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ARTICLE

# Early avian functional assemblages after fire, clearcutting, and post-fire salvage logging in North American forests

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**Abstract:** Increased demand for timber, the reduction in the available timber resources, and more frequent and severe forest fires under a changing climate have increased the use of salvage logging in North American forests despite concerns regarding impacts on biodiversity and long-term forest productivity. We aimed to complement previous approaches that used bird species richness or individual abundance in salvage-logged habitats to assess the sustainability of this practice. We looked for commonalities in the taxonomic, functional, and phylogenetic components of bird assemblages among these three post-disturbance habitats across a broad geographic range. We compiled six North American datasets selected from primary and grey literature that documented species composition of avian assemblages in habitats after recent fire, post-fire salvage logging, and traditional logging. Our results revealed contrasting patterns of bird trait assemblage among burned, post-fire salvage, and traditionally logged habitats. In salvage-logged habitats, taxonomic diversity, functional diversity, and functional and phylogenetic redundancy were significantly lower than in both burned and traditionally logged habitats. The frequency of insectivores was significantly lower after salvage logging than after both fire and traditional logging. These findings suggest that cumulative disturbances have a negative effect on early assembly of bird communities. The outcomes of this study encourage further assessments, at landscape level, of salvage logging intensity, burn size, and fire severity on bird functional structure to better plan for their conservation.

*Key words:* phylogenetic redundancy, forest disturbance, functional redundancy, taxonomic diversity, timber supply.

**Résumé :** La demande accrue de bois, la réduction des ressources ligneuses disponibles, les feux de forêt plus sévères et plus fréquents dans le contexte du changement climatique ont favorisé le recours à la coupe de récupération dans les forêts d'Amérique du Nord malgré les inquiétudes en ce qui a trait aux impacts sur la biodiversité et la productivité à long terme de la forêt. Nous avions pour objectif de compléter les approches précédentes qui ont utilisé la richesse ou l'abondance de chaque espèce d'oiseaux dans les habitats engendrés par la coupe de récupération pour évaluer la durabilité de cette pratique. Nous avons cherché des points communs dans les composantes taxonomique, fonctionnelle et phylogénétique des assemblages d'oiseaux entre trois habitats engendrés par cette perturbation à travers une vaste étendue géographique. Nous avons compilé six jeux de données nord-américaines choisies à partir de la littérature primaire ou grise qui a documenté la composition en espèces des assemblages aviaires dans les habitats issus d'un feu récent, d'une coupe de récupération après feu ou d'une coupe traditionnelle. Nos résultats révèlent différentes configurations de caractéristiques des assemblages d'oiseaux parmi les habitats brûlés, récupérés après feu ou exploités de façon traditionnelle. Dans les habitats issus d'une coupe de récupération, la diversité taxonomique, la diversité fonctionnelle, la redondance fonctionnelle et phylogénétique étaient significativement plus faibles que dans les habitats issus d'un feu ou d'une exploitation traditionnelle. La fréquence des insectivores était significativement plus faible après une coupe de récupération qu'après un feu ou une exploitation traditionnelle. Ces résultats indiquent que des perturbations cumulatives ont un effet négatif sur les premiers assemblages des communautés d'oiseaux. Les résultats de cette étude encouragent à poursuivre l'évaluation des effets, à l'échelle du paysage, de l'intensité de la coupe de récupération, de la taille

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du brûlis et de la sévérité du feu sur la structure fonctionnelle des oiseaux pour mieux planifier leur conservation. [Traduit par la Rédaction]

*Mots-clés :* redondance phylogénétique, perturbation forestière, redondance fonctionnelle, diversité taxonomique, approvisionnement en bois.

## Introduction

Post-fire salvage logging is becoming more prevalent worldwide (Lindenmayer et al. 2008; Müller et al. 2019). It may become even more so if forecasted increases in the frequency and severity of natural disturbances under climate change scenarios hold true (Price et al. 2013) and burned forests become more accessible with the expansion of road networks and infrastructure. Minimizing the ecological effects of salvage logging while maintaining its economic benefits is challenging (Lindenmayer and Noss 2006; McIver and Starr 2000). A potentially significant factor associated with salvage logging is the cumulative effect of following natural (e.g., fire) disturbance with anthropogenic (e.g., clear cutting) disturbances (Lindenmayer et al. 2017) on ecosystem composition (i.e., biotic and abiotic components) and function (i.e., collective biotic activity of plants, animals, and microbes and their effects on the physical and chemical conditions of their habitat) (Naeem 1998). After fire, forests are dominated by high snag densities in addition to patches of living trees of varying sizes according to fire severity (Lindenmayer et al. 2008; Nappi et al. 2004). By removing snags, post-fire salvage logging modifies habitat structure (Lewis and Hartley 2006; Lindenmayer and Noss 2006) and reduces resource availability for species feeding and (or) nesting in dead wood. After traditional logging, the majority of merchantable trees are removed and the harvested stands are dominated by shrubs, herbs, regenerating trees, and some canopy trees within block residual retention (Swanson et al. 2011).

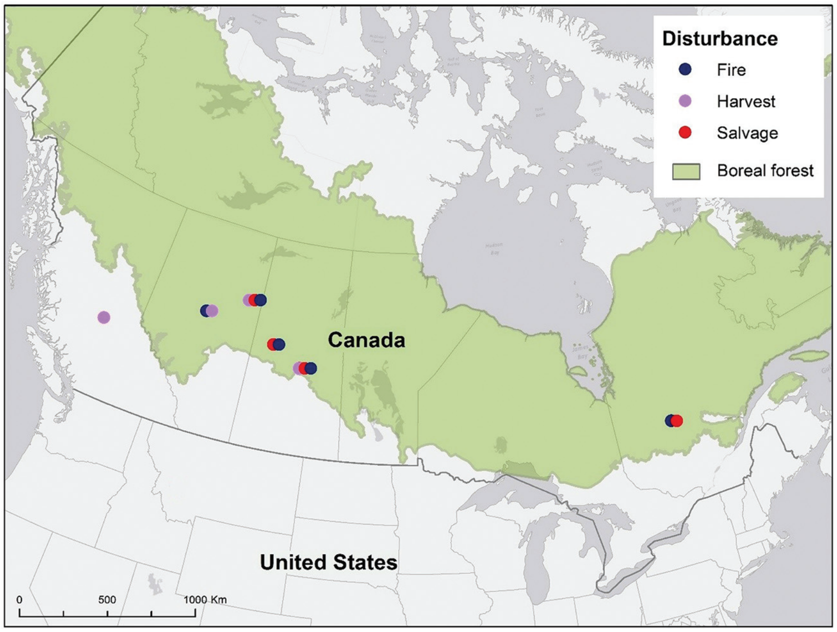
Several biodiversity indicators (e.g., species occurrence, species richness) have previously been used to assess the ecological impact of major forest disturbances (Lindenmayer and Noss 2006). The immediate stand-scale effect of salvage logging on biodiversity has received a lot of attention in the literature (Cahall and Hayes 2009; De Bello et al. 2007; Lindenmayer and Noss 2006; Nappi et al. 2004), with birds being one of the species groups having seen the most attention. Bird communities play many roles in ecosystem function (Mikusiński et al. 2018), including regulating predator populations, controlling populations of their prey (Van Bael et al. 2003), and enhancing plant reproduction via pollination or seed dispersal (Anderson et al. 2011). Some birds act as keystone species (Drever and Martin 2010; Hutto and Gallo 2006; Koivula and Schmiegelow 2007; Nappi et al. 2010). For example, woodpeckers generate habitat (i.e., excavation of cavities in trees) for secondary cavity users that can facilitate post-fire regeneration through seed dispersal, seed germination, and regulation of insect populations, which in turn affect vegetative growth (Gregory et al. 2005; Vandewalle et al. 2010; Venier and Pearce 2004). Since bird populations show relatively rapid responses to environmental change, they represent sensitive indicators of habitat conditions (Gregory et al. 2005; Vandewalle et al. 2010; Venier and Pearce 2004).

Previous work on the response of birds to salvage logging has primarily focused on cavity-nesting birds, which are thought to be particularly sensitive to post-fire logging because unlogged post-fire habitat provides cavity-nesting habitat (Drever and Martin 2010; Hutto and Gallo 2006; Koivula and Schmiegelow 2007; Nappi et al. 2010). Aside from work on cavity nesters, most bird studies have focused on taxonomic diversity (i.e., species richness or abundance) (Cahall and Hayes 2009; Morissette et al. 2002). Examining the impact of salvage logging on taxonomic diversity has the advantages of being sensitive to short-term dynamics and easily interpretable (Saint-Germain and Greene 2009). Unfortunately, the response of taxonomic diversity to a disturbance can rarely be generalized to other regions. It may not provide insight into the interaction between birds and their environment (Klingbeil and Willig 2016*a*; Lindenmayer and Noss 2006; Vandewalle et al. 2010) and other regions (Hobson and Schieck 1999). Examining the response of trait-based functional groups (as opposed to individual species) could complement single-parameter approaches (e.g., species richness) by providing possible mechanistic insights not revealed through analyses of taxonomic diversity (Lindenmayer et al. 2014; Mouillot et al. 2013; Tarbill et al. 2015; Vandewalle et al. 2010). Functional traits are presumed to either have an effect on ecosystem function (e.g., seed dispersal, structural transformation, pest regulation) or characterize a response to environmental change (e.g., resource availability and disturbance) (Lavorel and Garnier 2002; Luck et al. 2012). For instance, foraging and nesting traits are related to resource use (e.g., insects, seeds) and changes in ecosystem structure (e.g., modification of soil and tree structure) and thereby provide habitat to other organisms. After a forest fire, it is well established that the activity of cavity-excavating birds have cascading effects on forest succession (Tarbill et al. 2015). Less is known about whether other functional groups and interactions occur in early post-disturbance forests that may have ecological implications.

Bird communities can be described using many competing and (or) complementary indices such as taxonomic diversity, functional diversity considering trait distance (FD; i.e., range in the number of ecological functions represented in a community), functional diversity considering phylogenetic distance (PFD), functional redundancy (FR; i.e., the number of species playing the same functional role), or phylogenetic redundancy (PFR). Although, high FD is often linked to greater resilience (Elmqvist et al. 2003; Ricotta et al. 2016), it has been predicted that conserving high FR should buffer communities following disturbance via species compensation (i.e., remaining species playing similar ecological roles as those lost from disturbance) (Concepción et al. 2017; Laliberté et al. 2010; Ricotta et al. 2016). Functional diversity and redundancy have a more direct relationship with community resilience to environmental change than taxonomic diversity (Mayfield et al. 2010; Petchey et al. 2007; Ricotta et al. 2016), and functional and taxonomic diversity may differentially respond to disturbance (Laliberté et al. 2010). Ultimately, examining the response of both taxonomic and functional diversity may provide more robust measures of the potential implications of disturbance on bird communities' resilience to disturbances than taxonomic diversity alone (Klingbeil and Willig 2016*b*; Lavorel and Garnier 2002; Ricotta et al. 2016).

In this study, we use a set of taxonomic diversity, functional diversity, and functional and phylogenetic redundancy indices to test two hypotheses regarding the impact of disturbance on forest bird communities. We hypothesized that (*i*) assemblages based upon the ecological traits of birds would differ among burned, traditionally logged, and salvage-logged habitats due to the strong link between bird composition and habitat structure (Schieck and Song 2006); and (*ii*) salvage logging after fire should reduce taxonomic diversity, functional diversity, and functional and phylogenetic redundancy of bird communities because of the cumulative effects of both disturbances (Lindenmayer and Noss 2006). To assess these predictions, we used legacy datasets of bird species composition and abundance in burned nonsalvage, post-fire salvage, and traditionally logged North American forests, derived from peer-reviewed and grey literature.

