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Boreal Owl (*Aegolius funereus*) and Northern Saw-whet Owl (*Aegolius acadicus*) breeding records in managed boreal forests

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Abstract
During the 2016 breeding season we monitored 169 nest boxes suitable for Boreal Owl (*Aegolius funereus*) and Northern Saw-whet Owl (*Aegolius acadicus*) in high-latitude (>55°N) boreal forests of northwestern Alberta affected by partial logging. Despite the large number of boxes deployed, the number of boxes used by Boreal and Northern Saw-whet Owls was small. Boreal Owls used nest boxes (n = 4) in conifer-dominated stands with three being in uncut blocks and the other in a 50% green tree retention cut-block. In contrast, Northern Saw-whet Owls used boxes (n = 4) in a broader range of cover types, breeding in boxes placed in stands with at least 20% post-harvest tree retention. Although both species successfully bred in the same landscape, Boreal Owls produced fewer eggs (mean = 2.5) and raised fewer young (mean = 0.5) than Northern Saw-whet Owls (5 and 2.25, respectively). Furthermore, our observed Boreal Owl egg production was lower than has been found for the same species nesting in nest boxes in different regions or forest types. In contrast, breeding parameters of Northern Saw-whet Owls were similar to that found in nest boxes in the eastern boreal region of Canada and in the southern part of its range.

Key words: Nest boxes; breeding records; boreal forest; Boreal Owl; Northern Saw-whet Owl; clutch size; nesting success; partial logging

Introduction
Boreal Owl (*Aegolius funereus*) and Northern Saw-whet Owl (*Aegolius acadicus*) are obligate cavity nesters, occupying tree holes excavated by Pileated Woodpecker (*Dryocopus pileatus*) and Northern Flicker (*Colaptes auratus*; Hayward *et al.* 1993; Johnsgard 2002). Locating natural nest sites for study is difficult as these owls often breed in remote locations where lack of roads and deep snow conditions restrict access (Hayward *et al*. 1993; Korpimaki and Hakkarainen 2012). As a result, most breeding data come from nest box experiments (Hayward *et al.* 1993; Lauff 2009; Korpimaki and Hakkarainen 2012) because boxes provide an efficient (Korpimaki and Hakkarainen 2012) and cost effective (Hayward *et al.* 1992) method to document breeding, examine habitat associations of nesting owls, and provide demographic data.

Forestry activities that reduce cavity availability (Hayward 1997; Korpimaki and Hakkarainen 2012) or eliminate large trees from forest stands (Lopez *et al.* 2010) have been identified as risks to Boreal Owl populations. It is likely that Northern Saw-whet Owls, which have similar nesting habitats, are similarly impacted by logging. More than 35% of the Canadian boreal forest is now managed for forestry resulting in younger trees across the region (Gauthier *et al.* 2015). However, there is a trend to replace traditional clearcutting with management techniques that aim to maintain some old growth forest and to create features of older stands earlier in succession (Burton *et al.* 1999; Lindenmayer *et al.* 2006; Thorpe and Thomas 2007; Etheridge and Kayahara 2013; Fedrowitz *et al.* 2014).

Green tree retention forestry creates a landscape mosaic of old and young forest patches and leaves mature trees after harvest which may preserve cavity nesting communities (Woodley *et al.* 2006; Cooke and Hannon 2011), including cavity nesting owls

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(Hayward 1997). But, it is not clear what levels of retention (Lance and Phinney 2001) are most effective for owl conservation or what structures should be retained (Thorpe and Thomas 2007; Cooke and Hannon 2011; Straus *et al.* 2011). Density of primary cavity excavators is reduced in partially harvested stands (Straus *et al.* 2011), resulting in lower cavity density and inherently higher competition among secondary cavity nesters (Bonar 2000). As both Boreal Owls and Saw-whet Owls readily accept nest boxes, these artificial cavities could provide additional nesting opportunities in logged areas.

