SAPROXYLIC BEETLE SPECIES ASSOCIATIONS WITH STRUCTURAL COMPOSITION OF RED PINE COARSE WOODY DEBRIS AT HOGARTH PLANTATION

By

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ABSTRACT

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Keywords: beetles, coarse woody debris, decay, decomposition, ground dead wood, Hogarth Plantation, microhabitats, red pine, saproxylic, standing dead wood,

How forest management practices affect the biodiversity of saproxylic insects is currently poorly understood. Since these insects play a role in nutrient cycling, failure to properly manage for saproxylic insects could lead to their local extirpation, resulting in cascading effects on site productivity and nutrient cycling. We must take action to better understand these communities, their roles and niches, and how to best preserve them. In this study, the associations of saproxylic beetle assemblages with two different spatial orientations of coarse red pine woody debris at Hogarth plantation were examined. Flight interception traps were used to sample saproxylic beetle assemblages based on their association with either standing dead wood or dead wood lying on the ground. The insect samples were sorted, pinned and identified to morphospecies. Biodiversity analyses were conducted to better understand beetle diversity associated with dead wood orientation. A greater species richness of saproxylic beetles associated with dead ground wood was estimated than what was sampled, indicating that sampling effort was not sufficient. This highlights the need for additional studies that use more intensive sampling to improve understanding of Saproxylic insect species diversity at the Hogarth Plantation.

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INTRODUCTION

Declines in biodiversity due to anthropogenic influences are placing valuable ecological functions at risk (Caballos et al. 2015). Saproxylic arthropods assemblages change in abundance, species richness, and species composition in respond to human-caused disturbances (Langor and Hammond 2008). Forestry management practices lack critical knowledge of species that perform the important ecological service of nutrient cycling and their reliance on a variety of deadwood biomass (McGill and Spence 1985; Langor and Hammond 2008; Ranius et al. 2017). The potential for extirpation of saproxylic beetles associated with forestry operations is not yet understood and could result in cascading negative effects in forest ecosystems (Tilman et al. 2001, Naeem 2002). Valuable ecosystem services involved with nutrient cycling offered by saproxylic insects are at risk of being lost if not understood (Hägglund and Hjältén 2018). The assessment of saproxylic species, their habitat preferences, and how to best emulated natural habitat composition post disturbance is required to attain broad goals of sustainable forestry management (Langor and Hammon 2008). The composition of saproxylic insect communities are different depending on dead wood substrate, with the most apparent differences occurring between standing and lying dead wood (Hanglund and Hjaltven 2018).The objective of this study was to examine saproxylic beetle assemblages associated with different spatial orientations of coarse woody debris (Standing and ground) of red pine (*Pinus resinosa* Aiton) at Hogarth Plantation. My hypothesis was that ground deadwood would support a greater diversity of saproxylic beetle species because more there is more microhabitat abundance due the occurrence of multiple stages of decay and consistent abiotic factors (Hammond et al. 2004, Seibold et al. 2017).

LITERATURE REVIEW

LOSS OF BIODIVERSITY

Anthropogenic activity, such as human land use is one of the biggest threats to global species richness (Maxwell et al. 2016). Species diversity at a global scale has called for many precautionary measures such as that of the Nagoya protocol (a convention comprised on 96 countries) which called for 17% of terrestrial habitats internationally to be protected by 2020 (this year) to aid the status of biodiversity at a global scale (Hamalainen et al 2018). The conservation of biodiversity is thought to be a good approach to assessing and understanding ecological functions and processes that are poorly understood and difficult to monitor; the assumption being that the conservation of the biotic components of an ecosystem at natural levels ensures the preservation of ecosystem processes (Spence et al. 1999; Langor and Spence 2006).

INSECTS IN DECLINE

Presently, lists of threatened species feature saproxylic species, with 27% of the saproxylic beetle species of Europe designated as threatened and 500 species re-listed in Sweden (de Jong et al. 2004; Nieto and Alexander 2010; Hägglund and Hjältén 2018). Recent studies regarding the impacts of forestry operations on saproxylic beetles in all cases to date have shown that saproxylic arthropods respond to human-caused disturbances in terms of abundance, species richness, and species composition making it important to assess these saproxylic species to attain broad goals of sustainable forestry management (Langor and Hammond 2008).

For saproxylic beetles who have strong associations with dead wood, timber harvesting operations have significantly affected assemblages (Langor and Hammond

2008) because it reduces the amount of wood biomass and variety of different diameter CWD in a forest and thereby threatens the biodiversity of saproxylic beetles (Seilbold et al 2017). With increasing demand for bioenergy that utilizes logging residue (de Jong and Lönnberg 2010; Walmsley and Godbold 2010) which would otherwise be left to decompose on the forest floor postharvest acting as a source of dead wood for saproxylic species, the removal of this source of dead wood could potentially adversely affect saproxylic species (Stokland et al 2012). Large decreases in dead-wood volume, especially CWD, have been cited as a major factor leading to decreases of Fennoscandian invertebrate groups in northern Europe (Heliövaara and Väisänen 1984). With the present losses in biodiversity in the boreal ecosystems it is suggested that more proactive dead wood management is needed (Hänglund and Hjältén 2018).

NEED FOR BETTER-UNDERSTANDING THE HABITAT REQUIREMENTS OF SAPROXYLIC INSECTS

The diverse assemblages of saproxylic insects in Canadian forests' dead wood are poorly understood as their assessment poses significant challenges with respect to sampling, taxonomy, and analysis (Langor and Hammond 2008). Nonetheless, their assessment is critical as Canada's many successional stages of forests remain in their natural condition, providing an opportunity to gather baseline data to aid in the assessment of future trends (Langor and Hammond 2008). The saproxylic fauna consists of many families and genera that have poorly known taxonomic, biological, and microhabitat requirements (Langor and Hammond 2008).

