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Does surface-applied biochar alter insect utilization of downed ponderosa pine (*Pinus ponderosa*) bolts?

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Abstract

Biochar can be used as a soil amendment to restore degraded soils, sequester carbon, and increase soil water holding capacity and plant available water following harvest operations in a forest. On-site production and utilization of biochar is being explored as a forest management tactic. One benefit of the practice is the sequestration of C from unmerchantable forest biomass to produce biochar. Forest insects may be exposed to biochar when the material is applied to surface organic horizons and downed trees. How biochar affects insects' ability to locate and utilize downed woody material in the forest is undetermined. Two field experiments, with freshly downed sections (bolts) of ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson), were conducted to determine the potential impact of applied biochar on insect communities utilizing the bolts. In the first experiment, bolts were baited with a pheromone lure and biochar applied at a rate equivalent to 2,914 Kg ha^{-1} (1.30 tons acre^{-1}). The biochar treatment did not interfere with attack or emergence of the pine engraver *Ips pini* (Say) (Coleoptera: Curculionidae: Scolytinae) compared to untreated control bolts. In the second experiment, biochar applied at a rate equivalent to 5,604 Kg ha^{-1} (2.50 tons acre^{-1}) lowered species richness compared to non-treated bolts. In addition, one species, red turpentine beetle, *Dendroctonous valens* (LeConte) (Coleoptera: Curculionidae: Scolytinae) were more abundant in non-treated bolts compared with biochar-treated bolts. Utilization of bolts by other insect taxa such as longhorn beetles (Coleoptera: Cerambycidae) was similar in non-treated and biochar-treated bolts.

Keywords

Downed woody residue, forest management, soil amendment, Scolytinae, Cerambycidae

Introduction

Insects provide numerous ecosystem services contributing to the functionality and resilience of forest systems including decomposition and nutrient cycling (Furniss and Carolin 1977). Many taxa including bark beetles (Coleoptera: Curculionidae: Scolytinae), roundheaded wood borers (Coleoptera: Cerambycidae), flatheaded wood borers (Coleoptera: Buprestidae) and woodwasps (Hymenoptera: Siricidae), help cycle nutrients by increasing the breakdown rate of woody material which contributes to accumulation of soil organic matter (Furniss and Carolin 1977). These insects introduce microbial associates that assist in metabolism, breaking down lignin to begin the decomposition process (Adams et al. 2013, Hofstetter et al. 2015, Paine et al. 1997).

Biochar is a carbon-rich material created by the breakdown of organic biomass (Biederman and Harpole 2013) in a high temperature, low oxygen environment (Bridgwater and Maniatis 2004). The application of biochar to surface organic horizons in forest stands can sequester carbon while increasing soil nutrient retention (Borchard et al. 2019), water holding capacity (Abit et al. 2012, Lehmann et al. 2006), plant available water (Edeh et al. 2020; Razzaghi et al. 2020) and providing other ecosystem services (Blanco-Canqui 2021). Application methods vary depending upon the size of the area treated, but using current forest harvesting equipment biochar can be applied to the soil surface and surrounding vegetation without tilling activities (Page-Dumroese et al. 2017), therefore any exposed surface can become covered with biochar. Biochar becomes vertically incorporated into the soil structure over time as precipitation and freeze/thaw activities naturally disperse the material and gradually allow it to penetrate soil horizons. On-site production and utilization of biochar is being explored as a climate-smart management tactic in forestry to mitigate climate change by increasing C sequestration in the soil (Franco et al. 2024). Along with the sequestration of C from unmerchantable forest biomass, the potential benefits include retention of soil water and nutrients along with decreasing the occurrence of catastrophic wildfires and drought (Franco et al. 2022). We hypothesized that biochar on the surface of host materials may alter the ability of insects to locate and utilize that material when they bore through the biochar to enter the tree for reproduction (i. e. adult bark beetles) or when adults must land and chew through the material to oviposit (i. e. flatheaded and roundheaded wood borers).

