**Methods**

*Study Site*

This research was conducted at Powdermill Nature Reserve (PNR) in Rector, Westmoreland County, Pennsylvania in the Laurel Highlands. PNR has approximately 900 hectares of natural habitat across an elevation range of 392 to 647 m that is largely temperate deciduous forest composed of mesophytic species. In 1956, PNR was established as a nature reserve and the field research station for the Carnegie Museum of Natural History. Prior to this, the region experienced several major anthropogenic disturbances, including logging in the 19th century, agricultural production until the early- to mid-20th century and then some areas of the reserve were mined for coal in the 1940s.

Dominant tree taxa were maple (*Acer* spp.), oak (*Quercus* spp.), beech (*Fagus* spp.), poplar (*Populus* spp.), and hickory (*Carya* spp.) (Murphy et al. 2015). The understory was dominated by spicebush (*Lindera benzoin* (L.) Blume), but the invasive shrubs Multiflora rose (*Rosa multiflora* Thunb.) and Japanese barberry (*Berberis thunbergii* DC) were also present (Calinger et al. 2015). However, PNR has a diverse understory of herbaceous plants and woody shrub species, and some of the most abundant species were violet (*Viola* spp.), blackberry (*Rubus allegheniensis*), round lobed hepatica (*Hepatica americana*), common cinquefoil (*Potentilla* spp.), dewberry (*Rubus* *hispidus*), partridgeberry (*Mitchella repens*), bedstraw (*Galium* spp.), sedges (*Cyperaceae* spp.), nettle (*Urtica* spp.), greenbrier (*Smilax* spp.), and several species of ferns (*Polystichum* *acrostichoides*, *Dennstaedtia* *punctilobula*, *Thelypteris* *noveboracensis*, and *Dryopteris* spp.).

*Experimental Design*

A tornado impacted the forest in June 2012, uprooting many of the trees in two large areas (~120 × 480 m). From mid-summer through winter of 2013, half of each area affected by the tornado was salvaged, creating a subsequent anthropogenic disturbance from the use of heavy machinery for tree removal. In 2015, three transects were established across each section of forest impacted by the wind event. Transects were established across the unsalvaged and salvaged tornado disturbances into the surrounding undisturbed forest.

*Ground-dwelling Invertebrate Sampling*

Ground-dwelling invertebrates were sampled using pitfall traps (Spence and Niemelä 1994, Latty et al. 2006). Although pitfall traps are a standardized method for collecting ground-dwelling invertebrates, this method tends to collect taxa that are more active. Therefore, invertebrate abundances are reported as activity-abundance (individuals per trap). In 2015, three transects of four pitfall traps were installed across each tornado blowdown. Each transect had one trap in the center of the salvaged and unsalvaged treatments, and one pitfall trap on either side ≥ 50 m into the surrounding forest.

Pitfall traps consisted of two pairs of plastic cups (each pair consists of an inner 500 mL and outer 1 L plastic cup) dug into the ground so that the cups were flush with the soil surface and connected by garden edging (Suncast® eco edge) 1 m in length. The inner cup contained 4 cm of propylene glycol (recreational vehicle and marine antifreeze, Peak Company Old World Industries, Clear Lake, Texas) along with a few drops of detergent to facilitate collection. Masonite board (100 cm2) was placed 3 cm above each cup to prevent flooding from rainwater, and steel hardware cloth was secured over each trap with 30 cm stakes to limit animal disturbance.

Pitfall trap sampling was conducted continuously over the growing season in 2015. Trap catch was collected every two weeks, and cups were refilled with propylene glycol for the next sampling interval. Pitfall traps were installed on May 27-28, and samples were collected on June 9-10, June 24-25, July 8, July 22, August 5, and August 17. Trap catches were separated from the propylene glycol in the field using a 10 cm fine mesh strainer, and emptied into a specimen cup containing 70% ethanol for storage until sorting and identification.