Much greater research effort is required to better-understand the habitat requirements saproxylic arthropod species in Canada (approximately 180 species)

(Langor and Hammond 2008). To perform effective biodiversity monitoring, understanding how saproxylic insect abundance and diversity are affected by environmental conditions is required (Spence 2006). Saproxylic species such as bark- and wood-boring beetle families have the most complete information regarding host tree species relationships, most likely due to their economic importance (Langor and Hammond 2008). Baseline information on species composition and diversity under "natural" conditions is important, so that a body of knowledge is available to be compared with upon future studies or post disturbances (Langor and Hammond 2008). There is still little-known about the effects of forestry operations and intensification on saproxylic species (Ranius et al. 2017). Understanding the relative impact of forest practices on saproxylic insect biodiversity compared to that of natural disturbances provides mounting evidence that species richness is positively correlated to time since disturbance (Tilman et al. 2001; Naeem 2002).

IMPORTANCE OF DECOMPOSERS AND SAPROXYLIC SPECIES

The natural primary causes for dead and dying wood in a forest are low-intensity forest fires, self-thinning, and the actions of insects and fungi (Harmon et al. 1986). Saproxylic species are those that have some part of their life cycle associated with microhabitats found in or on ("feed, need, or breed on") dead wood. These species are of great ecological importance in regards to nutrient cycling and soil processes by direct feeding activity or by vectoring cellulolytic fungi (McGill and Spence 1985; Langor and Hammond 2008). The decay of wood is hastened by saproxylic insects as they mechanically break down wood, creating internal voids and introducing microbes and fungi which progressively degrade structural components of the cell walls of wood leading to loss of strength (Harmon et al. 1986). Saproxylic species have evolved foraging specializations and utilize different types of dead wood (Hägglund and Hjältén 2018). It is thought that saproxylic species that are fungivores, scavengers and generalist predators and have more general foraging requirements than a groups that feed exclusively on fresh phloem or sapwood and associated specialist predators (Langor and Hammond 2008). Other factors influencing forage preference include the spatial orientation, diameter, species of tree, stage of decomposition and abiotic factors (Hägglund and Hjältén 2018).

Taxonomically diverse saproxylic assemblages exhibit high functional diversity as they include wood and bark feeders, predators, parasitoids, fungivores, and scavengers (Langor and Hammond 2008). Succession of saproxylic species on dead wood is attributed primarily to wood decay, causing physical, chemical and biological changes in the wood (Hammond et al. 2004). The earliest colonization phase on dead wood tends to be dominated by bark beetles and woodborers, followed by fungivores dominating later saproxylic assemblages (Hammond et al. 2004). Many saproxylic species have very specific microhabitat associations, many of which are not distributed evenly within, or among, stands, causing assemblages to exhibit high spatial variability (Siitonen 2001; Hammond et al. 2004). Saproxylic beetles are closely tied to soil cycling the "fundamental level of ecosystem chemistry" thus aiding forest constituents, and their poor ability to disperse makes them vulnerable unsuitable or changing local conditions (Langor and Hammond 2008). Because of their narrow habitat associations, saproxylic species can be regarded as the "canary in the coal mine" of forests and aid as an early-warning system in evaluating forest management techniques (Langor and Hammond 2008).

MONITORING APPROACHES

Saproxylic beetles are a difficult group of species to study as they are small, cryptic, difficult to sample, and high in species richness (Bouget et al. 2008). Methods for sampling saproxylic insects are conducted primarily in two ways: activity-based traps or directed search. Activity-based traps have higher specimen yields, but assemblages are dependent on species activity and propensity to be trapped, while directed-search methods generally have a smaller yield of specimens per unit effort but can often provide greater information regarding habitat associations (Hammond 1997). There are advantages and biases to each approach. Some of the advantages to the activity-based trap, such as flight-intercept traps that attach to the boles of snags, logs and stumps, are that they are inexpensive, efficient and non-destructive to coarse woody debris (CWD) (Langor and Hammond 2008; Burns et al. 2014). Disadvantages associated with activity-based traps include a lack of representation of the species resident to the specific CWD and the possibility of catching individuals simply flying by the CWD that the trap is attached to (Jacobs 2004; Wikars et al. 2005). Also, it is widely recognized that composition of saproxylic insect assemblages obtained from activity-based traps is strongly affected by tree species composition (Siitonen 2001; Lindhe and Lindelöw 2004, Seibold et al. 2017). The main methodological challenges associated with sampling the canopies of trees is access due to height making the use of additional equipment to reach the crown a requirement (Seibold et al. 2017).

Flight interception traps are a form of passive trapping used for capturing flying Coleoptera and other insects (reference). These traps have the advantage of being low cost to obtain, making them ideal for conducting large-scale invertebrate surveys (Burns et al. 2014). Window-flight trapping was first developed by Chaman & Kinghorm (1995) and is now the most commonly used technique for catching flying saproxylic beetles (Bouget et al. 2008). Trunk window traps have been shown to be a highly effective method for surveying saproxylic beetles. Flying adults circling a tree of interest for food, mates, nesting or egg-laying sites will impact the transparent window that is situated at a right angle to the trunk and will fall down into or fly down into a container with preserving fluid (Burns et al. 2014). Most of the newly found species at the sites are those from the families Ptilidae, Nitidulidae and Tetratomidae which are difficult to collect due to their small size by hand but are caught in passive window-flight traps (Burns et al. 2014).