The pine engraver, *Ips pini* (Say) (Coleoptera: Curculionidae: Scolytinae) typically colonizes weakened, stressed, and recently killed trees such as fallen trees or logging residue (Cognato 2015, Hoffstetter et al. 2015). *Ips pini* males that successfully attack a host tree create a nuptial chamber where they mate with two to six female beetles (Cognato 2015). After mating, each female constructs an egg gallery radiating away from the nuptial chamber and oviposits in niches cut into the sides of the gallery (Furniss et al. 1977). In some *Ips* species, multiple males may use a single nuptial chamber and multiple females may create egg galleries coming from each single chamber (Cook et al. 1983). Therefore, while the density of nuptial chambers is not a precise measure of attack density, it does provide an estimate that is retained on the wood of the attacked tree and can be used to compare among treatments. *Ips pini* use aggregation pheromones released by colonizing male beetles in combination with host tree-emitted compounds to attract conspecifics (Wood 1982, Wegensteiner et al. 2015). Ipsenol, ipsdienol, and *cis*-verbenol are the main semiochemicals produced in the beetle's gut when the male beetle feeds on host phloem (Wood 1982) or are oxidation by-products of host tree terpene compounds (Renwick et al. 1976).

When applied in a forest, biochar will land on exposed surfaces, including surface organic matter, downed coarse and fine woody residues, seedlings, and understory plants. The application rate and method will determine the extent of the soil surface that is covered which influences the level of exposure to the material of larval and adult insects. While it is not established if biochar affects insects' ability to locate and utilize host material in the forest, recent laboratory studies demonstrate a potential negative impact of biochar on insects and the infectivity of entomopathogenic nematodes (Yaman et al. 2021). A second study reported that contact with dry biochar decreased survival in three of the four insect species examined including *Formica obscuripes* (Forel) (Hymenoptera: Formicidae), *I. pini* and *Temnochila chlorodia* (Mannerheim), but survival of *Enoclerus sphegus* (Fabricius) was not affected (Cook and Rodrigues de Andrade Neto 2018). Another study reported decreased fecundity and survival with an increased time of development for the brown rice planthopper, *Nilaparvata lugens* (Stal) (Homopera: Delphacidae) reared in arenas with high concentrations of dry biochar (Hou et al. 2015). In addition, Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Lepidoptera: Erebidae) reared on a synthetic diet showed decreased survival corresponding with increasing biochar concentration as well as evidence of potential compensatory feeding when ingesting diet containing a low (10% volume/volume) concentration of biochar (Rice-Marshall et al. 2021). Finally, depending on feedstock, Yaman et al. (2021) concluded that biochar application may have detrimental impacts on some beneficial nematodes such as *Heterorhabditis bacteriophora* Poinar (Rhabditida: Heterorhabditidae).

The effect of biochar on insect utilization of downed woody material has not been investigated. Our experiments were designed to examine the potential impacts of surface-applied biochar on insect utilization of sections (bolts) of ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson). The specific objectives were to determine if (1) applied biochar interfered with attack or emergence of *I. pini*,a bark beetle that frequently attacks slash following harvest and (2) biochar alters either species richness or abundance of insects utilizing treated bolts.