Ground-dwelling invertebrates were first identified to family using Triplehorn and Johnson (2005), Shear (1999), Weaver (1982), Dindal (1990), Borror and White (1970) and White (1983). Ground beetles were identified to species using keys in Lindroth (1961-1969), Freitag (1969), Arnett and Thomas (2001) and Bousquet (2010). Ants were identified to species using keys in Coovert (2005), Fisher and Cover (2007) and Ellison et al. (2012). Scarab beetles were identified to species using keys in Ratcliffe (1991), Arnett et al. (2002) and Harpootlian (2001). Carrion and burying beetles were identified to species using Arnett and Thomas (2001) and Ratcliffe (1996). Sap beetles were identified to species in 2013 and 2014 using Price (2003) and Arnett et al. (2002). Vouchers for taxa identified to species were deposited at the Museum of Biological Diversity, The Ohio State University, Columbus, OH where each specimen was given a unique identifier label (Table 1).

*Forest Floor Microclimate*

Environmental conditions were quantified to assess the effects of tornado disturbance and subsequent salvage logging on the ground-level microclimate factors. Percentage canopy openness was measured using a spherical crown densiometer directly above the pitfall traps to quantify the amount of light reaching the forest floor. Canopy openness was measured twice (June 9-10 and August 5). Percentage cover of understory ground-level vegetation, leaf litter, bare ground, fine woody debris (FWD; < 10 cm in diameter at the large end), coarse woody debris (CWD; ≥ 10 cm in diameter at the large end), rocks, and understory vegetation height were quantified in a 1m2 quadrat in two randomly selected locations surrounding each pitfall trap. Ground cover measurements were collected monthly during the growing season (June 9, July 7 and August 5). Soil temperature and moisture were measured adjacent to pitfall traps with a Durac (Bel-Art H-B Instrument, Wayne, New Jersey) Bi-Metallic dial thermometer and Dynamax Inc. (Houston, Texas) TH2O portable soil moisture meter with a Theta Probe ML2x sensor, respectively. Measurements were taken bi-weekly when trap samples were collected, and three readings were averaged together for the final value.