Unfortunately, there are currently no standardized sampling methods for saproxylic beetles. The creation of standardized sampling methods would aid in biodiversity monitoring schemes, optimize field methods, and allow for meaningful comparisons of data obtained from sites with different vegetation and soil types (Bouget et al. 2008). Still, little is known regarding the effectiveness of window-flight trapping regarding temporal and spatial parameters thus more investigation should be done to better understand the effects of trap parameters (Bouget et al. 2008).

MICROHABITAT PREFERENCES

Dead wood provides unique structural characteristics which provide habitat for organisms ranging from microorganisms to arthropods and vertebrates (Edmonds and

Eglitis 1989; Cobb 2006). The degradation of CWD due to the activity of fungi and other microorganisms results in changes to physical and chemical properties of CWD over time, (Boddy 1992; Renvall 1995). The decomposition of CWD over decades, is associated with successional changes in the composition of saproxylic species assemblages (Esseen et al. 1997, Siitonen 2001,).

Vertical gradients in light, temperature, moisture, and affect the properties of dead wood in the forest canopy compared to dead wood of lower strata or on the forest floor (reference). For example, forest floor versus canopy dead wood differ in the proportions of sun-exposed and shaded dead wood, and may be composed of different wood diameter classes and distributions (Seibold et al. 2017). This gradient gradients of saproxylic beetle assemblages in the vertical strata. For example, certain species of insects are better-able to colonize dead wood of the upper canopy that have harsher abiotic conditions (Seibold et al. 2017). Abundance of saproxylic beetles are found to be significantly higher near the ground than in the upper or mid-canopy, while the diversity of species in the upper canopy is highest and mid-canopy and ground level habitats are lower (Seildbold et al. 2017). Areas of greater dead-wood connectivity have been shown to have high species diversity than those with a clumped habitat distribution (Schiegg 2000). Composition of saproxylic insect communities are different depending on dead wood substrate, with the most apparent differences occurring between standing and lying dead wood (Hanglund and Hjaltven 2018).

Stand age appears to be an important predictor of saproxylic species richness, as as mixed spruce-hemlock-pine stands in Nova Scotia of 80 years or more in age have been found to support much higher saproxylic species richness than younger stands

(Dollin 2004). High abundance and species richness of saproxylic insects are generally associated with old and over-mature stands because theypossess more structurally diverse and larger diameter CWD, and a wider range of substrates and microhabitats than immature and mature stands (Martikainen et al. 2000). Structural and microhabitat diversity appears to increase as large snags are recruited in old stands (Langor and Hammond 2008).

Creating a variety of different dead wood substrates is of great importance when aiming to improve conditions for saproxylic insect biodiversity in boreal landscapes (Hanglund and Hjaltven 2018). Indicator-species analysis has shown old stands to have a greater number of species. For example, Hammond et al. (2004) reported the presence of ten indicator species in old stands but only three in mature stands . Species diversity of saproxylic beetles roughly three times higher around CWD in more advanced decay classes than newly deceased CWD, which has lower diversity but high activity/abundance of saproxylic beetles (Hammond 1996). Though newly dead wood has a higher amount of nutrient-rich resources, such as phloem and sapwood, it has lower microhabitat diversity than woody debris in more advanced stages of decay (Langor and Hammond 2008). Fauna that requires fresh phloem or sapwood are capable of colonizing fresh CWD such as phloeophages, xylophages, and ambrosia beetles while species richness of fungivores, scavengers, and predators tend to increase with more advanced decay classes (Hammond et al. 2004; Vanderwel et al, 2006).

Changes in saproxylic beetle fauna with increased decay of CWD in Canada proceeds most rapidly during the first two years after the death of a tree (Hammond et al. 2001, 2004; Vanderwel et al. 2006; Jacobs et al. 2007). The boreal forest landscape is shaped by natural disturbances such as fire, insect outbreaks, fungi, and windthrow that create a shifting habitat mosaic of the vary in size, shape, composition, and age (Langor and Hammond 2008). These disturbances all create dead wood, and there is a positive correlation between species richness of saproxylic beetle species and the diversity and volume of dead wood, with a greater wood volume being a stronger predictor for higher species richness than wood diversity (Hamalainen 2018). The natural-disturbance paradigm for forest management has been widely accepted as the optimal way towards sustainable management of the boreal forest (Hunter 1993). Mounting evidence indicates that the number and identity of species occurring in an ecosystem have a meaningful relationship to that ecosystem's stability (Tilman et al. 2001; Naeem 2002).

Comparisons of the effects of fire and harvesting indicate that clearcutting does not emulate wildfire disturbance with respect to biodiversity and faunal response, and ongoing studies in the Canadian boreal forest look to find harvesting that creates ecological conditions and habitats similar to those created following fire disturbance (Langor and Hammond 2008). Forest practices meant to mimic fire disturbance on the landscape leave smaller amounts of dead wood biomass and different wood diameters in a forest than a natural fire disturbance would, thus threatening the biodiversity of saproxylic beetles (Seilbold et al. 2017). Dead wood left behind after forestry operations is physically and ecologically different from that created by fire or other natural disturbances, each yielding a different quality and quantity of dead wood (Langor and Hammond 2008). Efforts are being made to understand how timber harvest operations can be improved to better preserve the structural and habitat complexity created by natural disturbances, as harvesting is quickly replacing fire as the major stand-replacing disturbance in boreal forests (Pratt and Urquhart 1994). Dead-wood is critical for the survival of some species, and it is becoming increasingly accepted that the incorporation of dead-wood management into forest ecosystem management is required (Franklin et al. 1997; Lee et al. 1997; Hagan and Grove 1999).