The northern boundary of the Northern Saw-whet Owl's breeding range is unclear (Buidin *et al.* 2006), and although the Canadian boreal forest represents a considerable part of the ranges of both species, there is little information concerning their population status and breeding ecology. We present results of a nest box experiment initiated to evaluate the responses of Boreal Owl and Northern Saw-whet Owl to variable retention forestry in the western boreal region of Alberta. Our specific objectives were to document owl breeding across three different forest types and a range of retention levels, to describe breeding habitat, and to compare reproductive success of owls breeding in partially logged stands with those from other forest types.

Methods

We conducted our study in the Clear Hills region of Alberta, Canada, an area of ~900 km^2, ranging in elevation from 470 to 920 m above sea level, including the land base of the Ecosystem Management Emulating Natural Disturbance (EMEND) Project located 90 km northwest of Peace River, Alberta (56.7703°N, 118.374°W). This predominantly forested region was historically shaped by fire (Work *et al.* 2004; Bergeron 2012), but the intensification of logging and oil and gas exploration has become a key driver of forest dynamics. The upland mixed wood landscape is comprised of deciduous hardwood patches dominated by Trembling Aspen (*Populus tremuloides* Michaux) and Balsam Poplar (*Populus balsamifera* L.), interspersed with conifer patches that are predominantly White Spruce (*Picea glauca* (Moench) Voss). Forests on poorly drained sites contain open and closed canopies of Black Spruce (*Picea mariana* (Miller) Britton) and Tamarack (*Larix laricina* (Du Roi) K. Koch).

The forest of the EMEND experiment (description of the complete design is available from Spence *et al.* 1999; Work *et al.* 2010) is a patchwork of four main cover types: conifer-dominated (CD, conifers >70% of the canopy), deciduous-dominated (DD, conifers <30% of the canopy), deciduous-dominated with conifer understorey (DU), and mixed (MX, relative equal composition of conifer and deciduous trees). Compartments of ~10 ha of each cover type were subjected to various levels of forest harvesting in winter of 1998–1999. Trees were retained by operators according to prescription and independent of size, status, and species. During August–October 2015 we placed nest boxes in compartments with 20%, 50%, and 75% retention as well as unharvested compartments in three cover types (CD, DD, and MX). A 20% retention means that 20% of the trees in a 10 ha compartment were not cut down. Additional boxes were placed in unharvested CD, DD, and MX stands outside EMEND that were at least 10 ha in size, and in residual trees found in recent (1–5 years) clear-cuts. Boxes were not evenly distributed on the landscape but rather along existing roads and trails to facilitate access. Not all forest cover types were equally available for box placement as many deciduous dominated stands had been previously harvested and the regenerating trees (5–15 years old) were too dense and too small to support boxes.

Nest boxes were built of 2 cm thick rough-cut spruce boards, with an entrance hole of 79 mm, following a box design described by Korpimaki (1985). The bottom 10 cm of each box was filled with aspen chips and shavings to provide insulation and prevent egg breakage. In the field, boxes were hung on live or dead trees at an average height of 5.2 m (range: 2.7–6.2 m), using a sectional Swedish tree climbing ladder (Forestry Suppliers Inc., Jackson, Massachusetts, USA). We did not follow any pattern for box orientation (although orientation was recorded) but ensured that there was a small opening through the vegetation in front of the box to allow a direct flight path to the entrance hole. Two boxes were placed in the three different cover types in the selected 36 EMEND compartments including both harvested and unharvested sites, with boxes set no closer than 200 m (range: 204–647 m) to each other. The average distance between the nest boxes placed outside EMEND was 1274 m (568–2968 m).

