss for cavity-nesting ducks.

Waterbird lifecycle perspective

In concert with nest site modifications, forestry operations could have influenced waterfowl population sizes in more subtle ways. Nutritional requirements of waterfowl species, which include various plant and animal foods (Bellrose 1976), have proved to be particularly influential during duckling and fledgling stages (Patterson 1976, Gunnarsson et al. 2004). In forested landscapes, animal foods could be considered as more vulnerable than plant foods to disturbances such as changes in water chemistry or in sediment runoffs. However, it has been demonstrated that the benthic macroinvertebrate communities of boreal lakes were little influenced by logging activities (Scrimgeour et al. 2000). Other effects associated with, but external to, forestry activities could include fish introductions into fishless lakes and disturbance caused by sport fishers in lakes only made accessible by resource extraction roads (Robert et al. 1999).

CONCLUSION

Our study provides a first approximation of the local, short-term effects of forest harvesting on waterfowl species and Common Loon. Our results suggest that these aquatic bird species might be resilient to major disturbances of the forest cover in their breeding grounds. This conclusion is in agreement with other studies on boreal terrestrial birds that have shown these species to be resilient to disturbances (Schmiegelow et al. 1997), and that their abundances and densities are highly variable (Niemi et al. 1998), perhaps as a result of the variability of the boreal environment itself (Pastor et al. 1998). Moreover, the ground-nesting bird species that we studied have a very large distribution range, and they are adapted to a wide variety of nesting covers and habitats (Baldassarre and Bolen 2006). Given that resilience to a disturbance could be predicted by the range of conditions across the distribution range of a species (Jiguet et al. 2006), ground-nesting waterfowl may on the one hand be even more resilient than other boreal bird species. On the other hand, because of their large body-size and their dependence of existing cavities and large trees, cavity-nesting ducks are among the bird species considered to be most vulnerable to forest management (Imbeau et al. 2001). From our results, these species appeared stable and therefore resilient to timber harvesting in the short term, adding some support to the hypothesis of general resilience of boreal birds to disturbance.

Although we have reported limited impacts of forest harvesting, the next step could be to investigate the mechanisms involved in population regulation by directly assessing nest sites and fitness effects in harvested vs. unharvested landscapes. Our results also reflected what happened within 2 km of clear-cuts in the study area and only over a short period (~ 4 years). These harvest treatments had to respect specific environmental regulations and were performed on specific stands that were often experiencing a first episode of severe clear-cutting (Crête and Marzell 2006). Results might be different with subsequent clear-cutting episodes and long-term forestry (Imbeau et al. 2001).

ACKNOWLEDGMENTS

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Table 1. Results of the nonparametric Mann-Whitney *U*-tests comparing pre- and post-harvest distributions of the percentage of nesting habitat left undisturbed by timber harvesting within a 1-km radius of indicated breeding pair (IBP) locations. Tests include all IBP located within 2 km of clear-cut areas. Median percentages of undisturbed nesting habitat and pre/post median differences are presented: a negative difference indicates a lower undisturbed nesting habitat (higher % of clear-cut) after treatment than before, and vice-versa. Statistics are given for all individual species totaling over 30 IBP, for guilds of ground nesters and cavity nesters, and for all species combined.

	Period	IBP numbers	Median % of undisturbed nesting habitat	Pre/post difference (%)	$Z^\dagger$	P
Ground nesters						
Canada Goose	Pre-	37	97.3	-13.0	-2.224	**0.026**
	Post-	94	84.3			
American Black Duck	Pre-	241	89.0	-0.4	-0.962	0.336
	Post-	344	88.6			
Mallard	Pre-	12	92.4	1.0	0.817	0.414
	Post-	39	93.4			
Green-winged Teal	Pre-	42	92.9	-10.4	-2.254	**0.024**
	Post-	65	82.5			
Ring-necked Duck	Pre-	149	93.1	-2.3	-1.092	0.275
	Post-	154	90.7			
Common Loon	Pre-	56	91.8	2.1	0.809	0.419
	Post-	71	93.9			
Total	Pre-	563	91.7	-2.0	-2.152	**0.031**
	Post-	778	89.6			
Cavity nesters						
Common Goldeneye	Pre-	144	85.9	-4.2	-0.907	0.365
	Post-	162	81.8			
Common Merganser	Pre-	148	89.9	1.0	-0.428	0.669
	Post-	152	90.9			
Hooded Merganser	Pre-	24	98.7	-0.6	0.053	0.958
	Post-	50	98.2			
Total	Pre-	337	89.6	0.3	-0.165	0.869
	Post-	380	89.9			
All species total	Pre-	901	91.3	-1.6	-1.618	0.106
	Post-	1,160	89.7			