**Fig. 1.** Study geographical distribution (adapted from Brandt 2009, created in ArcGIS). [Colour online.]



## Methods

### Literature search

Our literature survey included a search between September and November 2014 in ISI Web of Science and Google Scholar using the combination of different key words related to avian community in North America boreal forests and species composition changes after fire, post-fire salvage logging, and traditional logging. We used the following search terms: "boreal forest" OR "conifer forest" AND "salvage logging" OR "salvage cutting" OR "salvage harvesting" OR "commercial logging" OR "commercial cutting" OR "conventional harvesting" OR "traditional harvesting" OR harvesting OR logging OR fire OR wildfire AND bird* OR "species abundance" OR "functional diversity". We also obtained relevant papers, theses, and reports listed in the references of primary and grey literature from the aforementioned literature search. We only selected studies that explicitly considered changes in bird community within 5 years after disturbances (fire, post-fire salvage logging, and traditional logging) in Canadian forests. Studies targeting specific bird groups (such as cavity nesters, woodpeckers) or a limited number of species from the final data compilation were excluded to avoid biased comparisons.

### Data compilation

We compiled six North American datasets selected from primary (peer-reviewed) and grey literature that documented species composition of avian assemblages in coniferous, deciduous, and mixed wood forests after recent (≤5 years) fire, post-fire salvage logging, and traditional logging (Fig. 1; Table S1[1]). We obtained raw data from three studies and extracted data from three published studies that provided a complete list of species and abundances. When a study had missing information that was important to consider in the study such as species abundance or occurrence, we contacted the authors for additional information. We excluded any study for which the species abundance or occurrence data were unavailable within the study. For these latter studies, we extracted the mean frequency of occurrence or species abundance for each site where point count sampling had been applied. We pooled data from stand types within the same treatment nested within individual study and treated these as our study sites. For the three studies in which we had access to the raw data, we calculated mean frequency of occurrence or abundance of species per treatment within each stand from raw data (Azeria et al. 2011; S.J. Song and J. Hannah, unpublished data; Van Wilgenburg and Hobson 2008), to make them comparable to estimates extracted from the four published studies. To ensure comparability between datasets surveyed using different methods (see Table S1[1]), we calculated the relative contribution of each species to its community (pi). The data table $Y$ = [yij] presents sites in rows and species occurrence or abundance in columns. Each species mean frequency of occurrence or abundance (xi) was divided by the row sums yi+ following Legendre and Gallagher (2001): pi = xi/yi+. We had 17 sites in total distributed between the three treatments: fire (with no salvage logging or less than 33% area salvage logged; $n$ = 6), salvage logging (i.e., more than 33% area salvage logged after fire; $n$ = 7), and traditional logging (i.e., clear-cut forest; $n$ = 4).

### Bird trait selection

We selected seven species traits that are potentially sensitive to forest disturbances (Luck et al. 2013; Vandewalle et al. 2010). The selected traits are mainly related foraging and nesting behaviors, resource acquisition (foraging guild), mobility (body mass), reproduction (clutch size, nesting behaviour), and ecosystem engineering or structural transformation (nest location and guild). More details on potential response to environment and effect on ecosystem function of selected traits are reported in Table 1. We derived trait data from species accounts in the Birds of North America (Poole 2005) and phylogeny data in BirdTree.org (Jetz et al. 2014).

### Data analysis

To assess community trait variation among disturbances, the relationship between bird species traits and disturbance type (traditional logging, fire, salvage logging, undisturbed) was tested using RLQ analysis (Dray et al. 2014). RLQ analysis is a three-matrix ordination method that relates species abundance and traits

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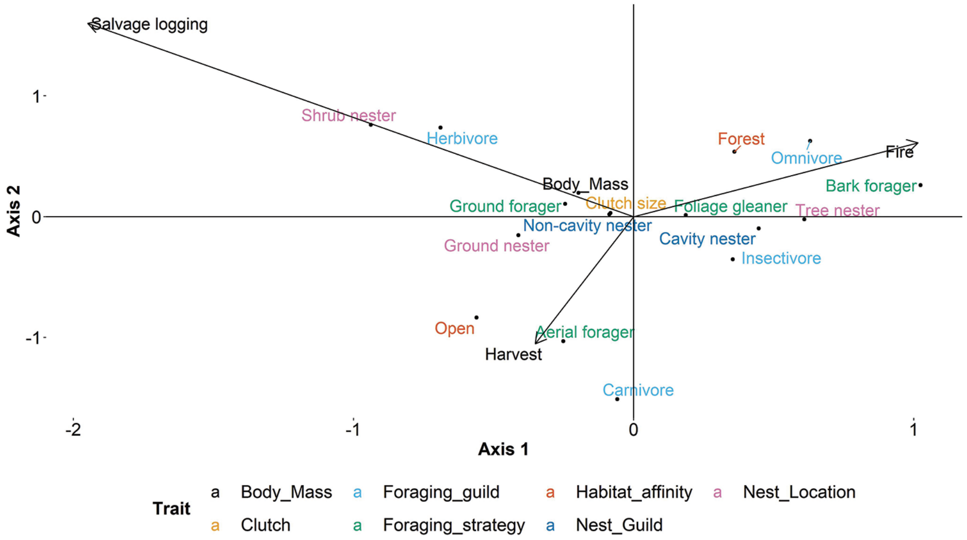
[1] Supplementary data are available with the article at https://doi.org/10.1139/cjfr-2020-0145.

**Table 1.** Description of the selected traits.

| Functional trait | Class | Example of responses and effects on ecosystem function |
|---|---|---|
| Foraging strategy | Ground forager<br>Bark forager<br>Foliage gleaner<br>Aerial forager | Resource use (e.g. reduced primary diet) and competitiveness (e.g. enhanced pollinisation by insects) |
| Foraging guild | Herbivorous<br>Insectivorous<br>Omnivorous<br>Carnivorous | Resource use, seed dispersal (e.g. reduced seed germination and seedling survival), and predation (e.g. pest regulation) |
| Habitat affinity | Open canopy<br>Forest | Resource use (e.g. reduced habitat specialists), reproductive effort (e.g. reduce reproduction sites), and ecosystem engineering (e.g. tree cavities excavation providing habitat features for seed dispersers, insectivores, and small predators) |
| Nest location | Ground<br>Shrub<br>Tree | Reproductive effort (e.g. reduced response capacity due to low reproductive sites) and ecosystem engineering (e.g. modification of soil, trees, and canopy structures, creating substantial nutrient concentration) |
| Nest guild | Non-cavity nester<br>Cavity nester | Reproductive effort (e.g. loss of large cavity bearing tree reduce cavity-nesting bird) and ecosystem engineering (e.g. modification of large trees and canopy structures, provision of nesting habitats for other organisms) |
| Clutch size (mean) | Quantitative | Reproductive effort (e.g. reduced response capacity due to low reproductive rates) and trophic interactions (e.g. prey availability and predation pressure) |
| Body mass (average) | Quantitative | Resource use (e.g. reduced response capacity due to low turnover rates) and mobility (e.g. habitat fragmentation) |

**Note:** Trait description and examples of potential responses to disturbance and effects on ecosystem function according to literature (Luck et al. 2012; Concepción et al. 2017; Williams and Purves 2011) are provided.

**Fig. 2.** Relationship between traits and disturbances using RLQ analysis. Disturbance classes (Fire, Harvest, and Salvage logging) are presented as vectors. Functional traits are presented as group centroids. [Colour online.]



to environmental factors. The three matrices are **L** (community data) with species as columns and sampling units as rows, **Q** (traits data) with traits as columns and species as rows, **R** (environmental data) with treatments (disturbance) as columns and sampling unit as rows. Prior to the analysis of trait data, we standardized body mass and clutch size (using Z-score scaling) to reduce the high variation in magnitude of species body mass and clutch size. We use the *rlq* function implemented in the "ade4" package version 1.7-15 (Bougeard and Dray 2018; Dray and Dufour 2007) of R the statistical and programming environment version 3.6.3 (R Core Team 2020) to perform RLQ analysis. We tested the significance of the relationship between treatments (**R**) and species functional traits (**Q**) using a "model 6" (Dray et al. 2014) Monte Carlo permutation test with 9999 permutations. Monte Carlo permutation tests were performed using the function *randtest* implemented in the "ade4" package version 1.7-15. Permutation "model 6" combines permutation "model 2" (i.e., permute entire rows of matrix **L** to test the null hypothesis that the distribution of species with fixed traits is not influenced by the environmental conditions) and "model 4" (i.e., permute entire columns of matrix **L** to test that the species composition of the sampling units is not influenced by the species traits) (Dray et al. 2014).

We used a set of complementary indices to describe the bird communities. (1) Taxonomic diversity (SD) is a measure of diversity that considers species relative abundance. (2) Functional diversity (FD) is the range in the number of ecological functions represented in a community considering trait distance (i.e., trait divergence between species) and (3) PFD when considering phylogenetic distance. (4) Functional redundancy (FR) is the number of species with similar functional roles considering trait distance

**Table 2.** Likelihood ration tests (LRT) for the predictors of (A) Gini–Simpson index, (B) Rao quadratic entropy considering trait distance, (C) Rao quadratic entropy considering phylogenetic distance, (D) Functional redundancy, and (E) Phylogenetic redundancy.

| | df | AIC | LRT | p-value |
|---|---|---|---|---|
| **(A) Gini–Simpson index (SIMPLEX, $\mu$ and $\sigma$)** | | | | |
| $\mu$ | | | | |
| Starting model | — | −62.31 | — | — |
| Disturbance | 5.46 | −49.02 | 24.21 | <0.001 |
| Random factor | 3.47 | −046.56 | 20.67 | <0.001 |
| $\sigma$ | | | | |
| Starting model | — | −62.31 | — | — |
| Disturbance | 2.70 | −56.73 | 10.98 | 0.009 |
| **(B) Rao quadratic entropy with trait distance (SIMPLEX, $\mu$ and $\sigma$)** | | | | |
| $\mu$ | | | | |
| Starting model | — | −57.88 | — | — |
| Disturbance | 1.94 | −60.39 | 1.38 | 0.488 |
| Random factor | 3.57 | −46.61 | 18.41 | <0.001 |
| $\sigma$ | | | | |
| Starting model | — | −57.88 | — | — |
| Disturbance | 2.50 | −52.47 | 10.41 | 0.009 |
| **(C) Rao quadratic entropy with phylogenetic distance (BE, $\mu$ and $\sigma$)** | | | | |
| $\mu$ | | | | |
| Starting model | — | −154.15 | — | — |
| Disturbance | 1 | −148.46 | 7.96 | 0.006 |
| Random factor | <0.01 | −153.67 | 0.48 | <0.001 |
| $\sigma$ | | | | |
| Starting model | — | −154.15 | — | — |
| Disturbance | −1.19 | −149.96 | 1.81 | <0.001 |
| **(D) Function redundancy (BE, $\mu$ and $\sigma$)** | | | | |
| $\mu$ | | | | |
| Starting model | — | −66.51 | — | — |
| Disturbance | 5.08 | −57.96 | 18.72 | 0.002 |
| Random factor | 3.08 | −63.50 | 9.18 | 0.029 |
| $\sigma$ | | | | |
| Starting model | — | −66.51 | — | — |
| Disturbance | 5.08 | −57.95 | 18.72 | 0.002 |
| **(E) Phylogenetic redundancy (BE, $\mu$ and $\sigma$)** | | | | |
| $\mu$ | | | | |
| Starting model | — | −60.76 | — | — |
| Disturbance | 5.26 | −48.45 | 22.64 | <0.001 |
| Random factor | 3.26 | −48.31 | 18.98 | <0.001 |
| $\sigma$ | | | | |
| Starting model | — | −60.76 | — | — |
| Disturbance | 2.37 | −55.44 | 10.07 | 0.010 |

and (5) phylogenetic redundancy (PFR) when considering phylogenetic distance. We used *rao.diversity* function implemented in "SYNCSA" package version 1.3.4 (Debastiani and Pillar 2012) to compute the indices. We calculated community taxonomic diversity within each treatment using the Gini–Simpson index (Simpson 1949). The rationale behind the use of Gini–Simpson index (SD) is its direct relationship with the functional diversity (FD) and functional redundancy (FR) indices (i.e., FR = SD – FD) (De Bello et al. 2007). We calculated FD and PFD using Rao's quadratic entropy index (Rao 1982). Functional diversity (FD) and FR were computed separately for each of the seven selected traits and for the overall trait assemblages by treatment, while SD, PFD, and PFR were computed for overall trait and phylogenetic assemblage. The values of the metrics (SD, FD, PFD, FR, and PFR) range between 0 (no diversity) and 1 (infinite diversity).