Nesting habitat

We monitored 169 nest boxes suitable for both Boreal Owl and Northern Saw-whet Owl at EMEND (72 boxes) or in the surrounding landscape (97 boxes) during the 2016 breeding season. Landscape characteristics at each nest box were tabulated using ArcMap 10.2.2 (2011 ArcGIS Desktop: Release 10, Environmental Systems Research Institute, Redlands, California, USA) at two scales: 1) nest site (NS, 3.14 ha or 100 m radius circle centred on the nest box) and 2) home range (HR, ~100 ha or 564 m radius circle centred on the nest box).We considered the NS scale was an adequate area to describe habitat associations in the immediate vicinity of potential nest sites of owls while maintaining the spatial separation between two neighbouring boxes. Hinam and Cassady St. Clair (2008) reported average home range size of Northern Saw-whet Owls in Alberta as 89.4 ha (range: 11.7–137.0 ha), which is about half the area of Boreal Owl home ranges in Fennoscandia (50–230 ha; Korpimaki and Hakkarainen 2012). Our choice of the HR scale certainly includes the core area for most owls and provides information about breeding habitat across a wider area. Tabulated characteristics included percent composition of the three dominant cover types and percent shrub land, grassland, and agricultural land from the Alberta Biodiversity Monitoring Institute Wall-to-wall Vegetation Layer (Alberta Biodiversity Monitoring Institute 2010). We checked every box at least twice during April–June. Initial visits consisted of a quick glance into the box, using a home-made observation device assembled from an extendable pole, wireless inspection camera (Gardner Bender Wi-Fi inspection Camera, Gardner Bender, Menomonee Falls, Wisconsin, USA), and a cell phone (connected to the inspection camera using the Gardner Bender WiFi Tool app). Occupant species, eggs, cached prey, or any other signs of occupancy (e.g., feathers, additional nest material) were noted and future check dates were scheduled based on the initial findings. Checks were scheduled to document each stage of breeding: number of eggs, hatching success, and fledging success. If a nest was found with a completed clutch, it was checked two more times: about a week after the estimated hatch time and around the estimated fledge time. All boxes were also cleaned in August–September when fledging was confirmed.

Reproductive success

Boxes occupied by owls were monitored until the clutch failed or nestlings were at fledgling age (28–30 days old). Reproductive success was measured as: (1) nesting effort (number of eggs laid), (2) hatching success (% of eggs hatched), and (3) fledging success (% nestlings reaching 28–30 days). The time of nest initiation was calculated based on a two-day egg laying interval (Korpimaki 1981).

Results

Nesting habitat

During the 2016 breeding season, 64 (39%) of 164 nest boxes available for study were used; of the 169 boxes placed, one was destroyed because of forest harvesting, and four boxes could not be accessed after beavers flooded the access trail. Other species were found using the nest boxes (Table 1) but 10 boxes (6%) were used by owls: four by Boreal Owls, four by Northern Saw-whet Owls, and two where the owl species could not be identified. In these latter two cases, the nest boxes contained cached prey, but no owls were detected and there was no sign of laid eggs or hatched young.

TABLE 1. Nest box occupancy during the 2016 breeding season at Clear Hills, Alberta. A nest box was marked used if presence of species, or any sign of usage (e.g., cached prey, eggs, feathers) was detected inside the box. Identity of users remained unknown when animal presence was never detected at the box, but signs indicated clear use by either group (owls or squirrels).

Nest box occupancy	Number of boxes (%)
American Kestrel (*Falco sparverius*)	2 (1.2)
Boreal Owl (*Aegolius funereus*)	4 (2.4)
Northern Flicker (*Colaptes auratus*)	5 (3.0)
Northern Flying Squirrel (*Glaucomys sabrinus*)	3 (1.8)
Northern Saw-whet Owl (*Aegolius acadicus*)	4 (2.4)
Red Squirrel (*Tamiasciurus hudsonicus*)	36 (22.0)
Unknown owl (*Aegolius* sp.)	2 (1.2)
Unknown squirrel	8 (4.9)
Empty boxes	100 (61.0)
Total	164