Methods

Field Sites

Field sites were located in the University of Idaho's Experimental Forest, West Hatter Unit, (46°50'12.3"N, 116°51'48.9"W, 954.3 m elevation) approximately 12.0 km south of Potlatch, ID in Latah County. The field site is a mixed conifer stand, primarily ponderosa pine, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and grand fir (*Abies grandis* (Douglas ex D. Don) Lindl). The soil is predominantly Vassar in a Vassar-Jacot-Aldermand soil series (generally, ashy over loamy, amorphic over isotic, frigid (Typic Udivitrands; Soil Survey Staff 1999). The surface organic horizon (inclusive of the Oa, Oe, and Oi) was 2.5 cm of slightly decomposed plant material and the mineral soil consisted of approximately 53 cm of volcanic ashy silt loam on top of 28 cm of coarse sandy loam underlain with 46 cm of gravelly loamy coarse sand (Soil Survey Staff 2022). The understory consisted of a mixture of plants including Columbia brome (*Bromus vulgaris* (Hook.) Shear), Oregon boxleaf (*Paxistima myrsinites* (Pursh) Raf. (Celastraceae)) northern twinflower (*Linnaea borealis* L.), Idaho goldthread (*Coptis occidentalis* (Nutt.) Torr. & A. Gray), fragrant bedstraw (*Galium triflorum* Michx.) hookspurred violet (*Viola adunca* Sm.), Nootka rose (*Rosa nutkana* C. Presl) and bride's bonnet (*Clintonia uniflora* (Menzies ex Schult. & Schult. f.) Kunth).

Biochar

Biochar was produced in a gasification system (Tucker Engineering Associates, Locust, NC) by pyrolysis of mixed conifer sawmill residues (including Douglas-fir and lodgepole pine (*Pinus contorta* Douglas ex Loudon). Biochar used in these two experiments is from the same manufacturer and lot as was used in previous experiments (Anderson et al. 2013, Rice-Marshall et al. 2021), and has pH = 10.2, moisture content = 2.94%, bulk density (dry) = 0.17 Mg m-3, carbon = 91.5%, nitrogen = 0.89%, C:N = 103.0, BET surface area = 15.0 m2g-1, energy = 33.98 MJ kg-1 and a particle size distribution of <44 μm to 6.35 mm, centered around 0.84 mm (Anderson et al. 2013).

Experimental Procedures

During the first experiment, field exposure occurred for eight consecutive days in July 2015. Mean temperature in July 2015 was 20.6° C and there was 0.3 cm precipitation. To help control for between tree variation, bolts were cut from five ponderosa pines that were felled and two, adjacent 75 cm bolts were cut from the base of each tree. Two adjacent bolts from individual trees were considered a single, paired replicate. Bolts within a pair were placed on the ground a minimum of 2.5 m apart, with similar canopy cover and exposure conditions. Each pair was separated by a minimum distance of 50.0 m. Bolt diameters were measured at the midpoint and used to estimate the total surface area of the individual bolts which were similar for control (7,301 $\pm$ 602 cm^2) and biochar-treated (7,464 $\pm$ 508 cm^2) bolts.

Biochar treatments were applied to the bark surface of one randomly selected bolt in each pair. Approximately 215 g of biochar was applied manually to approximate what would have been applied if 2.9 Kg ha^{-1} had been applied over the site. The application rates fall within the range of other experimental applications (3 to 25 Mg ha^{-1}) (Page-Dumroese et al. 2017). Depending on the bark surface properties, biochar ranged from < 0.5 cm on smooth surfaces to > 2.0 cm in bark crevices.

Because the first experiment was designed to determine if a common bark beetle, *I. pini*, would be able to utilize the bolts regardless of biochar treatment, to ensure colonization, each bolt was baited near its midpoint with a pheromone pouch containing ipsdienol (Lot No. 3075; Synergy Semiochemical Corp, Burnaby, BC). After eight days, bolts were removed and cut into three 25cm sections, placed into individual emergence containers (BugDorm-1, MegaView Science Education Services Co., LTD.) and maintained in the laboratory under ambient conditions (temperature ranged from 20-24^{o} C). *Ips pini* were collected daily as they emerged for a period of six weeks. When no emergence occurred from any bolt for seven consecutive days, the bark was removed to limit further foraging by larvae of any wood-boring insects that may have been present and therefore preserve evidence of *I. pini* nuptial chambers. Total nuptial chambers and emerged *I. pini* beetles were counted.