**Table 1.** Ground-dwelling invertebrates sampled with unbaited barrier pitfall traps in unsalvaged (US) and salvaged (S) tornado disturbance and surrounding forest (F) in 2013, 2014 and 2015 at Powdermill Nature Reserve in Rector, Westmoreland County, Pennsylvania, USA. Invertebrates were not sampled in salvaged areas in 2013 because salvaging operations were in progress.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Class** | **Order** | **Family** | **Species** | **2013** | **2014** | **2015** | **Total** |  |
|
| Clitellata | Haplotaxida |  |  | 13 | 12 | 32 | 57 |  |
| Gastropoda | Snails |  |  | 22 | 32 | 280 | 334 |  |
|  | Slugs |  |  | 3 | 31 | 29 | 63 |  |
| Chilopoda | Geophilomorpha |  |  | 14 | 10 | 5 | 29 |  |
|  | Lithobiomorpha |  |  | 26 | 19 | 37 | 82 |  |
|  | Scolopendromorpha |  |  | 17 | 3 | 12 | 32 |  |
| Diplopoda | Callipodida | Abacionidae |  | 12 | 9 | 9 | 30 |  |
|  | Chordeumatida | Caseyidae |  | 11 | 41 | 42 | 94 |  |
|  | Julida | Julidae |  | 92 | 142 | 198 | 432 |  |
|  |  | Parajulidae |  | 70 | 254 | 337 | 661 |  |
|  | Polydesmida | Paradoxosomatidae |  | 165 | 521 | 855 | 1541 |  |
|  |  | Polydesmidae |  | 149 | 463 | 597 | 1209 |  |
|  |  | Xystodesmida |  | 1 | 0 | 5 | 6 |  |
|  | Polyzoniida | Polyzoniidae |  | 0 | 0 | 3 | 3 |  |
|  | Spirobolida | Spirobolidae |  | 187 | 68 | 60 | 315 |  |
| Malacostraca | Isopoda |  |  | 9 | 13 | 48 | 70 |  |
| Arachnida | Araneae |  |  | 440 | 869 | 1505 | 2814 |  |
|  | Opiliones |  |  | 16 | 70 | 190 | 276 |  |
|  | Pseudoscorpiones |  |  | 7 | 13 | 55 | 75 |  |
| Collembola | Poduromorpha | Onychiuridae |  | 3 | 2 | 27 | 32 |  |
|  |  | Neanuridae |  | 557 | 617 | 1586 | 2760 |  |
|  |  | Hypogastruridae |  | 3754 | 2773 | 3374 | 9901 |  |
|  | Entomobryomorpha | Isotomidae |  | 592 | 7004 | 2339 | 9935 |  |
|  |  | Tomoceridae |  | 3232 | 2310 | 6342 | 11884 |  |
|  |  | Entomobryidae |  | 155 | 808 | 1348 | 2311 |  |
|  | Symphypleona | Dicyrtomidae |  | 1072 | 2312 | 5737 | 9121 |  |
|  |  | Katiannidae |  | 142 | 119 | 322 | 583 |  |
| Insecta | Blattodea | Blattidae |  | 0 | 1 | 1 | 2 |  |
|  | Hymenoptera | Formicidae |  | 1308 | 966 | 2399 | 4673 |  |
|  |  |  | *Aphaenogaster picea* Wheeler | 868 | 723 | 1268 | 2859 |  |
|  |  |  | *Aphaenogaster tennesseensis* | 0 | 0 | 1 | 1 |  |
|  |  |  | *Amblyopone pallipes* | 1 | 0 | 2 | 3 |  |
|  |  |  | *Camponotus noveboracensis* | 0 | 0 | 6 | 6 |  |
|  |  |  | *Camponotus pennsylvanicus* | 181 | 61 | 106 | 348 |  |
|  |  |  | *Formica argentea* | 0 | 1 | 0 | 1 |  |
|  |  |  | *Formica subsericea* | 69 | 50 | 169 | 288 |  |
|  |  |  | *Formica pallidefulva* | 0 | 0 | 1 | 1 |  |
|  |  |  | *Lasius alienus* | 18 | 10 | 128 | 156 |  |
|  |  |  | *Lasius nearcticus* | 4 | 0 | 10 | 14 |  |
|  |  |  | *Lasius umbratus* | 8 | 1 | 247 | 256 |  |
|  |  |  | *Leptothorax longispinosus* | 9 | 2 | 13 | 24 |  |
|  |  |  | *Myrmecina americana* | 48 | 34 | 154 | 236 |  |
|  |  |  | *Myrmica punctiventris* | 40 | 9 | 6 | 55 |  |
|  |  |  | *Ponera pennsylvanica* | 1 | 2 | 13 | 16 |  |