$\dagger$: *Z* approximation of Mann-Whitney *U* test statistic.
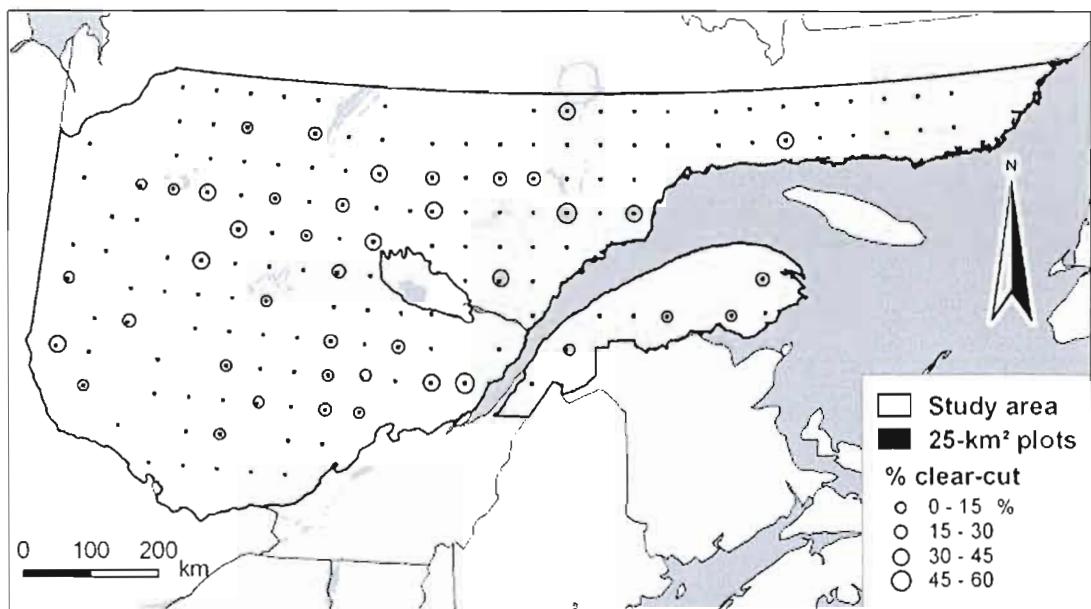
Figure 1. The study area, a 540,000-km² forest-dominated territory, with the 156 25-km² square plots. Circular grey-shaded pictograms symbolize clear-cut density (%) in each plot calculated over the total area located within 1-km from any clear-cut area. Low values indicate small, scattered clear-cut areas whereas high values (max. 59%) indicate large, clustered clear-cut areas.
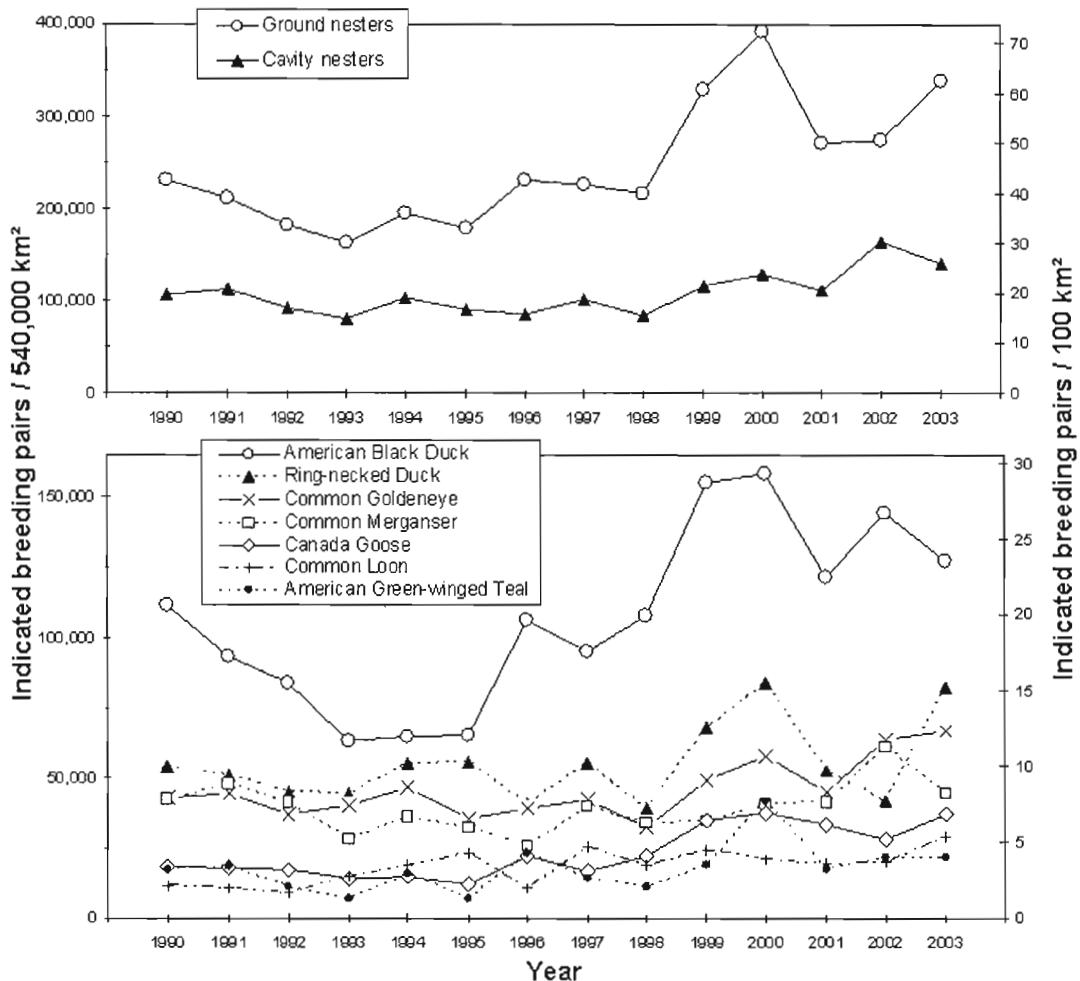