The second experiment was conducted in June 2018 when the mean air temperature was 14.2^{o} C and there was 3.2 cm of precipitation at the site. Ten ponderosa pine trees were felled and two, adjacent 1.0 m bolts removed (similar to the first experiment). Longer bolts were used in the second experiment because we were interested in the entire attacking community of insects, some of which forage over larger areas compared with *I. pini*. Two adjacent bolts cut from each tree were again considered a paired replicate. Bolt diameters were measured, and surface area estimates were similar for control (4,588 $\pm$ 224 cm^2) and biochar-treated (4,585 $\pm$ 206 cm^2) bolts. Bolt pairs were left in the field under similar canopy cover and exposure conditions, with a minimum of 5.0 m separating the two bolts and a minimum of 30 m distance between pairs. Because we were interested in the ability of the overall insect community to find and utilize the bolts, no pheromone lures were placed on the bolts.

One randomly selected bolt from each pair was treated with approximately 425 g of biochar manually applied to the upper surface, approximately 2.0 cm thick which approximates an overall application rate of 5.6 Kg ha^{-1}. The higher application rate was used because bolts were going to be left in the forest for significantly longer. After 35 days in the field, bolts were cut into two 50 cm sections, transferred to the lab, and placed in individual plastic emergence containers (Rubbermaid, United Solutions Inc. Leominister, MA), with both sections from a single bolt placed in the same container. Nylon mesh material was placed over openings cut on each of the four sides for ventilation. Bolts were maintained at ambient laboratory conditions with a range of approximately 20-24^{o} C. Insects were collected daily as they emerged. After allowing the insects to emerge for one year, the bolts were peeled of bark and split to collect insects that had not emerged. When possible, all adult insects were identified to species and larvae were identified to the family level.

Statistical analysis

All statistical analyses were conducted using SAS 9.4 analytical software (2016 SAS Institute Inc., Cary, NC, USA). Bolt surface area was compared between treated and control sections using a paired Student's t test for each experiment.

In the first experiment, *I. pini* attacks were quantified by counting individual nuptial chambers and dividing by total surface area (cm^2) for each bolt. Adult emergence density was calculated by dividing the total number of collected *I. pini* adults by surface area (cm^2) for each bolt. Paired Student's t tests were used to compare attack and emergence densities of *I. pini* between biochar treated and non-treated (control) bolts.

In the second experiment, the total number of individual insects (abundance) as well as the total number of species (richness) in a bolt were measured. Non-parametric Wilcoxon rank sum tests were conducted on taxa where at least 50% of the bolts within a treatment were infested. When the 50% criterion was met, all ten pairs of bolts were used to compare the total abundance of each taxon between treated and control bolts. Paired Student's t tests were used to compare species richness between treated and control bolts pairs.

Results

Bark Beetle Attack and Survival in Treated Bolts

In the first experiment, individual bolts had an *I. pini* aggregation pheromone placed at the mid-point to insure attack by this bark beetle. There were a total of 259 *I. pini* nuptial chambers present in the five biochar-treated bolts compared with 250 in the five control bolts. Surface area (P = 0.8400; Table 1) and density of nuptial chambers (P = 0.5056; Figure 1) were similar between treated and control bolts.

Similarly, a total of 1,494 adult *I. pini* emerged from the biochar-treated bolts and 1,640 adults emerged from the control bolts. Density of emerged beetles (P = 0.7322) was similar between treated and control bolts (Figure 1).

Species Richness and Abundance in Treated Bolts

No lures were used in the second field exposure. Bolt surface areas were similar (P = 0.9959) between biochar-treated and control bolts. On average, a greater number of species (2.90 $\pm$ 0.46 (SEM)) emerged from the non-treated control bolts compared to the bolts treated with biochar (1.80 $\pm$ 0.29) (P = 0.0318) (Figure 2).