METHODS

The method of collection of saproxylic insects for this thesis followed the methods outlined in Burns et al. (2014). Trunk window traps were constructed using collection trays containing a preservative (propylene glycol) and a solid transparent "window" that was fixed at a right angle to the tree trunk above a collecting tray (Figure 1). Both the window and collection trays were secured in between two wooden stakes; one tied against the tree trunk and another one placed into the ground approximately 20 cm away from the trunk (Burns et al. 2014). The trunk window trap functions by interrupting insects that are flying in close proximity to the trap, and when they strike the transparent window they fall into the preserving liquid inside the collection tray (Burns et al. 2014).

The sampling area consisted of multiple sites within the Hogarth Plantation (Figure 2), a 44-hectare woodlot located 14.3 km from the Lakehead University campus in Thunder Bay and is used by The Faculty of Natural Resources Management for teaching and research (Lakehead 2013). Sites for trunk window traps were selected based on the presence of dead or decaying wood structures (piles, trees, stumps, and snags), and also based on if the dead wood was free-standing (standing dead wood) or laying on the ground (ground dead wood).

Figure 1. Two examples of the SDW (left) and GDW (right) sites that were sampled with flight intercepting trunk window traps.

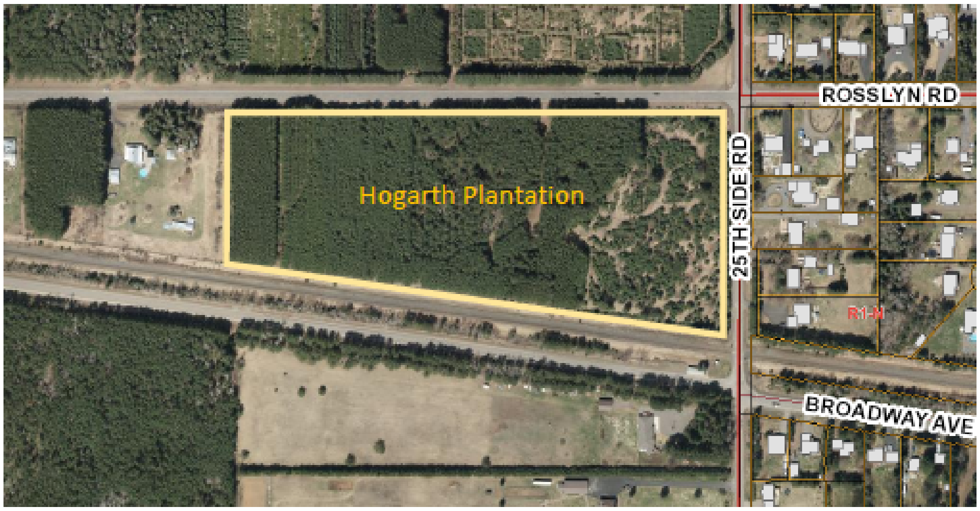

Figure 2. Arial map of Hogarth plantation at the corner of Rosslyn and 25th Side road.

Insect samples were collected from trunk window traps and were separated by site and dates collected. Samples were sorted and only individuals of the order

Coleoptera were transferred from the propylene glycol, placed into smaller containers containing 70% ethanol and labeled with corresponding sites and dates. Individuals of Coleoptera were then individually pinned and identified to family using keys to the Coleoptera in Marshall (2017) and Triplehorn and Johnson (2005). Individuals within each family were then sorted into 'morphospecies'. Data analysis was conducted using the Shannon Index (Shannon and Weaver 1949), Simpson Index (Simpson 1949), and RStudio packages "ggplot2", "Vegan", and "INext" (RStudio Team 2015) to create sample-size-based rarefaction and extrapolation curve for both types of dead wood trap sites with 95% confidence intervals.

RStudio was used to create and plot Hill numbers for both SDW and CDW using the calculated Shannon Index and Simpson Index. Hill numbers, also known as the effective number of species, are increasingly used to characterize the taxonomic, phylogenetic, or functional diversity of an assemblage (Chao et al. 2014). Empirical estimates of Hill numbers were used as an indicator of completeness of sampling effort such as that of species richness (Chao et al. 2014).

RESULTS

The collection trays of the flight intercept traps at Hogarth Forest caught a total of 311 individuals belonging to 13 different families and 60 morphospecies of Coleoptera. Standing dead wood (SDW) traps caught 154 individuals representing 42 morphospecies and ground dead wood (GDW) traps caught 157 individuals representing 46 morphospecies. Forty-five of the morphospecies were caught in both types of traps associated with SDW and GDW. SDW trap sites had a Shannon Diversity index of 3.43

and a Simpson index of 0.966 while GDW had a Shannon Diversity index of 3.3 and a Simpson index of 0.95 (Figure 3). Therefore, standing dead wood and ground dead wood have similar diversity. However, GDW had 10 singletons, a morphospecies represented by one individual, and SDW only had 5, making GDW more uneven. The Hill numbers calculated using the Shannon and Simpson indices' values were 31.11 and 25.12 for SDW and 27.14 and 18.63 for GDW, respectively. The greater variation between Hill numbers indicates unevenness in GDW. The variation between these values is greater in GDW because the Simpson index is more sensitive to evenness which is why this value is much lower than the hill number using the Shannon index. The extrapolated morphospecies richness curve for GDW does not reach an asymptote until approximately 150 morphospecies are found, requiring a sample of 3000 individuals. The extrapolated morphospecies richness curve for SDW reaches an asymptote at just over 50 morphospecies requiring the sampling of approximately 600 individuals. This suggests that the sampling of GDW was incomplete and a higher sampling effort is needed for more conclusive results that could possibly show that GDW has greater richness than SDW. The extrapolated richness for GWD may could also be much lower than the greater extrapolated value as shown by error bars (Shaded area in figure 3.)