The statistical analyses of the diversity and redundancy indices followed a protocol for data exploration described by Zuur et al. (2010), and protocols for conducting and presenting regression-type analyses (Stasinopoulos et al. 2017; Zuur and Ieno 2016; Zuur et al. 2010). We investigated what theoretical distribution came closest to the marginal distribution of the dependent variable (i.e., SD, FD, PFD, FR, and PFR). We used the *fitDist* function of "gamlss" package version 5.1-4 (Rigby and Stasinopoulos 2005) to find the best fit (based on the Akaike's Information Criterion (AIC) of the different fitting attempts) among a list of distributions adapted to positive real number (ranged between 0 and 1) data available in the "gamlss.dist" package version 5.1-4 (Stasinopoulos and Rigby 2019). The simplex distribution had the best fit based on AIC for SD, FD, and PFD, while beta distribution has the best fit for FR and PFD (Table S2[1]).

Since the data were from different locations and stand types, we therefore applied mixed effect models with the combination of Location (4 levels) and Stand_type (3 levels) being treated as a random effect. To model the community diversity indices as function of disturbance, we used a Generalized Additive Model for Location, Scale, and Shape (GAMLSS) with the best-fit family distribution (Table S2[1]) mentioned above for each response variable. GAMLSS family distributions have up to four parameters ($\mu$, $\sigma$, $\nu$, $\tau$). The terms location, scale, and shape refer to these parameters and are connected, but necessarily equal, to the four moments of a distribution, namely the mean ($\mu$), the variance ($\sigma$), the skewness ($\nu$), and the kurtosis ($\tau$). GAMLSS is a modern distribution-based approach to regression analysis that expands traditional approaches to accommodate distribution parameters that are modeled as additive functions of predictor variables (Barber 2018). We included disturbance type as a fixed effect factor in our models. Model assumptions were verified by plotting residuals against fitted values to assess homoscedasticity; making QQ plots and computing filliben correlation coefficients to verify normality and using worm plots to visualize model fit to the data (Stasinopoulos et al. 2017). We performed likelihood-ratio tests to assess significance of the fixed and random factors.

We investigated the functional rarity within communities between disturbance types. Rare species perform different functions in ecosystems, some being redundant with those of many other rare and common species, while others are unique (Violle et al. 2017). We computed the functional rarity (Uniqueness) and taxonomic scarcity (Scarcity) indices. Uniqueness (UI) measures how functionally rare a species is, with values ranging from 0, indicating that the focal species shares the exact same traits as other species in the pool, and conversely to 1, indicating the species shares no traits as others in the pool. Scarcity (SI) measures how abundant a species is in comparison to other species within a community with values ranging from 0, indicating that the focal species is abundant, to 1, indicating the opposite. We used the "funrar" package version 1.2.1 (Grenié et al. 2017) to compute the functional uniqueness and the taxonomic scarcity indices.

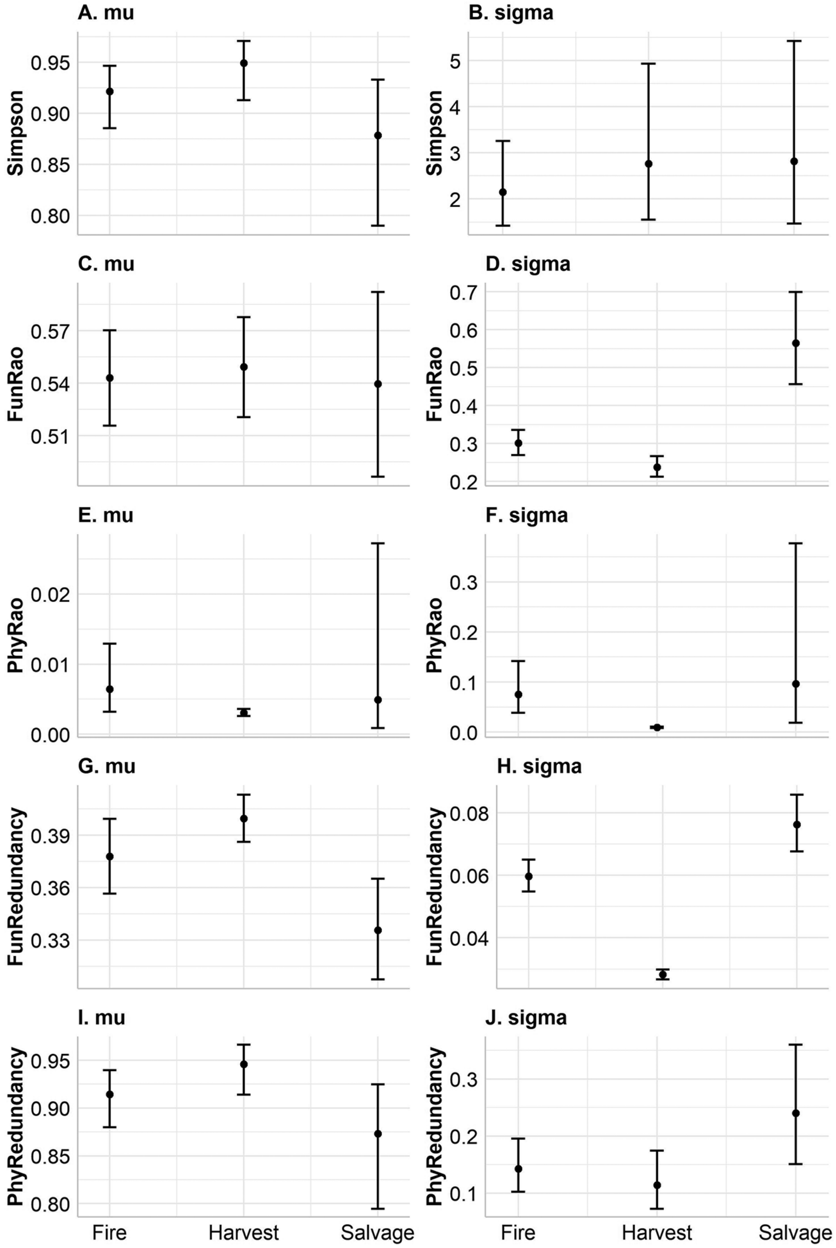
All graphics were produced using the "ggplot2" package version 3.3.0 (Wickham 2016).

## Results

### Bird traits response to disturbances

The first axis of the RLQ analysis captured 78% of the total association between traits and disturbance classes (i.e., co-inertia), accounting for most of their relation. The Monte Carlo permutation "model2" test was significant (*P* = 0.048), indicating that trait assemblages were significantly associated to disturbances. In addition, the Monte Carlo permutation "model 4" was not significant (*P* = 0.172), indicating that species composition of the sampling units was not significantly influenced by species characteristics. The summary statistics showed that the axis 1 describes 40% of the covariance between disturbances and traits. The RLQ axis 1 split the bird trait assemblage along a gradient from naturally disturbed (positive side of axis 1) to anthropogenically disturbed forest types (negative side of axis 1, Fig. 2), with logged forests falling between non-salvaged and salvaged habitats. For example, there were cavity

**Fig. 3.** Predicted values and confidence intervals of additive terms of Gini–Simpson index (A, mu; B, sigma), Rao quadratic entropy considering trait distance (C, mu; D, sigma), Rao quadratic entropy considering phylogenetic distance (E, mu; F, sigma), Functional redundancy (G, mu; H, sigma), and Phylogenetic redundancy (I, mu; J, sigma) for both $\mu$ and $\sigma$ components of the (SIMPLEX, $\mu$ and $\sigma$) and (BE, $\mu$ and $\sigma$) models.



nesters on the positive side versus non-cavity nesters on the negative side of axis 1; tree nesters versus shrub and ground nesters; omnivores and insectivores versus herbivores; and bark foragers, foliage gleaners, and aerial foragers versus ground foragers. Axis 2 of the RLQ analysis captured 22% of the association between traits and disturbances and described 20% of covariance between them. The second axis corresponded to a gradient of trait assemblage between traditionally logged and both non-salvaged and salvaged forests. Carnivores and aerial and ground nesters were associated with traditionally logged landscapes (i.e., fell on negative side of the axis 2), while herbivores and shrub nesters more associated with salvage-logged landscape (i.e., falling on negative side of axis 2).

Bark foragers that are mainly omnivores or insectivores and tree cavity nesters were the most frequent in burned and non-salvage habitat assemblages. Species associated with salvage-logged habitats were predominantly ground foragers that are herbivores and shrub nesters. The analysis also associated suggested body mass was positively correlated with salvage logging. Species using open habitats, ground nesters and carnivores, characterized harvested habitats.

## Birds' community metric response to forest disturbances

Bird taxonomic diversity (SD) differed substantially among disturbances (Table 2A). The validation of the model describing taxonomic diversity indicates no violation of assumptions (i.e., independence and absence of residual patterns, Fig. S1[1]), and the worm plots indicates an appropriate model fit (i.e., 95% of the worm plot lying within the dashed confidence bands). The taxonomic diversity in burned habitats was significantly lower compared to traditionally logged habitats (0.89 vs. 0.93), while it was significantly higher (0.89 vs. 0.77) in burned habitats compared to salvage-logged habitats (Fig. 3A; Table S3A[1]). The effect of disturbance on taxonomic diversity was largely masked by high variation among measurements (Fig. 3B; Table S3A[1]). The highest coefficient of variation ($\sigma$) was observed in salvage-logged habitats (2.84), while there were similar in burned and traditionally logged habitats (0.92 and 0.93, respectively).

Global functional diversity (FD, Univariate index), considering trait distance, did not statistically differ among disturbance types (Table 2B; Fig. 3C; Table S3B[1]). However, the coefficient of variation was significantly higher in salvage-logged habitats compared to the other disturbances (Table 2B; Fig. 3D). Analysis of individual traits showed that foraging strategy FD was significantly lower in salvage-logged habitats than in both burned or traditionally logged (0.51 vs. 0.53) habitats (Table 3A). Additionally, nesting guild FD in burned habitats was significantly higher than in salvage-logged habitats (0.31 vs. 0.24), while the latter was significantly higher than in traditionally logged ones (0.24 vs. 0.19). Functional diversity, considering phylogenetic distance, was significantly higher in burned habitats than in both harvested (0.01 vs. 0.00) and salvage-logged (0.01 vs. 0.00) habitats (Table 2C; Fig. 3E; Table S3C[1]) and the coefficient of variation followed the same pattern (Fig. 3F). Model validations suggested good fit (Figs. S2 and S3[1]).

Global functional redundancy (FR, Univariate index) in burned habitats was significantly lower than in traditionally logged habitats (0.37 vs. 0.33), while it was significantly higher in harvested habitats (0.40) than in burned ones (Table 2D; Fig. 3G; Table S3D[1]). The coefficient of variation exhibited converse pattern (Fig. 3H). The phylogenetic redundancy of the bird community followed the same pattern of the global functional redundancy (Table 2E; Figs. 3I and 3J; Table S3E[1]). Analysis of individual traits showed that functional redundancy in salvage-logged habitats was significantly lower than in burned habitats (e.g., foraging guild, habitat affinity, nest location, and body mass) and in traditionally logged habitats (clutch size; Table 3B). Only foraging strategy and nest guild FR did not exhibit significant differences among disturbances. Model validation suggested the data were well fit by the models (Figs. S4 and S5[1]).