The two owl species used the available cover types differently. Boreal Owls used boxes in conifer patches only (n = 4; three in unharvested areas and one nest box in a cutblock with 50% tree retention), while Northern Saw-whet Owls used the deciduous dominated (n = 2) and mixed (n = 2) cover types. For Boreal Owls, conifer cover was high at both scales (NS = 90.2 ± 9.7, HR = 80.1 ± 9.1) and included low levels of mixed forest only at the HR scale (5.7 ± 1.5). Northern Saw-whet Owls nests were in predominantly deciduous cover (93.4 ± 6.4, n = 4) at NS scale, although the mixed component cover increased (25.3 ± 10.9, n = 4) at the HR scale. Neither of the species used boxes placed in clear-cuts. Northern Saw-whet Owls did not nest in unharvested forests, occupying one box placed in the 50% tree retention compartment, one in 75%, and two in harvested patches with 20% tree retention.

Reproductive success

Both species successfully bred in a boreal landscape affected by partial harvesting, however breeding phenology of Northern Saw-whet Owls was different from that of Boreal Owls (Table 2). The earliest nest initiation for Boreal Owl was 10 April and the latest clutch was started on 31 May. Northern Saw-whet Owls started breeding one month later than Boreal Owls, with the earliest clutch initiated on 10 May and the latest on 15 June. Two Boreal Owl nests failed be-

TABLE 2. Breeding parameters at eight nest boxes where at least one egg had been laid for Boreal Owl (*Aegolius funereus*) and Northern Saw-whet Owl (*Aegolius acadicus*) at Clear Hills, Alberta, 2016.

Species	Nest initiation date	Fledging date	Eggs laid	Hatched young	Fledglings
Boreal Owl	31 May	n/a	2	0	0
Boreal Owl	2 May	28 June	3	2	2
Boreal Owl	10 April	n/a	3	3	0
Boreal Owl	n/a	n/a	2	0	0
Northern Saw-whet Owl	12 June	10 August	5	4	3
Northern Saw-whet Owl	8 June	10 August	6	5	2
Northern Saw-whet Owl	15 June	10 August	4	4	4
Northern Saw-whet Owl	10 May	n/a	5	4	0

fore clutch completion. The first nest contained two eggs and three cached prey items on 17 May; the eggs did not hatch. The second nest was started on 31 May and the female laid two eggs but on 2 July the nest box was empty. Northern Saw-whet Owls breeding in the ~900 km^2 boreal mixed-wood landscape produced more eggs (mean = 5; range: 4–6) than Boreal Owls (mean = 2.5; range: 2–3), and had also a higher hatching success (85%) than Boreal Owls (50%). Boreal Owls raised only 0.5 fledglings/nest while Northern Saw-whet Owls were more successful, producing 2.25 fledglings/nest. Boreal Owl young were ready to fledge on 28 June, while all Northern Saw-whet Owl nestlings were close to fledging on 10 August.

Discussion

Nesting habitat and retention forestry

Boreal Owl nest box occupancy (2.4%) in our partially harvested landscape was lower than in the highly managed boreal forests of Finland (15%; Korpimaki and Hakkarainen 2012), or China, where occupancy varied between 6–10% over five years for boxes placed in selectively logged forests lacking large trees (Fang *et al.* 2009). However, occupancy at our study site is comparable to that observed in uncut forests of the Northern Rocky Mountains, USA (1.7%; Hayward *et al.* 1993) and Yukon, Canada (1%; Mossop 1997).

Northern Saw-whet Owls also nested in four boxes (2.4%) at EMEND; and although Buidin *et al.* (2006) reported range expansion for this species in eastern Canada north of 50°N, we are unaware of any other studies that documented breeding at a similar latitude as ours. The low occupancy is consistent with findings reported at their northern breeding limit in the boreal forests of Quebec, Canada (2.5%; Buidin *et al.* 2006). In contrast, Saw-whet Owls occupied higher proportions of available boxes in the southern part of their breeding range: 3–36% at a hybrid poplar plantation in north-central Oregon, USA (Moser 2002; Marks *et al.* 2015), and 15% at the Custer National Forest in South Dakota, USA (Drilling 2013). Given the sparse data from the northern limits of the breeding range, it is not clear whether the difference in occupancy rates is due to lower owl densities in the north, cyclical changes in population size, or the relative availability of cavities in these different forest types found further south.