Figure 2. Population trends of ground nesters and cavity nesters, including the seven most abundant species: American Black Duck, Ring-necked Duck, Common Goldeneye, Common Merganser, and Canada Goose, Common Loon, and American Green-winged Teal. Population sizes are IBP for the whole study area: values extrapolated from survey plots to the whole 540,000-km² study area (left vertical axis), and IBP/100 km² (right vertical axis) for the 1990–2003 period. Population trends for all species surveyed are available in Bordage et al. (2003).
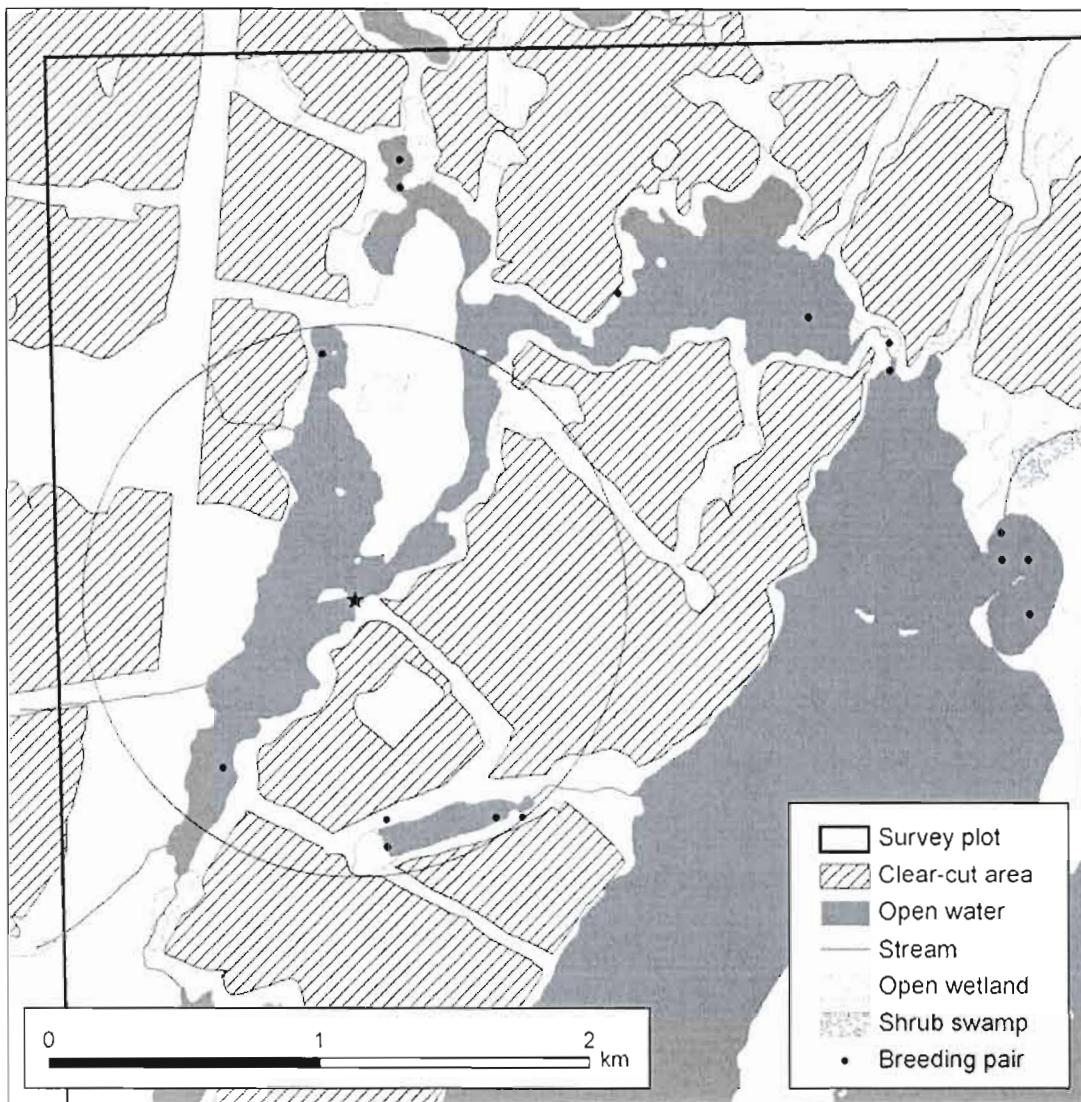
Figure 3. Example of a harvested plot (partial) with all indicated breeding pair (IBP) locations of a single survey