The functional uniqueness analysis revealed that insectivores with higher uniqueness values (i.e., high functional distance from other species) in salvage-logged habitats were *Cardellina pusilla*, *Catharus ustulatus*, *Certhia americana*, *Empidonax flaviventris*, *Empidonax minimus*, *Empidonax traillii*, *Mniotilta varia*, *Poecile atricapillus*, *Troglodytes aedon*, and *Troglodytes hiemalis* (Table 4; Table A1). The taxonomic scarcity analysis shows that at least 12 insectivores (*Chaetura vauxi*, *Contopus cooperi*, *Ixoreus naevius*, *Pheucticus melanocephalus*, *Poecile gambeli*, *Setophaga townsendi*, *Sialia currucoides*, *Sialia mexicana*, *Sphyrapicus nuchalis*, *Sphyrapicus thyroideus*, *Sturnus vulgaris*, and *Vireo gilvus*) were abundant (SI $< 0.01$) in non-salvage habitats, while in salvage-logged habitats these species were scarce (SI $> 0.80$) or not represented. Two species (*Bucephala albeola* and *Setophaga fusca*) were scarce (SI $> 0.90$) in non-salvage habitats, but they were absent in salvage-logged habitats.

**Table 3.** Predicted values (mean ± SE) across post-disturbed habitats of individual traits analysis for $\mu$ component of (A) the (SIMPLEX, $\mu$ and $\sigma$) model for functional diversity and (B) the (BE, $\mu$ and $\sigma$) model for functional redundancy.

| | Fire ($n = 7$) | Traditional logging ($n = 4$) | Salvage logging ($n = 6$) |
|---|---|---|---|
| **(A) Functional diversity measured as Rao's quadratic entropy index (FD)** | | | |
| Foraging strategy | **0.61 ± 0.06$^{a}$** | **0.59 ± 0.06$^{a}$** | **0.54 ± 0.11$^{b}$** |
| Foraging guild | 0.48 ± 0.06$^{a}$ | 0.50 ± 0.06$^{a}$ | 0.48 ± 0.11$^{a}$ |
| Habitat affinity | 0.54 ± 0.06$^{a}$ | 0.55 ± 0.06$^{a}$ | 0.54 ± 0.11$^{a}$ |
| Nest Location | 0.56 ± 0.06$^{a}$ | 0.55 ± 0.06$^{a}$ | 0.56 ± 0.11$^{a}$ |
| Nest guild | **0.31 ± 0.06$^{a}$** | **0.19 ± 0.06$^{c}$** | **0.24 ± 0.11$^{b}$** |
| Body Mass | 0.06 ± 0.06$^{a}$ | 0.07 ± 0.06$^{a}$ | 0.09 ± 0.11$^{a}$ |
| Clutch size | 0.20 ± 0.06$^{a}$ | 0.20 ± 0.06$^{a}$ | 0.16 ± 0.11$^{a}$ |
| **(B) Functional redundancy index (FR)** | | | |
| Foraging strategy | 0.31 ± 0.09$^{a}$ | 0.36 ± 0.10$^{a}$ | 0.34 ± 0.07$^{a}$ |
| Foraging guild | **0.42 ± 0.12$^{a}$** | **0.44 ± 0.05$^{ab}$** | **0.36 ± 0.08$^{b}$** |
| Habitat affinity | **0.52 ± 0.12$^{a}$** | **0.50 ± 0.11$^{ab}$** | **0.40 ± 0.13$^{b}$** |
| Nest Location | **0.36 ± 0.08$^{a}$** | **0.38 ± 0.11$^{ab}$** | **0.30 ± 0.14$^{b}$** |
| Nest guild | 0.66 ± 0.16$^{a}$ | 0.75 ± 0.22$^{a}$ | 0.66 ± 0.10$^{a}$ |
| Body Mass | **0.84 ± 0.09$^{b}$** | **0.86 ± 0.10$^{a}$** | **0.74 ± 0.07$^{c}$** |
| Clutch size | **0.70 ± 0.05$^{ab}$** | **0.73 ± 0.04$^{a}$** | **0.65 ± 0.13$^{b}$** |

**Note:** Bolded values indicate traits where a significant difference was detected between disturbance types (see Results).

## Discussion

Consistent with our first hypothesis, our study revealed contrasting patterns of bird community composition among burned and non-salvage, post-fire salvage, and traditionally logged habitats. The RLQ results showed that species displaying specific ecological traits are differentially associated with natural and anthropogenic disturbances, with traditional logging exhibiting intermediate effects between fire and salvage logging on bird species differing in their nest location and habitat affinities. This contrast is mainly due to the differences in the remaining configuration of habitat (e.g., canopy cover, snag density) left by each disturbance (Thorn et al. 2016). Forest fire generates "keystone structures" (i.e., distinct spatial structures providing resources, shelter, or goods and services that are crucial for other species (Tews et al. 2004)) for cavity nester and insectivores. These structures are characterized by stand structural complexity, habitats connectivity, and landscape heterogeneity (Burton et al. 2006; Lindenmayer et al. 2006). However, salvage logging after fire reduces these keystone structures quantity and (or) quality (Lindenmayer et al. 2008), favoring ground and shrub nesters.

A meta-analysis comparing changes in boreal forest bird assembly after fire and harvesting reported that post-fire communities still differed from post-harvest ones 30 years after disturbance (Schieck and Song 2006). Convergence between communities started to be observed around 60 years after disturbance (Schieck and Hobson 2000). To our knowledge, no studies have yet examined convergence between fire and salvage-logged stands. The reduction of keystone structures in salvaged habitats and the attendant impacts on insectivores (i.e., loss of perches, potential nest sites, and resource upon which insects forage) could exacerbate the widespread declines that North American insectivores are experiencing (Kelly et al. 2013; Nebel et al. 2010; Sauer et al. 2017) if salvage logging becomes more widely used. While the long-term consequences of declining insectivore populations on forest ecosystem health are unclear, it may reduce the extent of natural pest control (e.g., some bark beetles or long horn beetles) (Dolbeer 2008; Naylor and Ehrlich 1997).

Our results also showed that salvage-logged habitats had the lowest taxonomic diversity, global functional diversity, and functional and phylogenetic redundancy among all the disturbances considered. This is consistent with our expectations that salvage logging would reduce avian taxonomic diversity, functional diversity, and functional and phylogenetic redundancy after fire. Thorn et al. (2016) found that bird taxonomic diversity was significantly lower in salvage-logged habitat than in non-salvage habitats. Our results also revealed a decrease in bird functional diversity after salvage logging. For instance, individual traits such as foraging strategy and nest guild had lower functional diversity in salvage-logged habitats than in burned and non-salvaged habitats. This is consistent with previous studies (Cahall and Hayes 2009; Hutto et al. 2015; Nappi and Drapeau 2011) that reported negative effect of salvage

**Table 4.** Summary of abundant or scarce species with high functional uniqueness.

| | Species scarcity index | | | Functional uniqueness index | | |
|---|---|---|---|---|---|---|
| Species | Harvest | Fire | Salvage logging | Harvest | Fire | Salvage logging |
| *Bucephala albeola* | 0.974 | 0.948 | NA | 0.017 | 0.017 | NA |
| *Cardellina pusilla* | 0.000 | 0.485 | 0.655 | 0.145 | 0.145 | 0.146 |
| *Catharus ustulatus* | 0.079 | 0.220 | 0.521 | 0.021 | 0.021 | 0.145 |
| *Certhia americana* | 0.760 | 0.281 | 0.572 | 0.146 | 0.144 | 0.146 |
| *Chaetura vauxi* | NA | 0.000 | NA | NA | 0.018 | NA |
| *Contopus cooperi* | 0.000 | 0.012 | NA | 0.005 | 0.005 | NA |
| *Empidonax flaviventris* | 0.818 | 0.535 | 0.764 | 0.146 | 0.146 | 0.146 |
| *Empidonax minimus* | 0.241 | 0.394 | 0.497 | 0.143 | 0.018 | 0.143 |
| *Empidonax traillii* | NA | 0.007 | 0.985 | NA | 0.002 | 0.145 |
| *Ixoreus naevius* | 0.195 | 0.000 | NA | 0.017 | 0.017 | NA |
| *Mniotilta varia* | 0.810 | 0.641 | 0.897 | 0.144 | 0.144 | 0.144 |
| *Pheucticus melanocephalus* | NA | 0.005 | NA | NA | 0.011 | NA |
| *Poecile atricapillus* | 0.374 | 0.279 | 0.812 | 0.144 | 0.001 | 0.144 |
| *Poecile gambeli* | NA | 0.000 | NA | NA | 0.001 | NA |
| *Setophaga fusca* | 0.889 | 0.974 | NA | 0.003 | 0.003 | NA |
| *Setophaga townsendi* | NA | 0.000 | NA | NA | 0.003 | NA |
| *Sialia currucoides* | 0.000 | 0.003 | 0.856 | 0.006 | 0.004 | 0.007 |
| *Sialia mexicana* | NA | 0.002 | NA | NA | 0.004 | NA |
| *Sphyrapicus nuchalis* | NA | 0.000 | NA | NA | 0.002 | NA |
| *Sphyrapicus thyroideus* | NA | 0.000 | NA | NA | 0.001 | NA |
| *Sturnus vulgaris* | NA | 0.000 | NA | NA | 0.010 | NA |
| *Troglodytes aedon* | 0.736 | 0.155 | 0.080 | 0.146 | 0.146 | 0.146 |
| *Troglodytes hiemalis* | 0.334 | 0.246 | 0.580 | 0.146 | 0.146 | 0.146 |
| *Vireo gilvus* | 0.494 | 0.000 | 0.985 | 0.145 | 0.145 | 0.030 |

**Note:** All species scarcity and functional uniqueness indices are reported in Table A1.

logging on cavity nesters and bark and aerial foragers due of the reduction of the keystone structures.

We observed that functional and phylogenetic redundancy of bird communities was lowest in salvage-logged habitats, suggesting that many species in these habitats are functionally and phylogenetically unique compared to both burned and harvested habitats. In fact, post-fire habitats have high structural complexity (i.e., spatial heterogeneity) that results in greater representation of species displaying ecological traits such as insectivory and cavity nesting (Hutto et al. 2015; Morissette et al. 2002; Nappi et al. 2010). In contrast, traditionally (green) harvested habitats displayed patterns of community composition that were intermediate between fire and salvage logging with respect to the ecological traits of the constituent species.

The under scarcity of insectivores and cavity nesters species (e.g., *Bucephala albeola*, *Certhia americana*, *Chaetura vauxi, Contopus cooperi*, *Empidonax flaviventris*, *Empidonax minimus*, *Ixoreus naevius*, *Pheucticus melanocephalus*, *Pica hudsonia*, *Poecile atricapillus*, *Poecile gambeli*, *Poecile rufescens*, *Setophaga fusca*, *Setophaga townsendi*, *Sialia mexicana*, *Sphyrapicus nuchalis*, *Sphyrapicus thyroideus*, *Sphyrapicus vulgaris*, *Troglodytes aedon*, and *Troglodytes hiemalis*) in salvage-logged habitats compared to post-fire ones, suggests a loss of some functional roles after salvage logging. Salvage logging disrupts the specific functional roles of some bird species and their associated partners post-fire (e.g., marked reduction of insect population control or marked reduction in seed dispersal). The disruption of these specific functional roles of some birds depends on both fire severity and salvage logging intensity, since salvage logging targets the least burned forests (Koivula and Spence 2006). The least burned habitats can function as refugia for species associated with unburned habitats. If most of the burned forests are salvage logged, it could have a negative impact on the conservation of some bird species.

Limiting or reducing logging intensity to keep a suitable residual structure of fire legacy connected to green forest might help to mitigate salvage logging impact. As some ecological traits are positively associated with increased fire severity, the retention of the most severely burned stands, which have reduced timber value, may preserve components of the bird community and help maintain ecological functions performed by birds on the landscape (Koivula and Schmiegelow 2007; Smucker et al. 2005). However, the most severely burned stands are also the least colonized by saproxylic insects, which are the food for woodpeckers (Saint-Germain et al. 2004, 2007). These stands could be useful for at least one idiosyncratic longhorned beetle (*Gnathacmeops pratensis*), but they would not provide diverse and abundant food for bark foragers. Some authors suggested keeping the periphery of burned stands to make sure ecotones are maintained (Boucher et al. 2016; Nappi and Drapeau 2011). Maintaining ecotones along the burn periphery could facilitate species colonizing burned stands from adjacent green forest as it would reduce dispersal distances for birds and insects, many of which use both habitats. Since any single disturbance will disadvantage species not possessing traits adapted to the ecological conditions created by that disturbance, the precautionary approach would be to vary the level of retention between salvage-logged stands (Bunnell and Houde 2010) and to maximize the connectivity between residual stands (Boucher et al. 2016; Nappi and Drapeau 2011).