Our study shows for the first time that the breeding ranges of Boreal Owl and Northern Saw-whet Owl overlap in northwestern Alberta at >55°N. Northern Saw-whet Owls nested in relative proximity to conspecifics, with the minimum distance of 659 m between two occupied nest boxes. Similar results were obtained in the commercial poplar plantations in Oregon, where owls nested within 0.5–1.2 km of nest boxes occupied by conspecifics (Marks *et al.* 2015). In contrast, early nesting Boreal Owls at EMEND occupied boxes 11.4 km apart. However, a second clutch was initiated (potentially by the same female) only 330 m from a nest box that contained three Boreal Owl nestlings. It is probable that some home ranges overlapped within species, although substantial local overlap between these two species seems unlikely as the minimum distance between occupied nest boxes of a Boreal and a Northern Saw-whet Owl was 2770 m. Lane and McKeown (1991) reported aggressive interactions of Boreal Owl and Northern Saw-whet Owls and suggested that limited cavities might be a source of interspecific competition; this avenue for future work should be explored.

The nest site choices observed here for Boreal Owls corroborates their use of old conifer forests, which has been well documented elsewhere (Hayward *et al.* 1993; Korpimaki and Hakkarainen 2012). Low retention compartments lack the structural complexity of old forests. Stands with 20% green tree retention were at the time of our research 17 years post-harvest, and covered by dense aspen regeneration, with only a few trees large enough to potentially host a natural cavity created by primary cavity excavators. The absence of Boreal Owls from low retention patches (i.e., patches with more trees cut), even when nest boxes were provided, is consistent with suggestions that they key on forests with significant structural complexity not just nest sites (Hayward *et al.* 1993).

The pattern of nest box use by Northern Saw-whet Owls at our research site underscores their willingness to breed in a broader range of forest types if cavities are available (Moser 2002; Drilling 2013; Marks *et al.* 2015). Nesting of Northern Saw-whet Owls in younger stands could be explained by their higher maneuverability and lighter wing loading than Boreal Owls, allowing them to hunt in dense vegetation (Hayward and Garton 1988).

Variable retention forestry that creates a mosaic of stands of different cover types and structural complexity, including uncut patches that resemble old forests, seems capable of providing nesting habitat for cavity nesting owls—if nest sites are available. Our findings complement those of other studies showing that on logged landscapes at least 30% retention, with some patches at least 10 ha in size, is needed to maintain most cavity users associated with old boreal forests (Cooke and Hannon 2011). However, our nest box data suggest that further examining how these species react to disturbance by partial logging is warranted.

Timing of nesting

Timing of nest initiation (10 April–31 May) for Boreal Owls at our study site is comparable to laying dates at Chamberlain Basin, Idaho, USA (12 April–24 May; Hayward *et al.* 1993). However, they started breeding earlier in both Nova Scotia, Canada (20 March–1 June; Lauff 2009) and Finland (13 March–2 May; Korpimaki and Hakkarainen 2012). The latest clutch laid at EMEND was probably a replacement nest, or a second clutch initiated by a polyandrous female (see Korpimaki and Hakkarainen 2012 for criteria).

Timing of nest initiation (10 May–15 June) for Northern Saw-whet Owls breeding at EMEND was comparable to birds breeding in the Mignan Region, Quebec, Canada (nest initiation dates range from early-April to mid-June; Buidin *et al.* 2006). Nest initiation dates are seldom reported from Saw-whet Owl nest box experiments; however, birds breeding in nest boxes placed in hybrid poplar plantation in Oregon started laying in early and mid-March (1 March; Marks *et al.* 2015 and 16 March; McCullough and Conway 2017).