|  |  |  | *Prenolepsis impairs* | 0 | 2 | 0 | 2 |  |
|  |  |  | *Stenamma diecki-schmitti* | 13 | 10 | 70 | 93 |  |
|  |  |  | *Stenamma impar* | 48 | 61 | 205 | 314 |  |
|  | Orthoptera | Gryllidae |  | 10 | 88 | 86 | 184 |  |
|  |  | Rhaphidophoridae |  | 32 | 70 | 68 | 170 |  |
|  | Coleoptera | Carabidae |  | 372 | 463 | 977 | 1812 |  |
|  |  |  | *Notiophilus aeneus* (Herbst) | 1 | 0 | 2 | 3 |  |
|  |  |  | *Sphaeroderus canadensis canadensis* Chaudoir | 2 | 9 | 35 | 46 |  |
|  |  |  | *Sphaeroderus stenostomus lecontei* Dejean | 4 | 15 | 76 | 95 |  |
|  |  |  | *Scaphinotus* *viduus* (Dejean) | 0 | 0 | 1 | 1 |  |
|  |  |  | *Scaphinotus imperfectus* (Horn) | 1 | 0 | 0 | 1 |  |
|  |  |  | *Scaphinotus andrewsii mutabilis* (Casey) | 1 | 2 | 0 | 3 |  |
|  |  |  | *Scaphinotus ridingsii ridingsii* (Bland) | 0 | 1 | 0 | 1 |  |
|  |  |  | *Carabus goryi* Dejean | 62 | 35 | 66 | 163 |  |
|  |  |  | *Myas coracinus* (Say) | 1 | 1 | 0 | 2 |  |
|  |  |  | *Pterostichus mutus* (Say) | 0 | 0 | 1 | 1 |  |
|  |  |  | *Pterostichus corvinus* (Dejean) | 0 | 0 | 6 | 6 |  |
|  |  |  | *Pterostichus melanarius* (Illiger) | 0 | 0 | 1 | 1 |  |
|  |  |  | *Pterostichus coracinus* (Newman) | 1 | 5 | 28 | 34 |  |
|  |  |  | *Pterostichus lachrymosus* (Newman) | 84 | 34 | 27 | 145 |  |
|  |  |  | *Pterostichus stygicus* (Say) | 3 | 22 | 62 | 87 |  |
|  |  |  | *Pterostichus hamiltoni* Horn | 1 | 1 | 0 | 2 |  |
|  |  |  | *Pterostichus moestus* (Say) | 56 | 83 | 185 | 324 |  |
|  |  |  | *Pterostichus diligendus* (Chaudoir) | 0 | 0 | 1 | 1 |  |
|  |  |  | *Pterostichus rostratus* (Newman) | 9 | 15 | 36 | 60 |  |
|  |  |  | *Pterostichus adoxus* (Say) | 17 | 11 | 19 | 47 |  |
|  |  |  | *Pterostichus tristis* (Dejean) | 54 | 35 | 10 | 99 |  |
|  |  |  | *Cyclotrachelus fucatus* (Freitag) | 0 | 6 | 5 | 11 |  |
|  |  |  | *Cyclotrachelus convivus* (LeConte) | 0 | 0 | 1 | 1 |  |
|  |  |  | *Cyclotrachelus sigillatus* (Say) | 10 | 6 | 22 | 38 |  |
|  |  |  | *Chlaenius emarginatus* Say | 16 | 46 | 137 | 199 |  |
|  |  |  | *Chlaenius laticollis* Say | 0 | 0 | 2 | 2 |  |
|  |  |  | *Chlaenius* *tricolor tricolor* Dejean | 0 | 1 | 0 | 1 |  |
|  |  |  | *Dicaelus politus* Dejean | 0 | 14 | 54 | 68 |  |
|  |  |  | *Dicaelus teter* Bonelli | 13 | 32 | 68 | 113 |  |
|  |  |  | *Notiobia nitidipennis* (LeConte) | 3 | 12 | 6 | 21 |  |
|  |  |  | *Notiobia terminata* (Say) | 0 | 12 | 0 | 12 |  |
|  |  |  | *Xestonotus lugubris* (Dejean) | 1 | 0 | 0 | 1 |  |
|  |  |  | *Anisodactylus harrisii* LeConte | 0 | 0 | 2 | 2 |  |
|  |  |  | *Anisodactylus melanopus* (Haldeman) | 0 | 1 | 1 | 2 |  |
|  |  |  | *Anisodactylus nigerrimus* (Dejean) | 0 | 0 | 3 | 3 |  |
|  |  |  | *Amphasia interstitialis* (Say) | 10 | 4 | 6 | 20 |  |
|  |  |  | *Harpalus spadiceus* Dejean | 0 | 0 | 1 | 1 |  |
|  |  |  | *Trichotichnus autumnalis* (Say) | 0 | 2 | 10 | 12 |  |
|  |  |  | *Pseudamara arenaria* (LeConte) | 0 | 1 | 2 | 3 |  |
|  |  |  | *Synuchus impunctatus* (Say) | 1 | 0 | 0 | 1 |  |
|  |  |  | *Olisthopus parmatus* (Say) | 0 | 3 | 3 | 6 |  |