Although we recommend limiting post-fire salvage logging to conserve the functional roles played by birds, data on how trait assemblage patterns vary with fire size and severity are lacking and needed. Fire severity and size are known to have a strong effect on bird communities as well as the insects on which they feed (Boucher et al. 2016; Luck et al. 2012; Stephens et al. 2015). Understanding the relationship between bird community dynamics and fire size and severity would lead to the identification of high conservation value forests for burn-associated birds and would improve retention strategies for salvage logging operations. In conclusion, we show that in North American forests, ecological trait composition of bird communities varies between post-disturbance habitats. Importantly, salvage logging significantly reduces bird taxonomic diversity, functional diversity, and both functional and phylogenetic redundancy after fire. Although we believe that we can broadly generalize our findings to other North American forests, studies are needed to test the generality of this finding in other regions in the world and to determine the variation around this estimate.

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## Appendix A

Appendix Table A1 appear on the following pages.

**Table A1.** List of avian species with their functional traits, taxonomic scarcity, and functional uniqueness values in non-salvage, salvage, and traditionally logged habitats.

| | | | | | | | | | | | | Species scarcity index | | | Functional uniqueness index | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Species code | Species ID | English name | French name | Foraging strategy[*] | Foraging guild[†] | Habitat affinity[‡] | Nest location[§] | Nest guild[¶] | Body mass (g) | Clutch size (mean) | Harvest | Fire | Salvage logging | Harvest | Fire | Salvage logging |
| *Accipiter cooperii* | ACCO | COHA | Cooper's hawk | Épervier de Cooper | A | C | F | T | NCN | 473 | 4.2 | 0.993502429 | 0.564829518 | NA | 0.150651615 | 0.160069043 | NA |
| *Accipiter striatus* | ACST | SSHA | Sharp-shinned hawk | Épervier brun | G | C | F | T | NCN | 183 | 4.3 | 0.800583824 | 0.201033415 | 0.722245394 | 0.022199383 | 0.15385626 | 0.148619241 |
| *Actitis macularius* | ACMA | SPSA | Spotted sandpiper | Chevalier grivelé | G | C | O | G | NCN | 48.1 | 4 | 0.993502429 | 0.477519836 | NA | 0.027871448 | 0.027871448 | NA |
| *Aegolius acadicus* | AEAC | NSWO | Northern saw-whet owl | Petite Nyctale | G | C | F | T | CN | 131.1 | 5.67 | 0.711144773 | NA | NA | 0.021885383 | NA | NA |
| *Aegolius funereus* | AEFU | BOOW | Boreal owl | Nyctale de Tengmalm | G | C | F | T | CN | 166.8 | 3.25 | NA | NA | 0.551665614 | NA | NA | 0.028028946 |
| *Agelaius phoeniceus* | AGPH | RWBL | Red-winged blackbird | Carouge à épaulettes | G | I | O | S | NCN | 43.8 | 4 | 0.737429659 | 0.231662785 | 0.313663119 | 0.012994194 | 0.012994194 | 0.014153321 |
| *Ammospiza caudacuta* | AMCAU | SALS | Saltmarsh sparrow | Bruant à queue aiguë | G | I | O | G | NCN | 19 | 6 | 0.987041506 | NA | 0.772256657 | 0.007611057 | NA | 0.007816712 |
| *Ammospiza leconteii* | AMLE | LCSP | LeConte's sparrow | Bruant de LeConte | G | I | O | G | NCN | 13.2 | 4.51 | 0.565007609 | 0.708312459 | 0.385021479 | 0.004435768 | 0.004435768 | 0.004894452 |
| *Anas americana* | ANAME | AMWI | American wigeon | Canard d'Amérique | G | H | O | G | NCN | 1330 | 10 | 0.980625407 | NA | NA | 0.007954059 | NA | NA |
| *Anas crecca* | ANCRE | GWTE | Green-winged teal | Sarcelle d'hiver | G | H | O | G | NCN | 500 | 10 | 0.993502429 | NA | NA | 0.004224147 | NA | NA |
| *Anas cyanoptera* | ANCY | CITE | Cinnamon teal | Sarcelle cannelle | G | H | O | G | NCN | 394 | 10 | 2.29E-06 | NA | NA | 0.004224147 | NA | NA |
| *Anas discors* | ANDIS | BWTE | Blue-winged teal | Sarcelle à ailes bleues | G | H | O | G | NCN | 545 | 14 | 0.961573353 | NA | NA | 0.016565469 | NA | NA |
| *Anas platyrhynchos* | ANPLA | MALL | Mallard | Canard colvert | G | H | O | G | NCN | 1114 | 8.72 | 0.924724927 | 0.923499164 | 0.920653644 | 0.007954059 | 0.013049658 | 0.013908758 |
| *Anas rubripes* | ANRUB | ABDU | American black duck | Canard noir | G | I | O | G | NCN | 1600 | 14 | NA | NA | 0.555178626 | NA | NA | 0.081936597 |
| *Archilochus colubris* | ARCO | RTHU | Ruby-throated hummingbird | Colibri à gorge rubis | F | H | O | T | NCN | 3.4 | 2 | 0.987041506 | 0.973820305 | NA | 0.000914611 | 0.000914611 | NA |
| *Asio otus* | ASOTU | LEOW | Long-eared owl | Hibou moyen-duc | G | C | F | T | CN | 430 | 10 | 0.993502429 | NA | NA | 0.015452182 | NA | NA |
| *Aythya americana* | AYAME | REDH | Redhead | Fuligule à tête rouge | G | H | O | G | NCN | 1500 | 8 | 0.987041506 | NA | NA | 0.007981392 | NA | NA |
| *Aythya collaris* | AYCOLL | RNDU | Ring-necked duck | Fuligule à collier | G | H | O | G | NCN | 900 | 4 | 0.942509787 | 0.923499164 | NA | 0.021526346 | 0.021526346 | NA |
| *Bombycilla cedrorum* | BOCE | CEDW | Cedar waxwing | Jaseur d'Amérique | F | H | O | T | NCN | 32.7 | 4.5 | 0.239173332 | 0.340662615 | 0.346750945 | 0.008721584 | 0.008721584 | 0.020075283 |
| *Bonasa umbellus* | BOUM | RUGR | Ruffed grouse | Gélinotte huppée | F | O | F | G | NCN | 500.1 | 10.5 | 0.249411643 | 0.341480145 | 0.677454341 | 0.166460501 | 0.166460501 | 0.166765723 |
| *Botaurus lentiginosus* | BOLEN | AMBI | American bittern | Butor d'Amérique | G | C | O | G | NCN | 500 | 5 | 0.974251015 | 0.923499164 | NA | 0.002710712 | 0.018796992 | NA |
| *Branta canadensis* | BRCAN | CANG | Canada goose | Bernache du Canada | G | H | O | G | NCN | 9000 | 8 | 0.582116222 | 0.368865584 | 0.245543193 | 0.031766743 | 0.039748134 | 0.043611168 |
| *Bubo virginianus* | BUVI | GHOW | Great horned owl | Grand-duc d'Amérique | G | C | O | T | NCN | 1706 | 2 | 0.711144773 | NA | NA | 0.005668893 | NA | NA |
| *Bucephala albeola* | BUALB | BUFF | Bufflehead | Petit Garrot | G | I | O | T | CN | 600 | 15 | 0.974251015 | 0.94832605 | NA | 0.017467558 | 0.017467558 | NA |
| *Bucephala clangula* | BUCLA | COGO | Common goldeneye | Garrot à oeil d'or | G | I | O | T | CN | 1300 | 16 | 0.919244748 | 0.857014866 | 0.678657781 | 0.017467558 | 0.017467558 | 0.084280811 |
| *Buteo jamaicensis* | BUJA | RTHA | Red-tailed hawk | Buse à queue rousse | G | C | O | T | NCN | 1224 | 2.5 | 0.61495463 | 0.464400877 | 0.764247209 | 0.007766329 | 0.009675824 | 0.01048888 |
| *Buteo platypterus* | BUPL | BWHA | Broad-winged hawk | Petite Buse | G | C | F | T | NCN | 437 | 2.5 | 0.993502429 | NA | NA | 0.022199383 | NA | NA |
| *Cardellina canadensis* | CACA | CAWA | Canada warbler | Paruline du Canada | F | I | F | G | NCN | 10.2 | 4.5 | 0.801128678 | 0.530802563 | 0.905552385 | 0.00220533 | 0.00220533 | 0.002396117 |
| *Cardellina pusilla* | CAPU | WIWA | Wilson's warbler | Paruline à calotte noire | F | I | O | G | NCN | 7.72 | 5 | 5.89E-11 | 0.48527596 | 0.655366619 | 0.145378912 | 0.145378912 | 0.145641906 |
| *Catharus fuscescens* | CAFU | VEER | Veery | Grive fauve | G | I | F | G | NCN | 32.4 | 4 | 0.993502429 | NA | NA | 0.002682069 | NA | NA |
| *Catharus guttatus* | CAGU | HETH | Hermit thrush | Grive solitaire | G | I | O | G | NCN | 30.1 | 4 | 0.254597362 | 0.119422079 | 0.350758362 | 0.009017385 | 0.005141677 | 0.005450502 |
| *Catharus ustulatus* | CAUS | SWTH | Swainson's thrush | Grive à dos olive | F | I | F | S | NCN | 29.6 | 3.5 | 0.078597311 | 0.220446303 | 0.520630584 | 0.020875177 | 0.020875177 | 0.144868683 |
| *Certhia americana* | CEAM | BRCR | Brown creeper | Grimpereau brun | B | I | F | T | NCN | 8.4 | 5.5 | 0.760245448 | 0.281126585 | 0.572437739 | 0.145948316 | 0.144026203 | 0.146270694 |
| *Chaetura vauxi* | CHVA | VASW | Vaux's swift | Martinet de Vaux | A | I | F | T | NCN | 18.8 | 6 | NA | 1.87E-07 | NA | NA | 0.018186781 | NA |
| *Charadrius vociferus* | CHVO | KILL | Killdeer | Pluvier kildir | G | I | O | G | NCN | 101.5 | 4 | 0.847511413 | 0.899322238 | 0.771341483 | 0.00126391 | 0.00126391 | 0.001395722 |
| *Chlidonias niger* | CHNIG | BLTE | Black tern | Guifette noire | G | I | O | G | NCN | 60 | 3 | 0.924724927 | 0.766987656 | 0.96208944 | 0.005582994 | 0.005582994 | 0.005773176 |
| *Chordeiles minor* | CHMI | CONI | Common nighthawk | Engoulevent d'Amérique | G | I | O | G | NCN | 66.5 | 2 | 0.980625407 | 0.521225866 | 0.690815564 | 0.005582994 | 0.005582994 | 0.005773176 |
| *Cinclus mexicanus* | CIME | AMDI | American dipper | Cincle d'Amérique | G | I | O | G | NCN | 53.6 | 4.1 | NA | 0.289590038 | NA | NA | 0.00613513 | NA |
| *Circus cyaneus* | CICY | NOHA | Northern harrier | Busard des marais | G | C | O | G | NCN | 513 | 4.4 | 1.57E-15 | NA | NA | 0.002710712 | NA | NA |
| *Coccothraustes vespertinus* | COVE | EVGR | Evening grosbeak | Gros-bec errant | G | H | F | T | NCN | 62.6 | 3 | 0.553622659 | 0.449661119 | 0.856765146 | 0.144219515 | 0.018214726 | 0.144361596 |
| *Colaptes auratus* | COAU | NOFL | Northern flicker | Pic flamboyant | G | I | O | T | CN | 131.83 | 5.5 | 0.283081587 | 0.343241845 | 0.491926191 | 0.062581644 | 0.010479414 | 0.032741534 |
| *Contopus cooperi* | COCO | OSFL | Olive-sided flycatcher | Moucherolle à côtés olive | A | I | O | T | NCN | 31.9 | 3 | 1.57E-15 | 0.011756225 | NA | 0.004707041 | 0.004707041 | NA |
| *Contopus sordidulus* | COSO | WEWP | Western wood-pewee | Pioui de l'Ouest | A | I | O | T | NCN | 12.2 | 3 | 0.450457099 | 0.230440815 | 0.302386116 | 0.006933808 | 0.006933808 | 0.007264867 |