Nesting effort and success

Northern Saw-whet Owls in our study laid more eggs (mean = 5; range: 4–6; $n = 4$) than did conspecifics in the boreal forests of Quebec (mean = 3.5, range: 1–6; $n = 9$; Buidin *et al.* 2006). However, conspecifics breeding in a young poplar plantation in Oregon (mean = 5.8, range: 5–7; Marks *et al.* 2015) and in the Custer National Forest, South Dakota, USA (mean = 5.2 eggs/nest, range: 2–8; $n = 136$; Drilling 2013) laid more eggs than we observed.

Boreal Owl egg production (mean = 2.5; range: 2–3; $n = 4$) was lower than reported from Nova Scotia (mean = 3.5, range: 3–4; $n = 4$; Lauff 2009) or central Idaho (mean = 2.95, range: 2–4; $n = 16$; Hayward *et al.* 1993). Owls nesting in Alberta produced fewer eggs than did Finnish owls even in the poorest vole years (mean = 4.75, range: 4–5.4; Korpimaki and Hakkarainen 2012), although year to year variation of clutch size in Fennoscandia was high (mean = 5.71, range: 1–10; Korpimaki 1987).

Boreal Owls hatched only 50% of the eggs, less than birds breeding in spruce-fir forests affected by Spruce Budworm (*Choristoneura fumiferana* Clemens) in Nova Scotia (85.5%; Lauff 2009) or Finnish owls breeding in highly managed boreal forests (86.7%; Korpimaki and Hakkarainen 2012). In contrast, Northern Saw-whet Owls hatched 85% of their eggs, comparable to averages found in a poplar plantation in Oregon (83%; Moser 2002) but were less successful than owls breeding in nest boxes in Custer National Forest in northwestern South Dakota (96%; Drilling 2013).

Boreal Owls at EMEND fledged 0.5 young per nest and fledging success was 35%, lower than documented in both Nova Scotia (62%; Lauff 2009) and Finland (59%; Korpimaki and Hakkarainen 2012). Fledging success for Northern Saw-whet Owls was 52.9% with 2.25 fledglings per nest, comparable to data from the northern limit of their breeding range in the Mignan Region, Quebec (mean = 2.8, range = 1–6; Buidin *et al.* 2006). However, breeding owls at EMEND fledged fewer young than the nine-year average (3.4 fledgling/nest), but well within the range (0.4–4.1 young/nest) recorded for Northern Saw-whet Owls breeding in boxes placed in wooded ravines surrounded by grasslands in northwestern South Dakota (Drilling 2013).

Conclusion

The network of nest boxes established at EMEND provides the starting point for long-term monitoring of these two small owl species. Our early findings suggest that uncut forest patches of sufficient size will be required to conserve populations of Boreal Owl on harvested landscapes. We recommend long-term monitoring of breeding populations of these cavity nesting owls in landscapes affected by partial logging as it is well documented that habitat alteration and low fledging success contributed to negative growth rates (−2.1 to −2.3% per year) of local Boreal Owl populations in Finland, where the species is now considered near threatened (Korpimaki and Hakkarainen 2012). We also know that reduction of old growth forest cover is a main factor affecting male survival and reproductive success for Boreal Owl (Laaksonen *et al.* 2004; Korpimaki and Hakkarainen 2012), and that reduction of forest patch size and increasing fragmentation decreases reproductive output for Northern Saw-whet Owls (Hinam and Cassady St. Clair 2008). We suggest continuous monitoring of the nest box network established at EMEND as this could support useful conclusions about the effectiveness of nest box provisions in partially logged forests in maintaining cavity nesting owl populations. Additionally, studies for both owl species should focus on landscape characteristics that promote preservation of breeding populations during post-harvest recovery of stands impacted by variable retention logging.

Author Contributions

Conceptualization: Z.D. and J.R.S.; Methodology: Z.D. and E.M.B; Investigation: Z.D.; Formal Analysis: Z.D. and S.E.N.; Funding Acquisition: J.R.S. and Z.D.; Writing – Original Manuscript: Z.D.; Writing – Review & Editing: J.R.S., E.M.B., and S.E.N.

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