Following the year of collecting emerging insects, very few (alive or dead) were still present in the bolts, but there were some adult and larval *Dendroctonus valens* (LeConte) (Coleoptera: Curculionidae: Scolytinae), one adult *Anthaxia aeneogaster* Laporte and Gory (Coleoptera: Buprestidae), buprestid larvae, adult *Monochamus clamator* LeConte and *Monochamus obtusus* Casey (Coleoptera: Cerambycidae), cerambycid larvae and larval Siricidae (Hymenoptera). When comparing the number of species that were only found in the postemergence split bolts, the average number of species in the control bolts (0.10 species ± 0.10) was similar to the number in treated bolts (0.30 species ± 0.21) (P = 0.1679); several of the bolts had no insects present in them when they were examined.

Comparing both the number of individual taxa that either emerged or were found in the split bolts after the emergence period (with no species that were counted in the emerged category being double-counted in the split bolt category), the average number of taxa in the control bolts (3.00 ± 0.49) was marginally higher than in the treated bolts (2.10 ± 0.38), (P = 0.0676).

Overall, a total of 77 insects from 24 taxa emerged or were extracted from biochar-treated bolts, compared to total of 998 insects emerged or extracted from non-treated control bolts (Table 1). The total overall count of beetle larvae was more abundant in non-treated control bolts (P = 0.0278) as were the number of bark beetle larvae (predominantly *D. valens*) in bolts after a year-long emergence period (P = 0.0068). For all other emerged insects, no differences in abundance were found between biochar-treated and non-treated controls. However, the wasp, *Coeloides sympitys* Mason (Hymenoptera: Braconidae), flat bark beetle *Silvanoprus* sp. (Coleoptera: Silvanidae), minute pirate bug, *Anthocoris* sp. (Hemiptera: Anthocoridae) and flat bug *Aradus* sp. (Hemiptera: Aradidae) were only associated with non-treated control bolts. Minute pirate bugs are predators and specimens captured in the study were probably never in the bolts, but only on the surface of the bark. Many flat bugs are mycophagous and live under the bark of dead trees. Wood wasp larvae (Hymenoptera: Siricidae) and two species of flat-headed wood borers (Coleoptera: Buprestidae), *Anthaxia aeneogaster* Laporte and Gory and *Melanophila acuminata* (DeGeer) only emerged from biochar-treated bolts, although buprestid larvae were found in equal numbers in both treated and non-treated bolts.

Discussion

Carbon-rich biochar can contribute to long-term carbon sequestration and potentially reduce drought stress in vegetation because it can increase soil water holding capacity (Page-Dumroese et al. 2017, Sarauer et al. 2018) and plant available water (Blanco-Canqui, 2017). Therefore, the use of biochar as a soil amendment may benefit forest systems, especially in the restoration of disturbed sites with degraded soil. If biochar treatments are incorporated into forest management, it will be necessary to determine the potential effects on insects and other invertebrates. Although direct exposure of insects to biochar in a controlled laboratory setting may reduce weight gain, survival and fecundity (Cook and Rodrigues de Andrade Neto 2018, Hou et al. 2015, Rice-Marshall et al. 2021), direct exposure to biochar in the field may be less severe.

The first experiment was designed to examine the ability of *I. pini* to locate, attack and emerge from host material that had been surface-treated with biochar in the field and baited with their aggregation pheromone to ensure attack. The density of *I. pini* nuptial chambers and emerged beetles was similar for biochar-treated and control bolts indicating that attack and within-bolt survival were similar between treatments.

The second experiment did not use a pheromone attractant and was designed to examine species richness and abundance of the overall insect assemblage to find and utilize treated bolts under field conditions. After being placed into rearing containers, bolts in the second experiment were not disturbed for a year except to collect emerging insects.

The species of insects that emerged from individual bolts varied. Emergence of other taxa were similar between bolts that had biochar applied to the bark surface and control bolts. Some species of insects that emerged were only associated with non-treated control bolts (i.e. the parasitoid *Coeloides sympitys*, minute pirate bug (*Anthocoris* sp), fungus beetle *Silvanoprus* sp. and fungus-feeding flat bug *Aradus* sp.). The low number of bolts from which these species emerged probably affected statistical results. For example, the fungus beetles, *Silvanoprus* sp. only emerged from a single control bolt.

