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Timber harvest and tree size near nests explains variation in nest site occupancy but not productivity in northern goshawks (*Accipiter gentilis*)

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ABSTRACT

Conservation concern for the northern goshawk (*Accipiter gentilis*) reflects evidence that goshawks may abandon nest sites or suffer from reduced nesting success in response to some forms of timber harvest. However, this evidence is mixed and has yet to be reviewed systemically and quantitatively. Therefore, we conducted a meta-analysis to assess the extent to which timber harvest and tree size explain variation in goshawk productivity and site occupancy. Goshawk productivity was not significantly explained by the presence of nearby timber harvest nor by the average size of nearby trees either in North America or in Eurasia or when averaged across all studies. Effect sizes differed dramatically among studies and the average effect size was close to zero ($Zr = 0.04$). However, timber harvest and tree size together more strongly explained goshawk occupancy of nest sites or territories. Within studies, goshawk nest sites or territories with less timber harvest nearby or relatively larger trees were, in most cases, more likely to be occupied. When we estimated average effect sizes separately for the two continents, the averages were moderate, consistent ($Zr = 0.23–0.27$), and significantly > 0. When we combined studies from North America and Eurasia, average effect sizes for timber harvest ($Zr = 0.24$) and tree size ($Zr = 0.25$) were similar in strength and both significantly > 0. Thus taken together, our results suggest that although both timber harvest and a lack of large trees are associated with lower occupancy by nesting goshawks, pairs that nest near timber harvest or in small trees have indistinguishable nesting success from pairs nesting in large trees or farther from timber harvest. We found substantial heterogeneity in results among studies, especially within North America, which is not surprising given that studies differed greatly in research methods, forest type, and forest management. In conclusion, our results suggest goshawk nest sites in populations of conservation concern, such as *A. g. laingi*, may need more protection from timber harvest than they are currently receiving. Equally important, to better understand effects of forest management on goshawks, we recommend additional studies designed to: (1) better identify the spatial and temporal extent of the effect of timber harvest on goshawk site occupancy; and (2) determine what goshawks do and where they go after a timber harvest.

1. Introduction

Forest management that influences habitat of at-risk wildlife species has been one of the principal challenges to forest managers and wildlife biologists for the last several decades (Stephens et al., 2014). Globally an ongoing debate is focused on several species that nest in old-growth forest, including the northern goshawk (*Accipiter gentilis;* hereafter referred to as goshawk), a forest raptor with a Holarctic distribution. The goshawk has become an icon in the debate over retention of large or old-growth trees and dense-canopy conditions (Greenwald et al., 2005; Reynolds et al., 2008; Saga and Selås, 2012; Dickson et al., 2014). Several petitions to list the goshawk subspecies *A. g. atricapillus* as endangered in the US have been rejected due to lack of evidence of either population decline or restriction of nesting to older forests (Kennedy, 1997; Squires and Kennedy, 2006). However, in 2012 the British Columbia population of the *laingi* subspecies was designated by the US Fish and Wildlife Service as *Threatened* in both the United States and Canada, primarily because of continued timber harvest of low elevation, old-growth and suitable second-growth forests (http://globalraptors.org/grin/SpeciesResults.asp?specID=8132; last accessed 16 June, 2015). This subspecies was also listed in 2013 as *Threatened* in Canada under the Species at Risk Act (http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=56; last accessed 7 April, 2016). In Eurasia, the goshawk

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population may have declined in the 20th century because of reduced availability of breeding habitat (Rutz et al., 2006) but populations are currently stable or increasing (http://globalraptors.org/grin/SpeciesResults.asp?specID=8132; last accessed 16 June, 2015). Nevertheless, goshawks are considered a sensitive or management indicator species in many places worldwide.

Commercial harvest of mature forest stands may threaten goshawk nesting habitat availability and quality. Goshawks can have high nest site fidelity which makes protecting their nest sites critical in managed territories (Reynolds et al., 1994; Penteriani et al., 2002b; but see Boyce et al., 2006). Conservation efforts for goshawks have ranged from protection of individual nest sites by a range of public and private entities (Saga and Selås, 2012; Santangeli et al., 2012), to forest management plans based largely on goshawk habitat relations and providing suitable habitat for prey (Reynolds et al., 1992, 2008).

Goshawk habitat relations have been assessed in a number of landscapes and this body of work is summarized in Penteriani (2002), Andersen et al. (2005), Boyce et al. (2006), Squires and Kennedy (2006), Reynolds et al. (2008), and Bruggeman et al. (2014). These qualitative assessments indicate goshawks breed in a wide variety of forested landscapes and use large trees with appropriate structure to support nests in mature forest patches with high canopy closure. However, these conclusions should be understood as tree size or age relative to trees in nearby forests because, depending on availability in the landscape, goshawks use trees of a wide range of sizes and ages. The species of trees used for nesting varies both within and among regions, as do forest type and primary prey (Squires and Kennedy, 2006; Kennedy and Cartron, 2010). However, goshawk nest sites tend to be embedded in home ranges that are a mixture of forest types, ages and structural characteristics (Boyce et al., 2006; Squires and Kennedy, 2006).