year, as well as an example of an IBP (black star) with its 1-km radius circle. For that particular IBP, the percentage of nesting habitat undisturbed by timber harvesting was 47% for ground-nesting species and 45% for cavity-nesting species (see Methods for details on definition of nesting habitat). Clear-cut areas used for these calculations are the same for pre- and post-harvest periods.
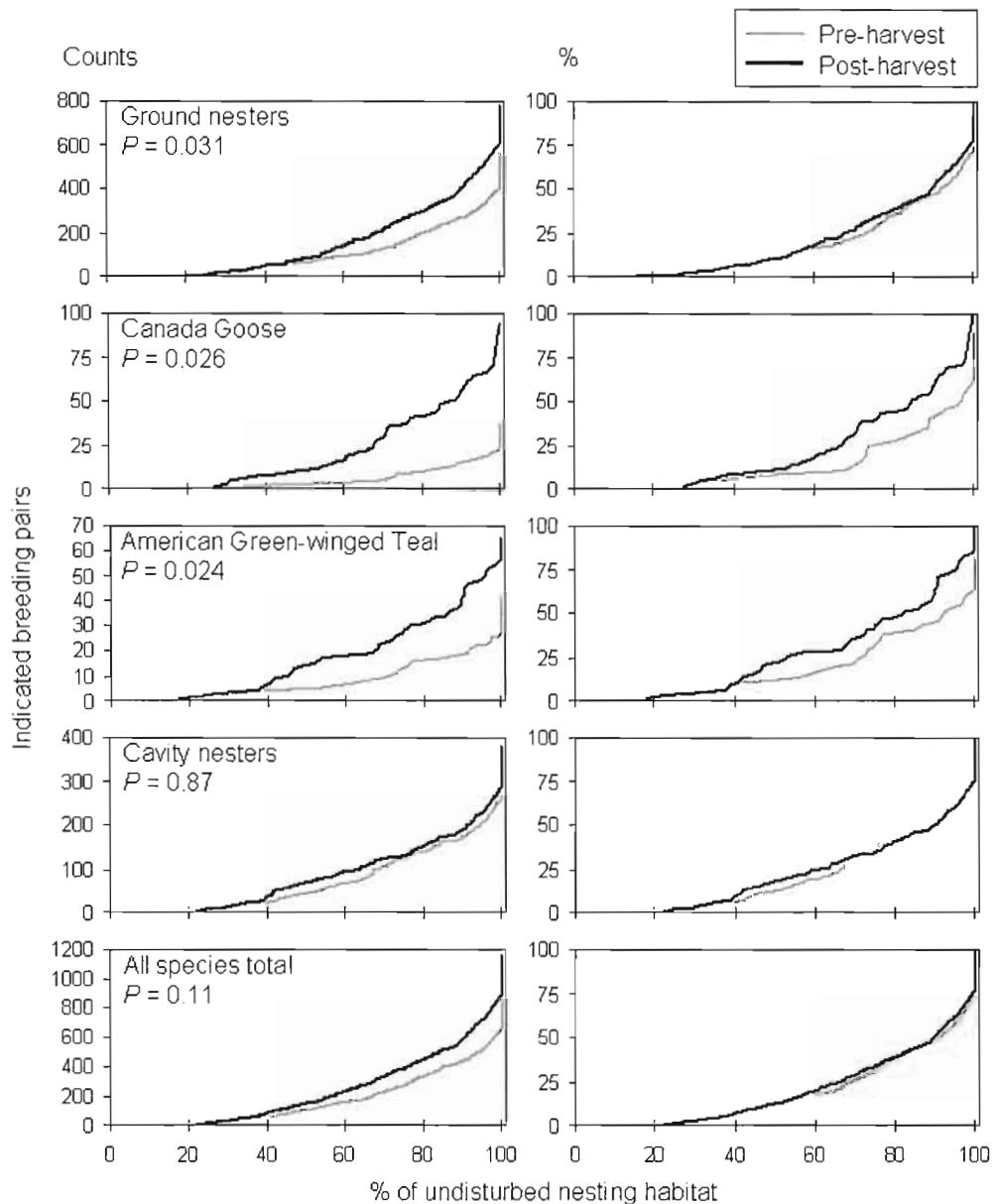
Figure 4. Indicated breeding pairs (IBP) cumulative numbers (left column) and percentages (right column) plotted against percentage of nesting habitat undisturbed by timber harvest for both pre- and post-harvest periods. For example, 92 indicated breeding pairs of ground nesters, representing 16% of all pairs detected within 2000 m, had more than 60% of undisturbed nesting habitat for the pre-harvest period. These values changed to 141 IBP and 18%, respectively, post-harvest. P-values are that of the Mann-Whitney U-tests. It is worth noting that in all cases, curves of IBP raw counts were higher post-harvest than pre-harvest, and post-harvest relative counts (%) had a generally lower percentage of nesting habitat left undisturbed by timber harvesting than pre-harvest relative counts.