Other insect taxa such as the buprestids *Anthaxia aeneogaster* and *Melanophila acuminata* and larval siricid woodwasps, were only associated with the bolts that had been surface-treated with biochar. Siricid wasps are frequently attracted to burned material following fire where they oviposit in the burned trees (Costello et al. 2011).

One bark beetle species commonly found in north Idaho, *D. valens*, attacked and emerged in higher numbers from bolts that were not treated with biochar. Only three individuals emerged from a single biochar-treated bolt. The difference in number of emerged beetles may indicate that *D. valens* actively avoided bolts treated with biochar or that biochar may provide a physical barrier or in some way inhibit the ability of *D. valens* to locate host material. *Dendroctonus valens* is attracted to host volatiles and also has an aggregation pheromone to attract conspecifics so there may have been a pheromone-mediated behavior for which we cannot directly account.

Unlike in the first experiment where pheromone lures were placed on the test bolts, *I. pini* were not prevalent in the second experiment. Response by bark beetle natural enemies may be influenced by beetle colonization of host material. It is possible that the parasitoid braconid wasps associated with the control bolts were not being influenced by the biochar, but more the lack of their own hosts being present in biochar-treated bolts. Some bark beetle predators such as the trogositid, *Temnochila chlorodia* (Mannerheim), and the clerid, *Enoclerus lecontei* (Wolcott), were found associated with both the control and biochar-treated bolts. These predators may have reduced the overall number of insects that would have otherwise survived in the bolts. While they do prey on bark beetles, both *Temnochila* and *Enocleus* are abundant generalist predators that impact abundance of multiple prey species (Person 1940, Wegensteiner et al. 2015).

Conclusion

The first experiment demonstrated that when baited with a pheromone lure, biochar did not change the density of attacks or emergence from the bolts by *I. pini*. However, few *I. pini* were captured in either treated or control bolts during the second experiment. Another bark beetle, *D. valens*, was associated more with control bolts compared with surface-treated bolts in the second experiment. Tree colonization and tunneling behaviors of bark beetles such as *I. pini* and *D. valens*, and wood borers including cerambycids, buprestids and siricids contribute to decomposition of woody material and create infection routes for wood rotting fungi (Furniss and Carolin 1977). Biochar applied to the surface of downed tree could interfere with the insects' ability to locate, successfully attack and/or survive in the tree. However, the application of biochar may mimic the natural disturbance process of deposition of charred material following a wildfire (Harvey et al., 1979, DeLuca and Aplet 2008, Matovic 2011, Page-Dumroese et al. 2017), although the rate of conversion during a wildfire is 1-10% of the biomass burned (DeLuca and Aplet 2008) which is likely less than the targeted application rates of biochar. Application of biochar may temporarily impede some insect activity on downed woody material but eventually, precipitation should remove some of the biochar from the bark surface to the soil organic horizons and ultimately the mineral soil. Therefore, application of biochar during the autumn and prior to rain and freeze/thaw events should limit the exposure of numerous forest insects.

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Table 1. Mean number (± SEM where applicable) of insects by taxa that emerged from bolts that received a surface treatment of biochar versus non-treated control bolts, and the number of bolts within each treatment that had taxa emerge from them. Insects listed to lowest possible identification. P-value for comparison of abundance using Wilcoxon ranked sum tests were conducted on taxa when at least 50% of the bolts within at least one treatment were occupied by that taxa.