**Table A1** (*continued*).

| | | | | | | | | | | | | Species scarcity index | | | Functional uniqueness index | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Species code | Species ID | English name | French name | Foraging strategy[*] | Foraging guild[†] | Habitat affinity[‡] | Nest location[§] | Nest guild[¶] | Body mass (g) | Clutch size (mean) | Harvest | Fire | Salvage logging | Harvest | Fire | Salvage logging |
| *Corvus brachyrhynchos* | COBR | AMCR | American crow | Corneille d'Amérique | G | O | O | T | NCN | 474 | 5 | 0.945635233 | 0.718840017 | 0.759148852 | 0.153528739 | 0.029325966 | 0.032188329 |
| *Corvus corax* | CORCOR | CORA | Common raven | Grand Corbeau | G | O | O | G | NCN | 1055 | 4.5 | 0.317146291 | 0.309342996 | 0.437292864 | 0.00915256 | 0.00915256 | 0.009911044 |
| *Cyanocitta cristata* | CYCR | BLJA | Blue jay | Geai bleu | G | O | F | T | NCN | 70.53 | 4.5 | 0.792065933 | 0.746908153 | 0.793035604 | 0.006391357 | 0.006391357 | 0.00646981 |
| *Cyanocitta stelleri* | CYST | STJA | Steller's jay | Geai de Steller | G | O | F | T | NCN | 128 | 3.06 | NA | 2.45E-09 | NA | NA | 0.01154438 | NA |
| *Dendragapus obscurus* | DEOB | DUGR | Dusky grouse | Tétras sombre | G | H | F | G | NCN | 839 | 7.1 | NA | 0.002036658 | NA | NA | 0.073872526 | NA |
| *Dryocopus pileatus* | DRPI | PIWO | Pileated woodpecker | Grand Pic | B | I | F | T | CN | 270 | 3.5 | 0.544874948 | 0.326838588 | 0.82290299 | 0.024447263 | 0.024447263 | 0.02699686 |
| *Empidonax alnorum* | EMAL | ALFL | Alder flycatcher | Moucherolle des aulnes | A | I | O | T | NCN | 10.2 | 4 | 0.156880258 | 0.255837043 | 0.273895971 | 0.006933808 | 0.006933808 | 0.007264867 |
| *Empidonax flaviventris* | EMFL | YBFL | Yellow-bellied flycatcher | Moucherolle à ventre jaune | A | I | F | T | CN | 10.83 | 3.5 | 0.818266088 | 0.535444358 | 0.764247209 | 0.145626433 | 0.145626433 | 0.145719208 |
| *Empidonax hammondii* | EMHA | HAFL | Hammond's flycatcher | Moucherolle de Hammond | A | I | F | G | NCN | 10.3 | 4 | 6.10E-11 | 7.76E-13 | NA | 0.142857143 | 0.142857143 | NA |
| *Empidonax minimus* | EMMI | LEFL | Least flycatcher | Moucherolle tchébec | A | I | F | T | NCN | 10.3 | 4 | 0.241409306 | 0.394120138 | 0.496795028 | 0.142857143 | 0.018186781 | 0.143048153 |
| *Empidonax oberholseri* | EMOB | DUFL | Dusky flycatcher | Moucherolle sombre | A | I | O | S | NCN | 11.06 | 3.6 | 1.57E-15 | 2.76E-40 | NA | 0.145796045 | 0.002184749 | NA |
| *Empidonax traillii* | EMTR | WIFL | Willow flycatcher | Moucherolle des saules | A | I | O | S | NCN | 12.3 | 3.68 | NA | 0.0070329 | 0.984542143 | NA | 0.002184749 | 0.144543591 |
| *Euphagus carolinus* | EUCA | RUBL | Rusty blackbird | Quiscale rouilleux | G | I | F | T | NCN | 64 | 4.5 | 0.493520753 | 0.73663459 | 0.660972711 | 0.017343268 | 0.017343268 | 0.058827564 |
| *Euphagus cyanocephalus* | EUCY | BRBL | Brewer's blackbird | Quiscale de Brewer | G | H | O | S | NCN | 58.1 | 4.98 | NA | 0.045129344 | NA | NA | 0.017076723 | NA |
| *Falcipennis canadensis* | FACA | SPGR | Spruce grouse | Tétras du Canada | F | H | F | G | NCN | 424 | 5 | 1.37E-06 | 0.941970664 | 0.551665614 | 0.166460501 | 0.162851762 | 0.166765723 |
| *Falco columbarius* | FACO | MERL | Merlin | Faucon émerillon | A | C | O | T | NCN | 243.6 | 4.2 | 0.496751215 | NA | NA | 0.154621774 | NA | NA |
| *Falco sparverius* | FASP | AMKE | American kestrel | Crécerelle d'Amérique | G | C | O | T | CN | 120 | 4 | 0.322640091 | 0.36476278 | 0.939587579 | 0.150163181 | 0.068795827 | 0.073030025 |
| *Fulica americana* | FUAME | AMCO | American coot | Foulque d'Amérique | G | H | O | G | NCN | 700 | 10 | 0.993502429 | 0.923499164 | 0.96208944 | 0.005965436 | 0.013049658 | 0.013908758 |
| *Gallinago delicata* | GADE | WISN | Wilson's snipe | Bécassine de Wilson | G | I | O | G | NCN | 109 | 4 | 0.28000026 | 0.370470691 | 0.525490052 | 0.00126391 | 0.00126391 | 0.001395722 |
| *Gavia immer* | GAIM | COLO | Common loon | Plongeon huard | G | C | O | G | NCN | 4657 | 2 | 0.69859306 | 0.695006304 | 0.617523655 | 0.041497865 | 0.041497865 | 0.043473266 |
| *Geothlypis philadelphia* | GEPH | MOWA | Mourning warbler | Paruline triste | F | I | F | G | NCN | 12.27 | 3.5 | 0.271899799 | 0.23778634 | 0.35018121 | 0.007035244 | 0.007035244 | 0.00737688 |
| *Geothlypis tolmiei* | GETO | MGWA | Macgillivray's warbler | Paruline des buissons | F | I | F | S | NCN | 10.4 | 4.12 | 5.50E-11 | 1.14E-38 | NA | 0.020875177 | 0.020875177 | NA |
| *Geothlypis trichas* | GETR | COYE | Common yellowthroat | Paruline masquée | F | I | O | S | NCN | 9.9 | 4 | 0.372669828 | 0.319693316 | 0.440753091 | 0.002425261 | 0.002425261 | 0.002482157 |
| *Grus canadensis* | GRCA | SACR | Sandhill crane | Grue du Canada | G | O | O | G | NCN | 3460 | 2 | 0.891476194 | 0.620958233 | 0.873687614 | 0.030456146 | 0.01877445 | 0.020732431 |
| *Haemorhous cassinii* | HACA | CAFI | Cassin's finch | Roselin de Cassin | G | H | F | T | NCN | 27.7 | 4 | NA | 4.40E-62 | NA | NA | 0.018214726 | NA |
| *Haemorhous purpureus* | HAPU | PUFI | Purple finch | Roselin pourpré | F | H | F | T | NCN | 24.6 | 3.5 | 0.477687649 | 0.852850706 | 0.856765146 | 0.002094603 | 0.002094603 | 0.002117015 |
| *Haliaeetus leucocephalus* | HALEU | BAEA | Bald eagle | Pygargue à tête blanche | G | C | F | T | NCN | 6300 | 3 | 0.803434358 | NA | NA | 0.049188213 | NA | NA |
| *Hirundo rustica* | HIRUS | BARS | Barn swallow | Hirondelle rustique | A | I | O | T | CN | 20 | 4 | 0.967917979 | NA | NA | 0.006588341 | NA | NA |
| *Icterus galbula* | ICGAL | BAOR | Baltimore oriole | Oriole de Baltimore | F | I | O | T | NCN | 40 | 6 | NA | NA | 0.984542143 | NA | NA | 0.029980266 |
| *Ixoreus naevius* | IXNA | VATH | Varied thrush | Grive à collier | G | I | F | T | NCN | 31.7 | 3.2 | 0.19471461 | 7.76E-13 | NA | 0.017343268 | 0.017343268 | NA |
| *Junco hyemalis* | JUHY | DEJU | Dark-eyed junco | Junco ardoisé | G | H | F | G | NCN | 20.25 | 4 | 0.098904379 | 0.136148267 | 0.208303315 | 0.003806724 | 0.003806724 | 0.004203726 |
| *Larus argentatus* | LAARG | HERG | Herring gull | Goéland argenté | G | O | O | G | NCN | 1200 | 2 | NA | 0.544727947 | 0.558691639 | NA | 0.011681697 | 0.011919811 |
| *Larus delawarensis* | LADEL | RBGU | Ring-billed gull | Goéland à bec cerclé | G | O | O | G | NCN | 700 | 4 | 0.707764624 | 0.973820305 | 0.96208944 | 0.00915256 | 0.00915256 | 0.009911044 |
| *Leucophaeus pipixcan* | LEPIP | FRGU | Franklin's gull | Mouette de Franklin | G | O | O | G | NCN | 300 | 4 | 0.900914199 | 0.923499164 | NA | 0.015022046 | 0.015022046 | NA |
| *Loxia curvirostra* | LOCU | RECR | Red crossbill | Bec-croisé des sapins | F | H | F | T | NCN | 26.54 | 3 | 0.490328498 | 5.79E-71 | 0.856765146 | 0.003225474 | 0.003225474 | 0.003365825 |
| *Loxia leucoptera* | LOLE | WWCR | White-winged crossbill | Bec-croisé bifascié | F | H | F | T | NCN | 24.9 | 4 | 0.207484117 | 0.552833552 | 0.368681133 | 0.002094603 | 0.002094603 | 0.002117015 |
| *Megaceryle alcyon* | MEAL | BEKI | Belted kingfisher | Martin-pêcheur d'Amérique | G | C | O | G | NCN | 151.6 | 6 | 0.929644277 | 0.602712764 | 0.555178626 | 0.02491695 | 0.02491695 | 0.03840166 |
| *Melospiza georgiana* | MEGE | SWSP | Swamp sparrow | Bruant des marais | G | I | O | G | NCN | 17 | 4.5 | 0.520948801 | 0.587241513 | 0.438604993 | 0.002991305 | 0.002991305 | 0.003107234 |
| *Melospiza lincolnii* | MELI | LISP | Lincoln's sparrow | Bruant de Lincoln | G | I | O | G | NCN | 18.1 | 4 | 0.194713551 | 0.311767984 | 0.294224354 | 0.002991305 | 0.00176975 | 0.003107234 |
| *Melospiza melodia* | MEME | SOSP | Song sparrow | Bruant chanteur | G | I | O | S | NCN | 23.4 | 4.5 | 0.429013888 | 0.213986345 | 0.31344408 | 0.012994194 | 0.012994194 | 0.013987548 |
| *Mergus merganser* | MEMER | COME | Common merganser | Grand Harle | G | C | O | T | CN | 1185 | 11.5 | NA | 0.467977064 | 0.555178626 | NA | 0.068795827 | 0.073030025 |