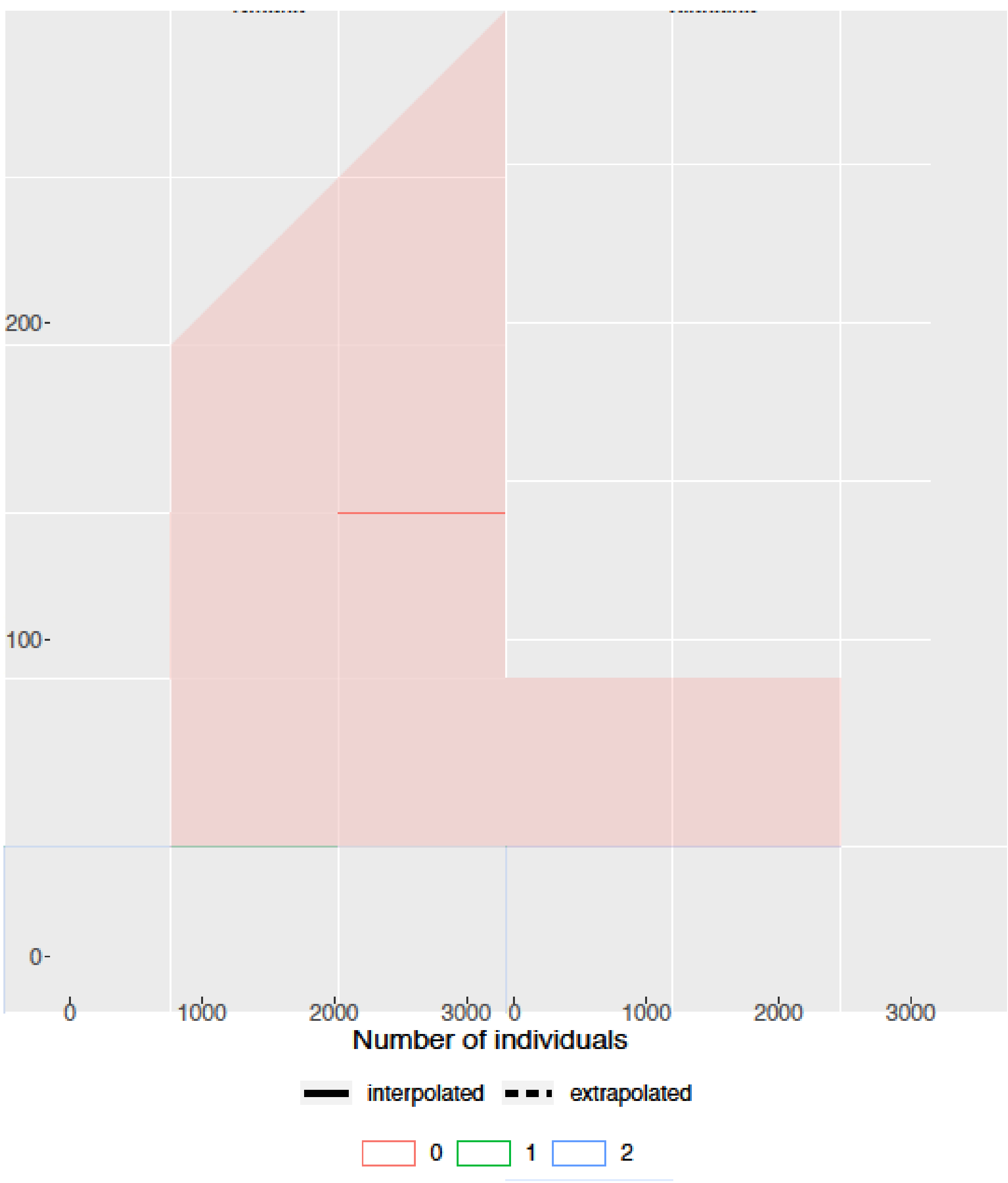

Figure 3. Sample-size-based rarefaction (solid lines) and extrapolation (dashed lines) of saproxylic beetle morphospecies diversity based on Hill numbers (0=Species richness, 1= Shannon Index, 2=Simpson Index) for ground and standing dead wood trap sites with 95% confidence intervals (Shaded areas of 0,1,2) based on 3000 replications.

MORPHOSPECIES COMPOSITION BY FAMILY

The 12 families of Coleoptera sampled during this study included Boridae, Buprestidae, Cerambycidae, Elatridae, Lampyridae, Leiodidae, Melandryidae, Mordellidae, Nitidulidae, Scarabaeidae, Silphidae, Staphylinidae and the 1 superfamily Curculionidae (Figures 4 & 5).

A total of two individuals representing one morphospecies were sampled from the Boridae family. Both larvae and adult forms of Boridae, or 'Conifer Bark Beetles', live under the bark of dead trees (Triplehorn and Johnson 2005). Some members of this family are capable of thanatosis (the act of withdrawing their legs and "playing dead") when exposed (Marshall 2017).

A total of two individuals representing one morphospecies were sampled from the Buprestidae family. Adults of Buprestidae are best known for their metallic jewel-toned exoskeleton and torpedo shape but it is the large, white larvae (known as flat-headed borers) who burrow in sapwood creating distinctive, flattened burrows (Marshall 2017). Most Buprestidae are attracted to and bore in dead or dying trees (Triplehorn and Johnson 2005) but some, such as the Emerald Ash Borer (*Agrilus planipennis)*, will attack healthy trees and can quickly kill them (Marshall 2017). Eggs are usually laid in crevices in the bark and larvae, once hatched, tunnel into the bark and some into the wood creating galleries where pupation occurs (Triplehorn and Johnson 2005). Most species of Buprestidae exist as wood borers in North America but some exist as leaf miners, live in galls or stems, and some feed on pollen as adults (Triplehorn and Johnson 2005; Marshall 2017).