	Biochar Treated		**Control**		
Taxa	**Number of Individuals (mean ± SEM)**	**Number of bolts**	**Number of Individuals (mean ± SEM)**	**Number of bolts**	***P*-value**
Curculionidae					
Dendroctonus valens LeConte	0.3 ± 0.3	1	60.83 ± 17.8	6	0.0309
Hylastes nigrinus (Mannerheim)	0.1 ± 0.1	1	0	0	NA
Ips integer (Eichhoff)	0.2 ± 0.2	1	0	0	NA
Ips pini (Say)	1.0 ± 1.0	1	0.8 ± 0.8	1	NA
Mecinus sp.	0.1 ± 0.1	1	0	0	NA

Pissodes sp.	0.2 ± 0.2	1	0.1 ± 0.1	1	NA
Larval*	0	0	0.7 ± 0.3	5	0.0325
Cerambycidae					
Megasemum asperum (LeConte)	0	0	0.1 ± 0.1	1	NA
Monochamus clamator LeConte	1.3 ± 0.5	5	1.3 ± 0.7	4	0.8032
Monochamus obtusus Casey	1.1 ± 1.1	1	1.5 ± 1.4	2	NA
Larval*	2.75 ± 1.18	4	0.8 ± 0.6	3	NA
Braconidae					
Coeloides sympitys Mason	0	0	0.9 ± 0.5	3	NA
Buprestidae					
Anthaxia aeneogaster Laporte and Gory	0.6 ± 0.4	2	0	0	NA

Melanophila acuminata (DeGeer)	0.1 ± 0.1	1	0	0	NA
Larval*	0.7 ± 0.4	4	0.8 ± 0.4	4	NA
Trogossitidae					
Temnochila chlorodia (Mannerheim)	0.3 ± 0.2	2	0.7 ± 0.4	3	NA
Cleridae					
Enoclerus lecontei (Wolcott)	0.2 ± 0.2	1	0.1 ± 0.1	1	NA
Silvanidae					
Silvanoprus sp.	0	0	12.5 ± 12.5	1	NA
Siricidae					
Larval*	0.4 ± 0.3	2	0	0	NA
Diprionidae	0	0	0.1 ± 0.1	1	NA
Anthocoridae					
Anthocoris sp.	0	0	1.1 ± 0.7	3	NA
Aradidae					
Aradus sp.	0	0	0.3 ± 0.2	2	NA