CONCLUSION GÉNÉRALE

Ce mémoire a exploré et documenté les relations entre les espèces de sauvagine et leur habitat en période de nidification dans les écosystèmes forestiers du Québec. Il s'est articulé en deux articles abordant des aspects distincts de ces relations : l'utilisation et la sélection de l'habitat et l'effet des coupes forestières. Il s'agit de la première étude touchant l'ensemble des espèces de sauvagine sur le territoire forestier québécois. Plus encore, il pourrait même s'agir de l'étude basée sur le plus grand nombre d'observations localisées de sauvagine réalisée à ce jour.

Les résultats de la première partie du projet ont démontré l'importance des petits milieux humides pour la sauvagine. Il a été mis en évidence que les étangs (étendues d'eau de superficie inférieure à 8 ha) qui sont reliés au réseau hydrographique représentent des habitats de première importance, étant à la fois très utilisés et sélectionnés. Les lacs sont quant à eux très utilisés mais peu sélectionnés et, à l'inverse, les étangs isolés sont très sélectionnés mais peu utilisés. Les ruisseaux sont pour leur part très utilisés, mais en raison de leur nature, ils ne sont pas comparables avec les étendues d'eau sur la base de la superficie. Enfin, il semble que les milieux influencés par le castor soient au cœur des relations qu'entretiennent bon nombre d'espèces avec les habitats humides. L'analyse des espèces individuelles a permis de distinguer les habitudes et préférences propres à chaque espèce. Dans le groupe faunique qui regroupe la sauvagine et le plongeon huard, les patrons d'utilisation de l'habitat suggèrent que les espèces ont des exigences variées, mais que certaines d'entre elles présentent tout de même d'étroites similitudes. Enfin, ce volet du mémoire dresse un portrait général des relations sauvagine-habitat constituant une source d'information distinctive pour baser les connaissances sur l'écologie des espèces. En revanche, certaines caractéristiques importantes des milieux humides n'ont été que partiellement révélées par la carte écoforestière et les retombées potentielles du projet s'en trouvent affectées. Il aurait notamment été pertinent de pouvoir distinguer les marais à plantes émergentes des rivages entourbés, pour pouvoir mieux comprendre leur relation avec les différentes espèces.

En seconde partie, l'étude visait un enjeu fréquemment soulevé : l'impact possiblement négatif de la récolte forestière sur les aires de nidification de la sauvagine. En effet, les activités d'aménagement forestier ont le potentiel d'affecter les populations d'utilisateurs

secondaires de cavités, particulièrement ceux de grande taille tels que les canards (Newton 1994). Pour les espèces nichant au sol, l'effet de la récolte forestière constituait une interrogation pour les biologistes de la sauvagine (Rusch et al. 1989, Nichols 1991, Conroy et al. 2002) et n'avait jamais été examiné auparavant. En utilisant les données localisées de sauvagine et les informations des cartes écoforestières, il a été possible d'étudier l'effet local et à court terme des aires coupées sur ces deux groupes de sauvagine et sur les espèces les plus abondantes. Aucun effet négatif n'a été détecté, et deux espèces nichant au sol (Bernache du Canada et Sarcelle d'hiver) semblent même avoir connu un effet positif. Cependant, il n'a pas été possible de quantifier l'effet des coupes sur le nombre absolu de couples nicheurs car 1) l'effet a été possiblement de faible amplitude et 2) le dispositif d'échantillonnage ornithologique ne permettait pas l'utilisation de zones témoin de grande superficie. Aussi, le fait de ne pas détecter d'effet ne peut à lui seul prouver l'absence d'effets, qui peuvent évidemment se refléter autrement que par la distribution locale des équivalents-couples nicheurs.

Le principal élément pouvant affecter la crédibilité des résultats et des interprétations présentés est le même pour les deux articles : ceux-ci sont tributaires de l'efficacité des équivalents-couples nicheurs (Appendice A) à refléter la localisation réelle des couples reproducteurs. La justesse de la mesure « équivalent-couple nicheur » dépend elle-même d'une multitude de facteurs, dont le moment de l'inventaire par rapport à la chronologie de reproduction, le degré de synchronisation des individus à l'intérieur de chaque espèce, le taux de détection des individus, la compétence des observateurs et des pilotes, le calendrier d'inventaire, la météo, l'heure du jour, etc. Les études basées sur la supposition selon laquelle les équivalents-couples nicheurs représentent réellement la population nicheuse sont d'ailleurs toujours sujettes à cette importante incertitude.

Somme toute, l'étude réalisée a permis de mettre en valeur des données existantes pour approfondir avec rigueur certaines questions de recherche. Cette étude pourra à son tour servir de base ou de point de référence pour divers travaux à venir.