A total of 28 individuals representing 10 morphospecies were sampled from the Cerambycidae family. This large family consists of 900 species and 300 genera in North America, all of which are phytophagous (Triplehorn and Johnson 2005). Commonly known as the long-horned beetles, the diverse family of Cerambycidae is easily identified by their long antennae and the characteristic "squeak" they make (Marshall 2017). Larvae of this family are called round-headed borers because of their habit of boring into dead or living wood or herbaceous plants and creating circular galleries (Triplehorn and Johnson 2005; Marhsall 2017). Larvae that pupate wood have relatively long developmental times due to the low nutrition available in wood, and some even have symbiotic organisms that aid in the digestion of wood cellulose (Marshall 2017). Nocturnal adults seek shelter during the day under the bark or resting on the surface of trees (Triplehorn and Johnson 2005).

A total of 27 individuals representing seven morphospecies were sampled from the Curculionidae family. The charismatically beaked beetles of the Curculionidae, the weevils, are the largest superfamily of living things on the planet (there are more weevil species than all vertebrates combined) consisting of 7-13 taxonomic families (Triplehorn and Johnson 2005; Marshall 2017). Weevils are chewing insects that use their mandibles at the end of the prolonged anterior of their heads (or "snout") to drill and bore into nuts, fruits, bark and other plant tissues (Triplehorn and Johnson 2005; Marshall 2017). Northern America is home to more than 3500 species (Triplehorn and Johnson 2005) and is graced with the "evil weevils", a variety known for their destructive abilities (Marshall 2017). For example, the White Pine Weevil (*Pissodes strobi*), have larvae that will tunnel into and kill the terminal leader of young white pines, distorting the growth of the tree (Marshall 2017). Practically all North American species of Curculionoidae are phytophagous with burrowing larvae infesting nuts, twigs, and bark (Triplehorn and Johnson 2005). The stout cylindrical weevils of the subfamilies Platypodinae and Scolytinae are known for their striking centipede-like engravings on the surface of the wood underneath the bark, giving them the name "engraver beetles" (Marshall 2017). Adult engraver beetles (both males and females) bore into wood and create galleries, damaging the host tree (Triplehorn and Johnson 2005; Marshall 2017). Females lay eggs that, once hatched as larval form, burrow out from galleries, pupate, and adults emerge from a round hole they chew through bark (Marshall 2017). Highly destructive species of engraver beetles in North America include Elm Bark Beetles (*Scotlytus multitriatus)* and Pine Shoot Beetles *(Tomicus piniparda)* which are both associated with pathogenic fungi that aid them in overcoming host tree defenses. This symbiotic relationship between the insect and fungi species is responsible for a great majority of insect-caused tree deaths in North American timber forests (Marshall 2017).

A total of 95 individuals representing 12 morphospecies were sampled from the Elateridae family. The family of click beetles, Elateridae, are impressive as they are able to "jump" without the use of any appendages but rather through the "clicking" of the head and thorax into a jackknife shape unique to this family of beetles (Marshall 2017). Members of this family are primarily recognized by the elongated posterior corners of their pronotum (Triplehorn and Johnson 2005). They are a physically large, diverse and widespread family with phytophagous adults that are often found in or near rotten or dead wood, as this is where their larvae are able to feed on other insects and pupate (Triplehorn and Johnson 2005; Marshall 2017).

A total of 27 individuals representing three morphospecies were sampled from the Lampyridae family. Fireflies of the family Lampyridae produce an efficient light by combining luciferin and luciferase with ATP in their abdomen for the purpose of mating (Marshall 2017). Adults are typically found on vegetation during the day while larvae are typically found where they are able to feed on smaller insects or snails (Triplehorn and Johnson 2005).

A total of 22 individuals representing two morphospecies were sampled from the Leiodidae family. The very cryptic family Leiodidae was once divided into at least two families and consists of beetles that live in mammal nests, carrion, and fungi (Triplehorn and Johnson 2005; Marshall 2017). The Leiodinae, a subfamily of Leiodidae, live in fungi, under bark, in decaying wood and in similar places (Triplehorn and Johnson 2005).

A total of 23 individuals representing four morphospecies were sampled from the Melandryidae family. The family of False Darkling Beetles, Melandryidae, consists of members that are often found under the bark of tree or CWD (Triplehorn and Johnson 2005; Marshall 2017). Members of this family are so variable in shape and size it is a bit of a “wastebasket” for beetles without notched eyes that do not fit into any other family (Marshall 2017).

A total of 12 individuals representing four morphospecies were sampled from the Mordellidae family. The Tumbling flower beetles of Mordellidae, named for their habit of launching themselves clumsily away when disturbed, are typically found on flowers but occasionally on dead wood as they develop in plant stems (Marshall 2017). The larvae of these species live exclusively in dead wood or plant piths with some being predaceous feeding on other small insects within the substrate (Triplehorn and Johnson 2005).

A total of 22 individuals representing five morphospecies were sampled from the Nitidulidae family. This family possesses a variety of decomposing genera that are frequently found under bark, damaged ears of corn, compost, and even on cadavers (Marshall 2017). Prominent members of this family are the beer beetles; shiny, reddish-yellow or orange-spotted, black beetles that are attracted to plant fluids that are fermenting or souring (Triplehorn and Johnson 2005; Marshall 2017). Some species are very commonly found under loose bark of CWD, especially if damp and moldy (Triplehorn and Johnson 2005).