**Table A1** (*continued*).

| | | | | | | | | | | | | Species scarcity index | | | Functional uniqueness index | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Species code | Species ID | English name | French name | Foraging strategy[*] | Foraging guild[†] | Habitat affinity[‡] | Nest location[§] | Nest guild[¶] | Body mass (g) | Clutch size (mean) | Harvest | Fire | Salvage logging | Harvest | Fire | Salvage logging |
| *Mniotilta varia* | MNVA | BAWW | Black-and-white warbler | Paruline noir et blanc | B | I | F | G | NCN | 10.7 | 4.5 | 0.809592312 | 0.641362324 | 0.896685657 | 0.143705599 | 0.143705599 | 0.143794085 |
| *Molothrus ater* | MOAT | BHCO | Brown-headed cowbird | Vacher à tête brune | G | H | O | T | NCN | 32 | 40 | 0.88409647 | 0.237890675 | 0.653687114 | 0.268321737 | 0.165067824 | 0.270428539 |
| *Myadestes townsendi* | MYTO | TOSO | Townsend's solitaire | Solitaire de Townsend | A | I | O | G | NCN | 32.6 | 4 | NA | 1.15E-52 | NA | NA | 0.007274189 | NA |
| *Myiarchus crinitus* | MYCRI | GCFL | Great crested flycatcher | Tyran huppé | A | I | O | T | CN | 40 | 8 | 0.980625407 | NA | NA | 0.014624114 | NA | NA |
| *Nucifraga columbiana* | NUCO | CLNU | Clark's nutcracker | Cassenoix d'Amérique | F | O | F | T | NCN | 129 | 3.06 | NA | 5.62E-43 | NA | NA | 0.142995115 | NA |
| *Oporornis agilis* | OPAG | CONW | Connecticut warbler | Paruline à gorge grise | G | I | F | G | NCN | 15.32 | 4.5 | 0.591824771 | 0.261769344 | 0.711619078 | 0.002760141 | 0.002760141 | 0.006816262 |
| *Oreothlypis celata* | ORCE | OCWA | Orange-crowned warbler | Paruline verdâtre | F | I | F | G | NCN | 9.2 | 4.6 | 0.338090391 | 0.486910154 | 0.939587579 | 0.00157163 | 0.00157163 | 0.001696329 |
| *Oreothlypis peregrina* | ORPE | TEWA | Tennessee warbler | Paruline obscure | F | I | F | G | NCN | 8.9 | 5 | 0.001974553 | 0.200673681 | 0.409113905 | 0.002091527 | 0.002091527 | 0.002152825 |
| *Oreothlypis ruficapilla* | ORRU | NAWA | Nashville warbler | Paruline à joues grises | F | I | F | G | NCN | 8.6 | 4.5 | 0.484859891 | 0.52707538 | 0.605525218 | 0.00157163 | 0.00157163 | 0.001696329 |
| *Pandion haliaetus* | PAHA | OSPR | Osprey | Balbuzard pêcheur | G | C | O | T | NCN | 1900 | 3 | 0.562297904 | 0.353427385 | 0.612429865 | 0.005668893 | 0.009675824 | 0.01048888 |
| *Parkesia noveboracensis* | PANO | NOWA | Northern waterthrush | Paruline des ruisseaux | G | I | F | G | NCN | 16.1 | 4 | 8.79E-09 | 6.46E-07 | NA | 0.002760141 | 0.002760141 | NA |
| *Passerculus sandwichensis* | PASA | SAVS | Savannah sparrow | Bruant des prés | G | I | O | G | NCN | 20 | 4 | NA | 3.37E-60 | NA | NA | 0.00176975 | NA |
| *Passerella iliaca* | PAIL | FOSP | Fox sparrow | Bruant fauve | G | I | F | G | NCN | 33.9 | 3.5 | 0.496751215 | NA | NA | 0.002682069 | NA | NA |
| *Passerina amoena* | PAAM | LAZB | Lazuli bunting | Passerin azuré | G | I | O | S | NCN | 14.9 | 3.13 | 0.993502429 | 0.002036658 | 0.965706335 | 0.013152961 | 0.013152961 | 0.013987548 |
| *Perisoreus canadensis* | PECA | CAJA | Canada jay | Mésangeai du Canada | G | O | F | T | NCN | 67.6 | 3 | 0.248892809 | 0.179656596 | 0.372406245 | 0.006391357 | 0.006391357 | 0.00646981 |
| *Petrochelidon pyrrhonota* | PEPY | CLSW | Cliff swallow | Hirondelle à front blanc | A | I | O | G | NCN | 24.15 | 3.48 | NA | 4.15E-06 | NA | NA | 0.007274189 | NA |
| *Pheucticus ludovicianus* | PHLU | RBGR | Rose-breasted grosbeak | Cardinal à poitrine rose | G | O | F | T | NCN | 45.1 | 3.5 | 0.355625885 | 0.775474041 | 0.781135041 | 0.009055226 | 0.009055226 | 0.00980356 |
| *Pheucticus melanocephalus* | PHME | BHGR | Black-headed grosbeak | Cardinal à tête noire | F | I | F | T | NCN | 48.2 | 3.4 | NA | 0.004932909 | NA | NA | 0.010780811 | NA |
| *Pica hudsonia* | PIHU | BBMA | Black-billed magpie | Pie d'Amérique | G | I | O | T | NCN | 25 | 4 | NA | 0.289590038 | NA | NA | 0.011712438 | NA |
| *Picoides arcticus* | PIAR | BBWO | Black-backed woodpecker | Pic à dos noir | B | I | F | T | CN | 68 | 3.5 | 0.450457099 | 0.226695515 | 0.483349531 | 0.000540022 | 0.000540022 | 0.000596341 |
| *Picoides dorsalis* | PIDO | ATTW | American three-toed woodpecker | Pic à dos rayé | B | I | F | T | CN | 52 | 3.87 | 0.45340438 | 0.4156907 | 0.632107807 | 0.002957721 | 0.002957721 | 0.003019179 |
| *Picoides pubescens* | PIPU | DOWO | Downy woodpecker | Pic mineur | B | I | F | T | CN | 27.64 | 4.5 | 0.955375298 | 0.496480575 | 0.925063568 | 0.010615294 | 0.010088252 | 0.01172236 |
| *Picoides villosus* | PIVI | HAWO | Hairy woodpecker | Pic chevelu | B | I | F | T | CN | 65.96 | 3.5 | 0.431391912 | 0.353333266 | 0.592421117 | 0.000540022 | 0.000540022 | 0.000596341 |
| *Pinicola enucleator* | PIEN | PIGR | Pine grosbeak | Durbec des sapins | F | H | O | T | NCN | 48.1 | 4 | 0.496751215 | 0.0070329 | NA | 0.008721584 | 0.008721584 | NA |
| *Pipilo chlorurus* | PICH | GTTO | Green-tailed towhee | Tohi à queue verte | G | H | O | S | NCN | 29.4 | 3.65 | NA | 1.20E-06 | NA | NA | 0.016765069 | NA |
| *Pipilo erythrophthalmus* | PIER | EATO | Eastern towhee | Tohi à flancs roux | G | O | O | G | NCN | 39.3 | 4 | NA | 0.045129344 | NA | NA | 0.036035945 | NA |
| *Piranga ludoviciana* | PILU | WETA | Western tanager | Piranga à tête rouge | F | I | F | T | NCN | 29.8 | 4 | 0.360188598 | 0.484176739 | 0.830474 | 0.009038612 | 0.009038612 | 0.009785213 |
| *Podiceps grisegena* | POGRI | RNGR | Red-necked grebe | Grèbe jougris | G | C | O | G | NCN | 1600 | 8 | 0.961626189 | 0.973820305 | 0.955079116 | 0.028140712 | 0.028140712 | 0.030291366 |
| *Podilymbus podiceps* | POPOD | PBGR | Pied-billed grebe | Grèbe à bec bigarré | G | C | O | G | NCN | 500 | 10 | 0.974251015 | 0.899322238 | 0.92561609 | 0.018796992 | 0.018796992 | 0.030291366 |
| *Poecile atricapillus* | POAT | BCCH | Black-capped chickadee | Mésange à tête noire | F | I | F | T | CN | 11 | 6.5 | 0.374372156 | 0.278846693 | 0.812237326 | 0.144195843 | 0.000809309 | 0.144335456 |
| *Poecile gambeli* | POGA | MOCH | Mountain chickadee | Mésange de Gambel | F | I | F | T | CN | 10.78 | 6.38 | NA | 7.35E-45 | NA | NA | 0.000809309 | NA |
| *Poecile hudsonicus* | POHU | BOCH | Boreal chickadee | Mésange à tête brune | F | I | F | T | NCN | 9.8 | 6 | 0.767329029 | 0.529179582 | 0.702538481 | 0.002588968 | 0.002588968 | 0.002662938 |
| *Poecile rufescens* | PORU | CBCH | Chestnut-backed chickadee | Mésange à dos marron | F | I | F | T | CN | 9.1 | 6.2 | NA | 0.15583873 | NA | NA | 0.003680367 | NA |
| *Pooecetes gramineus* | POGR | VESP | Vesper sparrow | Bruant vespéral | G | I | O | G | NCN | 22.95 | 3.6 | NA | 6.46E-07 | 0.031085015 | NA | 0.003943065 | 0.005723948 |
| *Porzana carolina* | POCAR | SORA | Sora | Marouette de Caroline | G | H | O | G | NCN | 100 | 12 | 0.918713907 | 0.821131444 | 0.668382318 | 0.031828949 | 0.042018532 | 0.045616499 |
| *Quiscalus quiscula* | QUQU | COGR | Common grackle | Quiscale bronzé | G | O | O | T | NCN | 100.8 | 4.5 | NA | 0.544727947 | 0.631626521 | NA | 0.029325966 | 0.032188329 |
| *Regulus calendula* | RECA | RCKI | Ruby-crowned kinglet | Roitelet à couronne rubis | F | I | F | T | NCN | 6.4 | 8.5 | 0.046187079 | 0.194237363 | 0.421869939 | 0.000851173 | 0.000851173 | 0.000939941 |
| *Regulus satrapa* | RESA | GCKI | Golden-crowned kinglet | Roitelet à couronne dorée | F | I | F | T | NCN | 6.1 | 8.5 | 0.43598151 | 0.43063547 | 0.882824818 | 0.000851173 | 0.000851173 | 0.000939941 |
| *Salpinctes obsoletus* | SAOB | ROWR | Rock wren | Troglodyte des rochers | G | I | O | G | NCN | 18 | 5.6 | NA | 0.045129344 | NA | NA | 0.00514872 | NA |
| *Sayornis phoebe* | SAPHO | EAPH | Eastern phoebe | Moucherolle phébi | A | I | O | T | CN | 20 | 6 | 0.961626189 | NA | 0.939587579 | 0.002828943 | NA | 0.002927939 |
| *Seiurus aurocapilla* | SEAU | OVEN | Ovenbird | Paruline couronnée | G | I | F | G | NCN | 21.7 | 4.5 | 0.076031225 | 0.218473966 | 0.508046685 | 0.00617253 | 0.00617253 | 0.006816262 |
| *Selasphorus calliope* | SECAL | CAHU | Calliope hummingbird | Colibri calliope | F | H | O | T | NCN | 2.85 | 2 | 1.57E-15 | 0.000589796 | NA | 0.003128459 | 0.003128459 | NA |
| *Selasphorus rufus* | SERU | RUHU | Rufous hummingbird | Colibri roux | F | H | O | T | NCN | 3.58 | 2 | 1.57E-15 | 6.51E-14 | NA | 0.000914611 | 0.000914611 | NA |