Perspectives de recherche

Toute recherche permet d'identifier un nombre important de questions encore inexplorées et de recommander des avenues de recherche pour combler les besoins de connaissances. En ce

qui a trait aux populations de sauvagine nichant dans les forêts québécoises, plusieurs données de base concernant l'écologie des espèces manquent. Il serait donc envisageable de :

- Décrire les paramètres biologiques des diverses espèces et en plusieurs localités, notamment la chronologie de la nidification, le comportement des individus non reproducteurs, le succès de nidification et le succès reproducteur;

- Évaluer la production annuelle de canetons éclos et de jeunes à l'envol afin de vérifier l'existence d'une variabilité significative d'une année à l'autre et, le cas échéant, en étudier les principaux facteurs;

- Développer un système opérationnel de classification écologique et de cartographie des milieux humides, et intégrer les variables de milieu physique liées à la nature et à la productivité des sites. Ce système devrait idéalement être applicable à partir de photographies aériennes, afin de rendre compte de l'importance des ruisseaux linéaires, lesquels demeurent peu détectables par imagerie satellitaire.

Par ailleurs, certaines activités humaines sont susceptibles d'influencer les populations de sauvagine. À ce chapitre, il serait intéressant de :

- Évaluer l'effet de la construction de routes forestières sur les superficies de milieux humides, sous l'angle des interactions avec le castor. Étudier l'utilisation de ces milieux par la sauvagine;

- Concernant les canards cavicoles, trouver et, si possible, échantillonner aléatoirement des nids de Grand Harle, de Garrot à œil d'or, et de Garrot d'Islande dans des secteurs coupés et intacts de même que dans des zones nordiques pour vérifier l'absence d'effet des coupes forestières et évaluer le degré de dépendance de ces espèces aux grandes cavités d'arbres;

- Examiner et évaluer l'ampleur du dérangement des canes au nid et des couvées par les activités récréatives, notamment la pêche sportive et l'utilisation d'embarcations motorisées sur les lacs.

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APPENDICE

Appendice A. Équivalents-couples nicheurs de l'inventaire en hélicoptère du Plan conjoint sur le canard noir-Service canadien de la faune au Québec.

Observation[1]				Nombre d'équivalents-couples					
M	F	I	T	Canards barboteurs (sauf le canard noir)	Canard noir	Canards plongeurs (sauf le fuligule à collier) et canards de mer	Fuligule à collier	Bernache du Canada	Plongeon huard
1	0	0	1	1	1	1	1	1	1
0	1	0	1	0	1	0	0	1	1
0	0	1	1	0	1	0	0	1	1
2	0	0	2	2	1,5	2	2	1	1
1	1	0	2	1	1,5	1	1	1	1
1	0	1	2	1	1,5	1	1	1	1
0	2	0	2	0	1,5	0	0	1	1
0	1	1	2	0	1,5	0	0	1	1
0	0	2	2	0	1,5	0	0	1	1
3	0	0	3	3	3	3	3	1	0
2	1	0	3	2	3	2	2	1	0
2	0	1	3	2	3	2	2	1	0
1	2	0	3	1	3	1	1	1	0
1	1	1	3	1	3	1	1	1	0
1	0	2	3	1	3	1	1	1	0
0	3	0	3	0	3	0	0	1	0
0	2	1	3	0	3	0	0	1	0
0	1	2	3	0	3	0	0	1	0
0	0	3	3	0	3	0	0	1	0
4	0	0	4	4	4	4	4	0	0
3	1	0	4	0	4	3	3	0	0
3	0	1	4	3	4	3	3	0	0
2	2	0	4	2	4	2	2	0	0
2	1	1	4	2	4	2	2	0	0
2	0	2	4	2	4	2	2	0	0
1	3	0	4	1	4	1	1	0	0
1	2	1	4	1	4	1	1	0	0
1	1	2	4	1	4	1	1	0	0
1	0	3	4	1	4	1	1	0	0
0	4	0	4	0	4	0	0	0	0
0	3	1	4	0	4	0	0	0	0
0	2	2	4	0	4	0	0	0	0
0	1	3	4	0	4	0	0	0	0
0	0	4	4	0	4	0	0	0	0
1	x^2	x^2	>4	0	0	0	1	0	0
2	x^2	x^2	>4	0	0	0	2	0	0
3	x^2	x^2	>4	0	0	0	3	0	0
4	x^2	x^2	>4	0	0	0	4	0	0
Autre combinaison				0	0	0	0	0	0

[1] M : mâle; F : femelle; I : sexe inconnu; T : total.

[2] N'importe quel nombre pourvu que M + F + I > 4.