A total of six individuals representing three morphospecies were sampled from the Scarabaeidae family. Species of Scarabaeidae vary greatly in size, colour, and habitat (Triplehorn and Johnson 2005). Scarab species are made up of groups feeding on roots, foliage, or dung (Marshall 2017). Rotting heartwood of standing trees is where the large white grubs of certain species of scarabs may be found (Marshall 2017).

A total of 16 individuals representing three morphospecies were sampled from the Silphidae family. These Burying Beetles bury carcasses in the soil by excavating underneath the carcass to avoid competition with some substrate-specific species (Marshall 2017). Certain members eat plant material, fungi, or maggots and other animals that live in decaying organic matter (Triplehorn and Johnson 2005; Marshall 2017).

A total of 29 individuals representing five morphospecies were sampled from the Staphylinidae family. This is the largest Coleoptera family in North America, with over 3,000 species and only second to the weevil family globally (Marshall 2017). Rove beetles are found often under decaying material such as logs where they may feed upon other insects, fungal spores and tissue, and pollen with very few parasitic upon insects (Triplehorn and Johnson 2005; Marhsall 2017).

Families with the lowest number of morphospecies (Figure 4) and individuals (Figure 5) sampled were the Boridae and Buprestidae, and the family with the greatest number of morphospecies and individuals sampled was Elateridae (Figures 4 & 5).

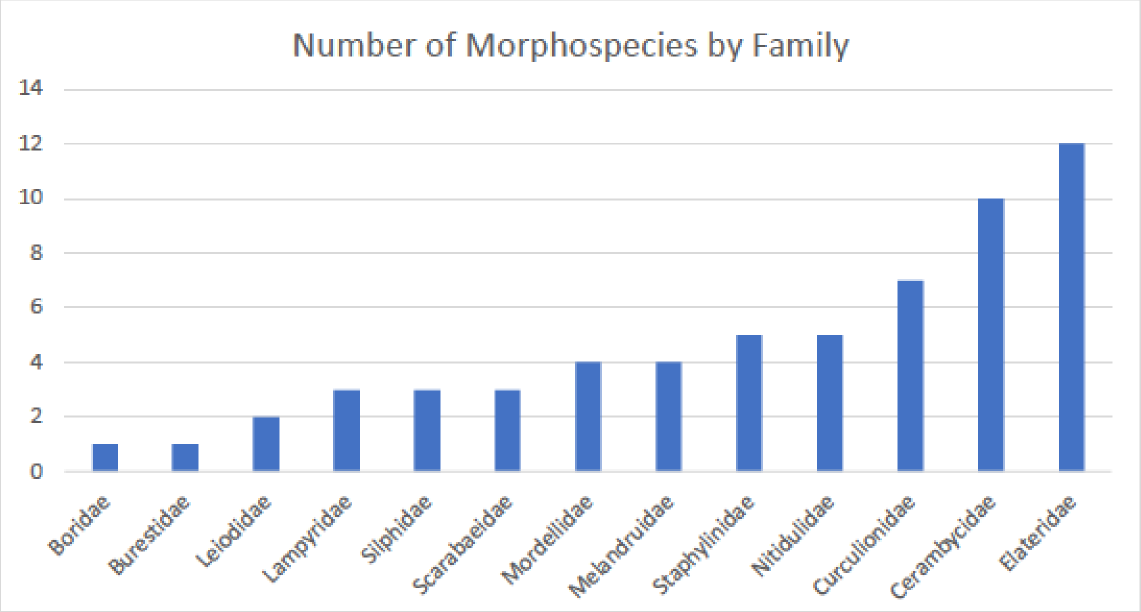

Figure 4. Number of morphospecies sampled by family.

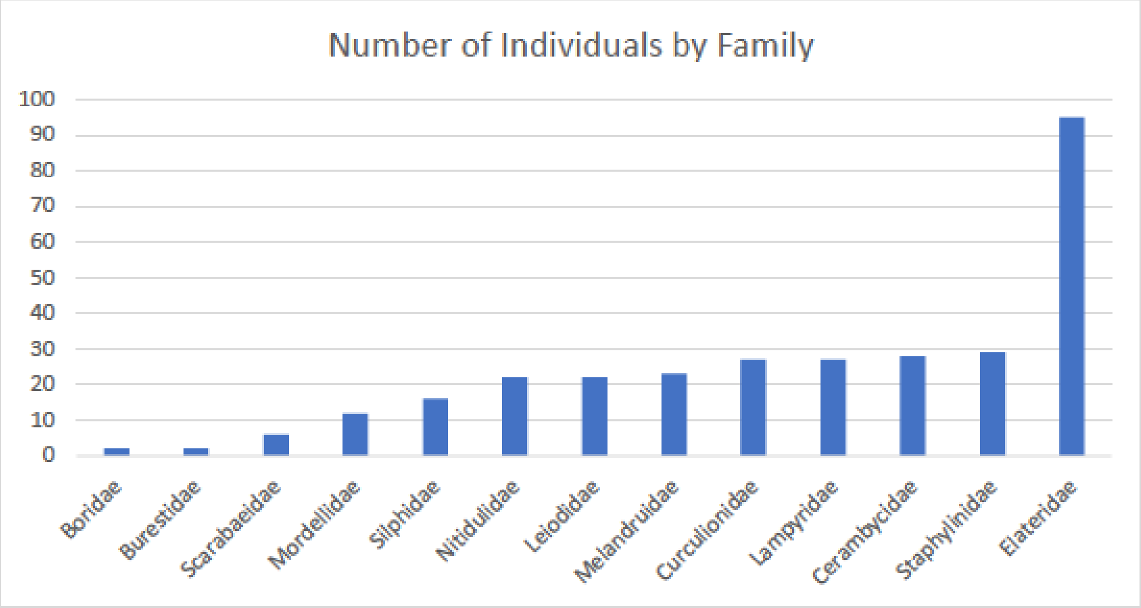

Figure 5. Number of individuals sampled by family.