Many studies have investigated forest management effects on goshawk nesting site occupancy and reproduction but results are inconsistent across studies. In some studies, breeding pairs in timber-harvested areas have shown significantly reduced reproductive performance relative to pairs in non-harvested areas (Crocker-Bedford, 1990; Patla, 2005), but this pattern does not appear consistent (Penteriani et al., 2002a; Mahon and Doyle, 2005; Moser and Garton, 2009). Similarly, some have found significant reduction in goshawk site occupancy near timber harvest (e.g., Crocker-Bedford, 1990; Patla, 2005; Santangeli et al., 2012), but these patterns are not universal either (Mahon and Doyle, 2005; Moser and Garton, 2009). Further, there is evidence of threshold responses in which territory occupancy does not cease until some level of harvest or proximity to harvest is exceeded (Penteriani and Faivre, 2001; Moser and Garton, 2009; Saga and Selås, 2012; Santangeli et al., 2012). Season of harvest may also affect goshawk reproduction. For instance, in Wales, timber harvest after the fledgling phase did not cause breeding goshawks to relocate but timber harvest during the nestling phase notably reduced nesting success (Toyne, 1997).

Similar to habitat summaries, numerous authors have qualitatively summarized timber-harvest effects on goshawks (Andersen et al., 2005; DeStefano, 2005; Greenwald et al., 2005; Rutz et al., 2006; Squires and Kennedy, 2006; Reynolds et al., 2008) and no clear pattern has emerged from these reviews suggesting a more quantitative approach is warranted. We therefore conducted a meta-analysis of results from this literature to specifically address two questions: (1) *Does timber harvest affect goshawk site occupancy and/or productivity*; and (2) *Does tree size in the vicinity of nests affect goshawk site occupancy and/or productivity?*

A meta-analysis combines all published effect sizes (regardless of statistical significance), weighted by sample size, to produce an average effect bounded by confidence intervals. We assembled all published studies that compared occupancy or productivity in timber-harvested and non-harvested areas or compared occupancy or productivity in relation to tree size near nests. We chose to assess statistical relationships with both timber harvest and tree size because, although we recognize that they are not identical variables, they are often related as timber harvest frequently reduces the number of large trees at a site. Further, it is typically hypothesized that if timber harvest harms goshawks this harm results, at least in part, in some way from reduction in availability of large trees. The published studies of goshawk occupancy and productivity come from a diverse array of habitats and geographic locations, and have been conducted with many different methodologies. Thus we expected there to be biologically relevant variation in statistical effects among studies. We both tested for heterogeneity in statistical effects among studies and compared statistical effects between subsets of studies that we thought might differ. The subsets we compared were studies from North America versus those from Eurasia, and studies that used timber harvest as an independent variable versus those that used tree size. If goshawks were influenced by timber harvest, then we predicted goshawk occupancy and productivity would be lower in areas with timber harvest or with small trees (relative to other sites within individual studies) compared to non-harvested areas and sites with relatively large trees.

2. Methods

On Web of Science we searched "*Accipiter gentilis*" paired with each of the following terms in turn: "*stand*∗", "*nest*∗", "*habitat*∗", "*timber*∗", "*fledgling*", "*product*∗", "*reproduc*∗", "*occupan*∗", "*fidelity*", "*territor*∗", "*presence*", "*harvest*", "*timber*", "*abandon*∗", and "*site*". To augment our search we also examined the literature cited sections of the aforementioned reviews. We evaluated >200 papers published in the peer-reviewed primary literature to determine which had data that could be included in the analysis. We completed our search 26 December 2014. To be included in our analysis each study had to meet one or more of the following criteria: (1) assessed occupancy or productivity as a function of proximity to nearby timber harvest, (2) compared occupancy or productivity between timber-harvested sites and non-harvested sites, (3) examined site occupancy or productivity as a function of measures of average tree size per site, or (4) compared occupied sites with random sites or with unoccupied sites in the vicinity as a function of average tree size. We defined *occupancy* as the presence of an adult goshawk associated with a nest structure. Steenhof and Newton (2007) define *productivity* as the number of young produced per pair, and we adhered to this definition to the extent allowed by the available data. In our analyses of productivity, we also included data on young produced per nest or per nesting attempt, and from one study, whether or not nests fledged any young.

The literature on goshawk nesting habitat used in this analysis reports data at two spatial scales: the nest site (<1 ha area surrounding the nest tree) and nest stand (the 1–30 ha area surrounding the nest tree, often including alternative nest trees; per McGrath et al., 2003). In our study, *site* refers to both scales and because of the small number of studies we do not evaluate each scale separately. This is one of several plausible source of variability in our results.

Acceptable tree-size variables included diameter at breast height, canopy height, stand age, stand height, mean tree height, percent late seral forest, or forest structure calculated from diameter at breast height, canopy closure, and tree density. It is important to note that we are not assessing preference for particular ages or sizes of trees, only whether within each original study, local variation in tree size or age correlated with occupancy or productivity. We excluded measures of tree size that were confounded by measures of tree density (such as basal area per stand) because in