Tortricidae	0.1 ± 0.1	1	0.1 ± 0.1	1	NA
Formicidae	0	0	0.1 ± 0.1	1	NA

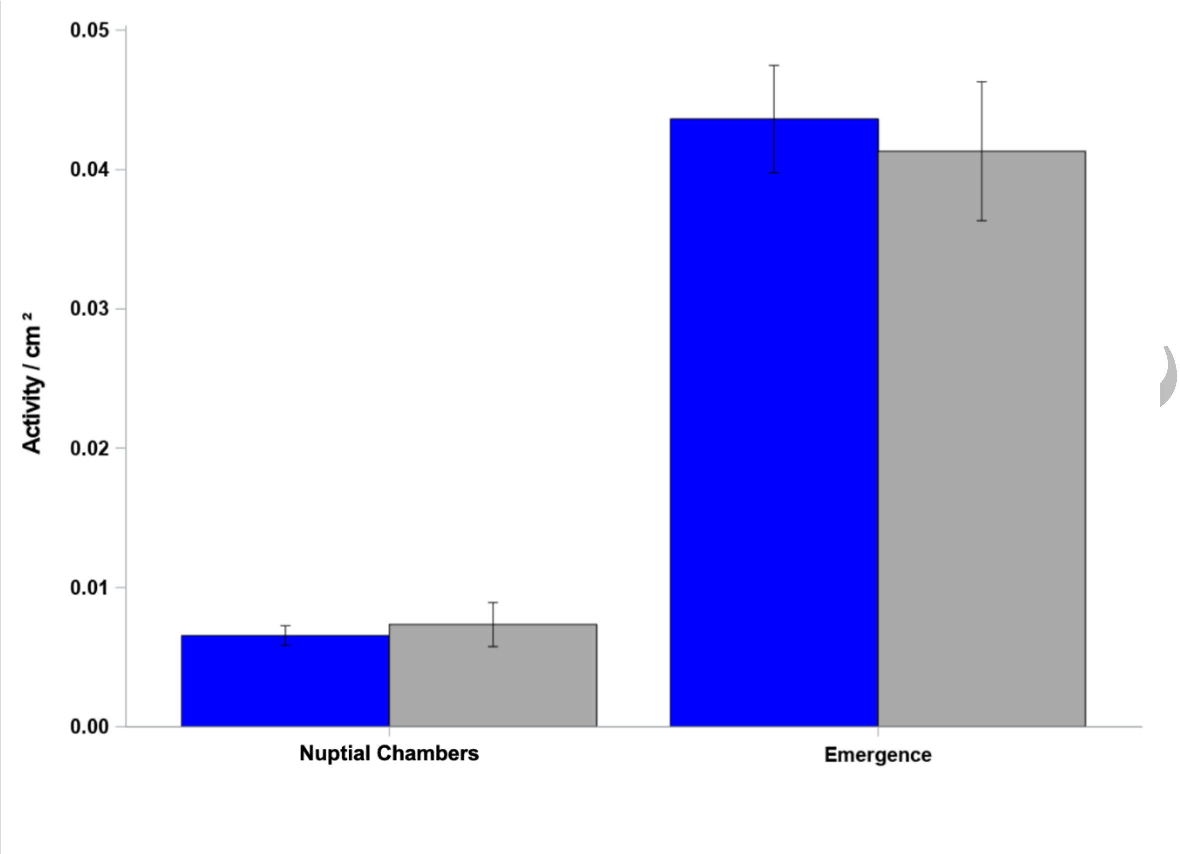

Figure 1. Mean density (± SEM) of nuptial chambers and emerged *Ips pini* adults/cm2 of bark surface on biochar treated and non-treated control bolts.

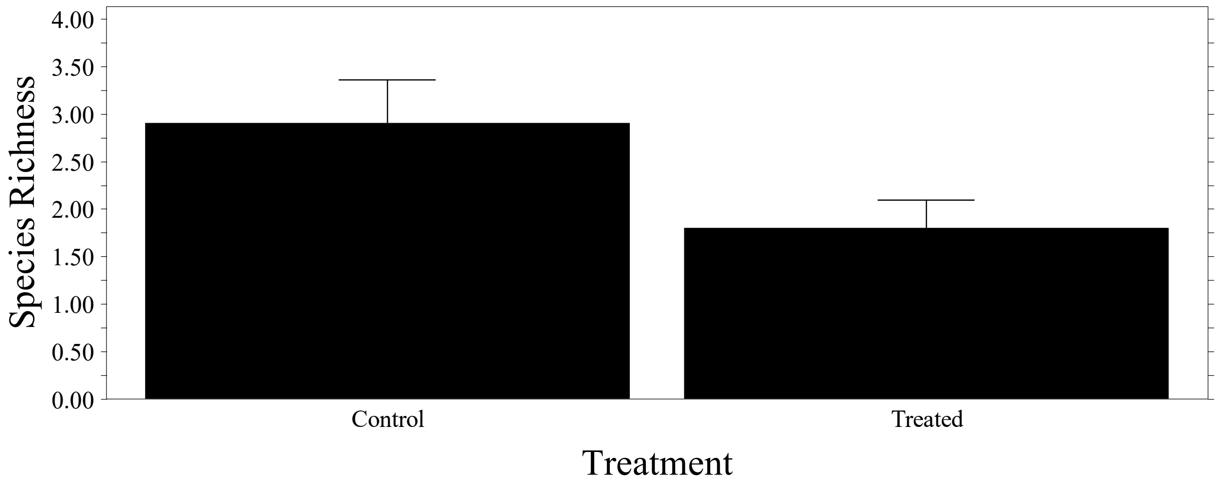

Figure 2. Mean species richness (± SEM) of captured insects from the ten bolts that were not (control) or were surface-treated with biochar.