DISCUSSION

Ground dead wood trap sites had the greatest number of individuals and morphospecies sampled, and very high extrapolated richness. However, the Shannon and Simpson indices for these traps had a lower, but very similar value as that of standing dead wood. This is likely due to the greater occurrence of singleton species in ground dead wood indicating some unevenness in the species richness. This is evident in the extrapolation of GDW morphospecies diversity, as the confidence intervals are extremely large for species richness. Future research conducted regarding this topic should increase the sample size for GDW associated traps to ensure more complete sampling of species richness.

The richness of GDW is extrapolated to be much larger than that of SDW. This is consistent with findings in the literature that conclude that CWD on or near the ground supports a greater abundance and diversity of saproxylic species than other types of

CWD (Seildbold et al. 2017; Hanglund and Hjaltven 2018). This is because there are a greater number of microhabitats available at GDW sites due to the variety of structure, stages of decomposition (succession of decay), and different diameters of CWD at the ground level of the forest floor (Martikainen et al. 2000; Langor and Hammond 2008; Hanglund and Hjaltven 2018). Fraver et al. (2018) define decomposition as the process of structural and chemical changes that occur in wood upon the death of a portion or the entire tree, thus creating microhabitats. Because GDW have a collection of different diameter classes of CWD accumulated over time, each portion may be at a different stage of decomposition. Depending on where the wood is located on the ground, it may also affect the rate of decay due to increased moisture (González et al 2008).Standing dead wood tends to decompose at a similar rate, with the bulk of the biomass existing at one successional stage of decay at a time, resulting in fewer microhabitats available. Harsher abiotic factors, such as temperature fluctuations, and desiccation due sunlight are prominent at exposed sections of the crown, but severity decreases in proximity to the cool, moist, shaded ground that facilitates more consistent temperatures (Seibold et al. 2017; Hanglund and Hjaltven 2018). The differences between the number and availability of microhabitats of these two dead wood sites and the abundance of singletons sampled at the GDW site aids in the explanation of why the extrapolation of species richness for the GDW trap sites in this research is so high.

The two beetle families with the lowest number of morphospecies and individuals sampled were the Boridae and Burestidae. Their low occurrence can be attributed to the small cryptic nature of Buprestidae and the strong associations of Boridae with hardwood tree species, as opposed to predominantly Red Pine composition at the study area (Marshall 2017). The most abundant morphospecies and individuals were those of the family Elateridae (Click Beetles). Their abundance may be attributed their large body size that is more easily trapped. Also, females in Elateridae lay their eggs in CWD, where their larvae will feed on other insects associated with dead wood (Marshall 2017). This could account for the high diversity of Elateridae species sampled.

The removal of CWD after harvest for uses such as biofuel should be conducted sparingly as it greatly reduces the amount and availability of microhabitats for saproxylic beetles (Seildbold et al. 2017). Further research should be conducted to better understand how forest harvest practices may be utilized to more closely replicate similar amounts and compositions of different diameter CWD as disturbances in the boreal (Tilman et al. 2001; Naeem 2002; Seilbold et al. 2017). Once a better understanding of disturbances' role in the creation of CWD is achieved, implementing practices to achieve similar results post-harvest may be used alongside knowledge of saproxylic beetle habitat preferences. Such knowledge should be incorporated into forest management practices to ensure the conservation of critical ecological processes. This will maintain forest health and improve the biodiversity of managed forest ecosystems.

CONCLUSION

Ground dead wood supports a greater biodiversity abundance of saproxylic beetle species. This is likely due to relatively greater diversity in microhabitats available than standing dead wood. This supports the body of knowledge that explains the habitat preferences of saproxylic beetles that provide the important ecological service of nutrient cycling. When making decisions regarding dead wood management during and post timber harvest, Forest Manager should try to best emulate composition and abundance CWD post fire disturbance to best mimic the natural conditions that saproxylic beetles species have evolved under in the Boreal Forest. A greater focus should be made to provide GDW habitats for saproxylic beetles than SDW. This is due to the greater species richness associated with GDW, thus ensuring more species (especially rarer singletons) have preferential habitat available. Because habitat loss and degradation is the primary cause for species decline it should be the first step in the preservation of biodiversity.

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APPENDICES

Table 1. Number of individuals at each dead wood site by morphospecies.

Morphospecies ID #	Standing dead wood	Ground dead wood
1	8	6
2	6	0
3	4	3
4	3	5
5	0	2
6	0	1
7	1	0
8	0	1
9	1	0
10	0	1
11	0	1
12	1	0
13	2	1
14	10	1
15	5	0
16	3	0
17	0	1
18	7	1
19	3	0
20	0	1
21	1	1
22	7	1
23	1	1
24	0	3
25	2	0
26	1	0
27	0	6
28	2	3
29	0	3
30	0	14
31	0	14
32	0	1
33	0	1
34	10	2
35	4	1
36	0	1

37	0	1
38	2	1
39	4	17
40	0	1
41	2	0
42	2	0
43	1	1
44	1	1
45	0	3
46	2	0
47	5	1
48	1	11
49	11	3
50	5	5
51	6	1
52	2	0
53	1	1
54	1	7
55	3	3
56	12	15
57	4	0
58	0	2
59	5	5
60	1	0
61	1	1

Table 2. Hill numbers created in RStudio for SDW and CDW trap sites.

Site	Diversity Observed Estimator	Hill Number
SDW	Species richness	42.00
	Shannon Diversity	31.11
	Simpson Diversity	25.12
GDW	Species richness	46.00
	Shannon Diversity	27.14
	Simpson Diversity	18.631