**Table A1** (*continued*).

| | | | | | | | | | | | | Species scarcity index | | | Functional uniqueness index | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Species code | Species ID | English name | French name | Foraging strategy* | Foraging guild† | Habitat affinity‡ | Nest location§ | Nest guild¶ | Body mass (g) | Clutch size (mean) | Harvest | Fire | Salvage logging | Harvest | Fire | Salvage logging |
| *Setophaga castanea* | SECAS | BBWA | Bay-breasted warbler | Paruline à poitrine baie | F | I | F | T | NCN | 11.1 | 5.5 | 0.792993341 | 0.512496507 | 0.954339624 | 0.004088116 | 0.004088116 | 0.004318431 |
| *Setophaga coronata* | SECO | YRWA | Yellow-rumped warbler | Paruline à croupion jaune | F | I | F | T | NCN | 12.2 | 3.5 | 0.011152337 | 0.113042363 | 0.386872395 | 0.001879699 | 0.001879699 | 0.001879699 |
| *Setophaga fusca* | SEFU | BLBW | Blackburnian warbler | Paruline à gorge orangée | F | I | F | T | NCN | 10.3 | 4 | 0.889239707 | 0.973820305 | NA | 0.002993085 | 0.002993085 | NA |
| *Setophaga magnolia* | SEMA | MAWA | Magnolia warbler | Paruline à tête cendrée | F | I | F | T | NCN | 8.4 | 4 | 0.325828437 | 0.282332985 | 0.737916135 | 0.000622147 | 0.000622147 | 0.00068703 |
| *Setophaga palmarum* | SEPA | PAWA | Palm warbler | Paruline à couronne rousse | G | I | O | G | NCN | 10.3 | 4.5 | 0.830079778 | 0.814083341 | 0.922457129 | 0.004435768 | 0.004435768 | 0.004894452 |
| *Setophaga pensylvanica* | SEPE | CSWA | Chestnut-sided warbler | Paruline à flancs marron | F | I | O | S | NCN | 12 | 4 | 0.686098104 | 0.354156842 | 0.734046515 | 0.00341063 | 0.00341063 | 0.003766323 |
| *Setophaga petechia* | SEPET | YEWA | Yellow warbler | Paruline jaune | F | I | O | S | NCN | 9.6 | 4.5 | 0.809592312 | 0.284256156 | 0.65822571 | 0.002425261 | 0.002425261 | 0.002482157 |
| *Setophaga ruticilla* | SERUT | AMRE | American redstart | Paruline flamboyante | F | I | F | T | NCN | 8.7 | 4 | 0.492468396 | 0.455843844 | 0.905552385 | 0.000622147 | 0.000622147 | 0.00068703 |
| *Setophaga tigrina* | SETI | CMWA | Cape may warbler | Paruline tigrée | F | I | F | T | NCN | 10.2 | 6.5 | 0.850015297 | 0.945148357 | 0.958214532 | 0.002588968 | 0.002588968 | 0.002662938 |
| *Setophaga townsendi* | SETO | TOWA | Townsend's warbler | Paruline de Townsend | F | I | F | T | NCN | 8.6 | 5.7 | NA | 7.08E-10 | NA | NA | 0.003443631 | NA |
| *Setophaga virens* | SEVI | BTNW | Black-throated green warbler | Paruline à gorge noire | F | I | F | T | NCN | 9 | 3.5 | 0.735676047 | 0.923499164 | 0.92561609 | 0.002480752 | 0.002480752 | 0.002543436 |
| *Sialia currucoides* | SICU | MOBL | Mountain bluebird | Merlebleu azuré | A | I | O | T | CN | 29.6 | 5.53 | 1.57E-15 | 0.003340567 | 0.855742604 | 0.006114193 | 0.004390542 | 0.006740078 |
| *Sialia mexicana* | SIME | WEBL | Western bluebird | Merlebleu de l'Ouest | A | I | O | T | CN | 27.09 | 4.78 | NA | 0.002036658 | NA | NA | 0.004390542 | NA |
| *Sialia sialis* | SISI | EABL | Eastern bluebird | Merlebleu de l'Est | G | I | O | T | CN | 30 | 4.5 | NA | 0.489353985 | 0.534315694 | NA | 0.019525032 | 0.032741534 |
| *Sitta canadensis* | SICA | RBNU | Red-breasted nuthatch | Sittelle à poitrine rousse | B | I | F | T | CN | 10 | 5.5 | 0.273708198 | 0.196730989 | 0.583695136 | 0.020005214 | 0.021784461 | 0.02366429 |
| *Sitta carolinensis* | SICAR | WBNU | White-breasted nuthatch | Sittelle à poitrine blanche | B | I | F | T | CN | 21.1 | 7.3 | 0.974251015 | NA | NA | 0.015313082 | NA | NA |
| *Sphyrapicus nuchalis* | SPNU | RNSA | Red-naped sapsucker | Pic à nuque rouge | B | I | F | T | CN | 49.2 | 4.8 | NA | 2.07E-17 | NA | NA | 0.001519841 | NA |
| *Sphyrapicus ruber* | SPRU | RBSA | Red-breasted sapsucker | Pic à poitrine rouge | B | I | F | T | CN | 57.7 | 4.69 | 8.47E-14 | NA | NA | 0.003147677 | NA | NA |
| *Sphyrapicus thyroideus* | SPTH | WISA | Williamson's sapsucker | Pic de Williamson | B | I | F | T | CN | 47.6 | 4.38 | NA | 0.00031739 | NA | NA | 0.001429297 | NA |
| *Sphyrapicus varius* | SPVA | YBSA | Yellow-bellied sapsucker | Pic maculé | B | I | F | T | CN | 50.3 | 4.5 | 0.405404256 | 0.664484009 | 0.628235083 | 0.002957721 | 0.001429297 | 0.003019179 |
| *Spinus pinus* | SPPI | PISI | Pine siskin | Tarin des pins | F | H | O | T | NCN | 12.91 | 4 | 0.121991039 | 0.34884614 | 0.764689783 | 0.018356882 | 0.018356882 | 0.020075283 |
| *Spinus tristis* | SPTR | AMGO | American goldfinch | Chardonneret jaune | F | H | O | S | NCN | 11.97 | 5.5 | 0.873300581 | 0.620324691 | 0.793035604 | 0.005976531 | 0.005976531 | 0.006011721 |
| *Spizella pallida* | SPPA | CCSP | Clay-colored sparrow | Bruant des plaines | F | H | O | S | NCN | 12.2 | 4 | 0.318602487 | 0.126710326 | 0.23336388 | 0.005976531 | 0.005976531 | 0.006011721 |
| *Spizella passerina* | SPPAS | CHSP | Chipping sparrow | Bruant familier | G | H | O | S | NCN | 12.3 | 4 | 0.014711867 | 0.021519339 | 0.010803745 | 0.143001873 | 0.016765069 | 0.143016967 |
| *Strix nebulosa* | STNE | GGOW | Great gray owl | Chouette lapone | G | I | F | T | NCN | 1267 | 4.6 | 0.711144773 | 0.970551732 | 0.984542143 | 0.053307361 | 0.053307361 | 0.058827564 |
| *Strix varia* | STVAR | BADO | Barred owl | Chouette rayée | G | C | F | T | CN | 1000 | 5 | 0.958342892 | NA | NA | 0.02665583 | NA | NA |
| *Sturnella neglecta* | STNEG | WEME | Western meadowlark | Sturnelle de l'Ouest | G | I | O | G | NCN | 100 | 6 | NA | NA | 0.76297118 | NA | NA | 0.007810291 |
| *Sturnus vulgaris* | STVU | EUST | European starling | Étourneau sansonnet | G | I | O | T | CN | 79.46 | 5.1 | NA | 8.45E-09 | NA | NA | 0.010479414 | NA |
| *Surnia ulula* | SUUL | NHOW | Northern hawk owl | Chouette épervière | G | C | F | T | CN | 339.8 | 7 | 0.993502429 | 0.419868992 | 0.665406724 | 0.015452182 | 0.163979704 | 0.028028946 |
| *Tachycineta bicolor* | TABI | TRES | Tree swallow | Hirondelle bicolore | A | I | O | T | CN | 21.1 | 5.5 | 0.393455169 | 0.242376162 | 0.351670822 | 0.002828943 | 0.006114193 | 0.002927939 |
| *Tringa flavipes* | TRFL | LEYE | Lesser yellowlegs | Petit Chevalier | G | I | O | G | NCN | 85.2 | 4 | 0.967917979 | NA | 0.886675142 | 0.003103654 | NA | 0.003427334 |
| *Tringa melanoleuca* | TRME | GRYE | Greater yellowlegs | Grand Chevalier | G | I | O | G | NCN | 176 | 3.7 | 0.450756915 | 0.804867306 | 0.589638832 | 0.009622595 | 0.009622595 | 0.010508512 |
| *Tringa solitaria* | TRSO | SOSA | Solitary sandpiper | Chevalier solitaire | G | I | O | T | NCN | 48.4 | 4 | 0.840597684 | 0.650351057 | 0.92561609 | 0.00964495 | 0.00964495 | 0.010454786 |
| *Troglodytes aedon* | TRAE | HOWR | House wren | Troglodyte familier | F | I | O | T | CN | 12 | 6.8 | 0.736008058 | 0.154851198 | 0.079938879 | 0.145527618 | 0.145527618 | 0.145688501 |
| *Troglodytes hiemalis* | TRHI | WIWR | Winter wren | Troglodyte des forêts | G | I | F | T | CN | 8.6 | 5.5 | 0.333695929 | 0.246272733 | 0.58003591 | 0.145531136 | 0.145531136 | 0.145810006 |
| *Turdus migratorius* | TUMI | AMRO | American robin | Merle d'Amérique | G | I | O | T | NCN | 75 | 3.5 | 0.331941358 | 0.191026963 | 0.32502978 | 0.00964495 | 0.00964495 | 0.010454786 |
| *Tyrannus tyrannus* | TYTY | EAKI | Eastern kingbird | Tyran tritri | A | I | O | T | NCN | 41.6 | 3 | 0.980625407 | 0.708312459 | 0.544410571 | 0.004707041 | 0.004707041 | 0.024016056 |
| *Vireo cassinii* | VICA | CAVI | Cassin's vireo | Viréo de Cassin | F | I | F | T | NCN | 14.6 | 3.87 | 1.78E-09 | NA | NA | 0.001434512 | NA | NA |
| *Vireo gilvus* | VIGI | WAVI | Warbling vireo | Viréo mélodieux | F | I | O | T | NCN | 13.98 | 3.5 | 0.493520753 | 2.74E-33 | 0.984542143 | 0.145017464 | 0.145271736 | 0.029980266 |
| *Vireo olivaceus* | VIOL | REVI | Red-eyed vireo | Viréo aux yeux rouges | F | I | F | T | NCN | 19.9 | 3.5 | 0.068594943 | 0.237885939 | 0.418276509 | 0.006424659 | 0.006424659 | 0.006898652 |
| *Vireo philadelphicus* | VIPH | PHVI | Philadelphia vireo | Viréo de Philadelphie | F | I | F | T | NCN | 12.2 | 4 | 0.716403383 | 0.611058781 | 0.826887966 | 0.001879699 | 0.001879699 | 0.001879699 |

**Table A1** (*concluded*).

| | | | | | | | | | | | | Species scarcity index | | | Functional uniqueness index | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Species code | Species ID | English name | French name | Foraging strategy[*] | Foraging guild[†] | Habitat affinity[‡] | Nest location[§] | Nest guild[¶] | Body mass (g) | Clutch size (mean) | Harvest | Fire | Salvage logging | Harvest | Fire | Salvage logging |
| *Vireo solitarius* | VISO | BHVI | Blue-headed vireo | Viréo à tête bleue | F | I | F | T | NCN | 15.4 | 4 | 0.432768827 | 0.28544884 | 0.68027066 | 0.001434512 | 0.004129727 | 0.004560415 |
| *Xanthocephalus xanthocephalus* | XAXAN | YHBL | Yellow-headed blackbird | Carouge à tête jaune | G | I | O | S | NCN | 100 | 4 | NA | 0.899322238 | NA | NA | 0.014636229 | NA |
| *Zenaida macroura* | ZEMA | MODO | Mourning dove | Tourterelle triste | G | H | O | T | NCN | 112 | 2 | NA | 0.404390272 | NA | NA | 0.154123613 | NA |
| *Zonotrichia albicollis* | ZOAL | WTSP | White-throated sparrow | Bruant à gorge blanche | G | H | F | G | NCN | 25.1 | 4 | 0.002530435 | 0.043200345 | 0.107924505 | 0.003806724 | 0.003806724 | 0.004203726 |
| *Zonotrichia leucophrys* | ZOLE | WCSP | White-crowned sparrow | Bruant à couronne blanche | G | I | O | G | NCN | 25.47 | 4.58 | NA | 5.06E-26 | 0.984542143 | NA | 0.005141677 | 0.005450502 |

[*] Foraging strategy: A, aerial; B, bark; F, foliage; G, ground.

[†] Foraging guild: C, carnivorous; H, herbivorous; I, insectivorous; O, omnivorous.

[‡] Habitat affinity: F, forest; O, open canopy.

[§] Nest location: G, groud; S, shrub; T, tree.

[¶] Nest guild: CN, cavity nester; NCN, non-cavity nester.

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