|  |  |  | *Agonum retractum* LeConte | 0 | 0 | 1 | 1 |  |
|  |  |  | *Agonum ferreum* Haldeman | 0 | 0 | 1 | 1 |  |
|  |  |  | *Agonum fidele* Casey | 0 | 0 | 31 | 31 |  |
|  |  |  | *Platynus tenuicollis* (LeConte) | 4 | 7 | 3 | 14 |  |
|  |  |  | *Platynus angustatus* Dejean | 4 | 57 | 19 | 80 |  |
|  |  |  | *Cymindis limbata* Dejean | 0 | 1 | 0 | 1 |  |
|  |  |  | *Apenes lucidula* (Dejean | 1 | 1 | 0 | 2 |  |
|  |  | Curculionidae |  | 94 | 49 | 71 | 214 |  |
|  |  | Scolytinae |  | 275 | 810 | 2413 | 3498 |  |
|  |  | Cucujidae |  | 0 | 1 | 1 | 2 |  |
|  |  | Elateridae |  | 2 | 2 | 16 | 20 |  |
|  |  | Histeridae |  | 3 | 9 | 46 | 58 |  |
|  |  | Phalacrididae |  | 11 | 82 | 13 | 106 |  |
|  |  | Ptiliidae |  | 7 | 49 | 48 | 104 |  |
|  |  | Nitidulidae |  | 233 | 442 | 1394 | 2069 |  |
|  |  |  | *Carpophilus corticinus* | 19 | 13 | - | 32 |  |
|  |  |  | *Carpophilus lugubris* | 0 | 5 | - | 5 |  |
|  |  |  | *Colopterus unicolor* | 0 | 1 | - | 1 |  |
|  |  |  | *Epuraea rufomarginata* | 1 | 0 | - | 1 |  |
|  |  |  | *Glischrochilus sanguinolentus* | 81 | 50 | - | 131 |  |
|  |  |  | *Glischrochilus quadrisignatus* | 0 | 12 | - | 12 |  |
|  |  |  | *Pallodes pallidus* | 11 | 11 | - | 22 |  |
|  |  |  | *Phenolia grossa* | 0 | 1 | - | 1 |  |
|  |  |  | *Stelidota geminata* | 119 | 334 | - | 453 |  |
|  |  |  | *Stelidota octomaculata* | 2 | 5 | - | 7 |  |
|  |  | Geotrupidae |  | 100 | 102 | 594 | 796 |  |
|  |  |  | *Geotrupes balyi* | 40 | 39 | 20 | 99 |  |
|  |  |  | *Geotrupes semiopacus* | 58 | 52 | 548 | 658 |  |
|  |  |  | *Geotrupes splendidus* | 2 | 10 | 22 | 34 |  |
|  |  |  | *Odonteus* spp. | 0 | 1 | 3 | 4 |  |
|  |  |  | *Odonteus liebeckii* | 0 | 0 | 1 | 1 |  |
|  |  | Lucanidae |  | 0 | 1 | 0 | 1 |  |
|  |  | Scarabaeidae |  | 17 | 71 | 45 | 133 |  |
|  |  | Aphodiinae |  | 11 | 21 | 24 | 56 |  |
|  |  |  | *Dialytellus striatulus* | 9 | 17 | 14 | 40 |  |
|  |  |  | *Dialytes dialytoides* | 2 | 4 | 9 | 15 |  |
|  |  |  | *Dialytes tragicus* | 0 | 0 | 1 | 1 |  |
|  |  | Melolonthinae |  | 0 | 0 | 1 | 1 |  |
|  |  |  | *Serica* spp. | 0 | 0 | 1 | 1 |  |
|  |  | Scarabaeinae |  | 6 | 50 | 30 | 86 |  |
|  |  |  | *Canthon chalcites* | 0 | 19 | 6 | 25 |  |
|  |  |  | *Copris minutus* | 4 | 0 | 1 | 5 |  |
|  |  |  | *Onthophagus hecate* | 1 | 29 | 16 | 46 |  |
|  |  |  | *Onthophagus orpheus canadensis* | 0 | 1 | 4 | 5 |  |
|  |  |  | *Onthophagus striatulus* | 1 | 1 | 2 | 4 |  |
|  |  | Trogidae |  | 11 | 8 | 2 | 21 |  |
|  |  |  | *Trox variolatus* | 11 | 8 | 2 | 21 |  |
|  |  | Silphidae |  | 96 | 50 | 153 | 299 |  |
|  |  |  | *Nicrophorus defodiens* | 7 | 0 | 3 | 10 |  |
|  |  |  | *Nicrophorus orbicollis* | 52 | 25 | 37 | 114 |  |
|  |  |  | *Nicrophorus tomentosus* | 21 | 9 | 4 | 34 |  |
|  |  |  | *Nicrophorus sayi* | 1 | 1 | 1 | 3 |  |
|  |  |  | *Necrophila americana* | 15 | 13 | 108 | 136 |  |
|  |  |  | *Oiceoptoma noveboracense* | 0 | 2 | 0 | 2 |  |
|  |  | Leptodiridae |  | 0 | 2 | 0 | 2 |  |
|  |  | Staphylinidae |  | 875 | 1746 | 2625 | 5246 |  |
|  |  | Pselaphidae |  | 1 | 1 | 2 | 4 |  |
|  |  | Scydmaenidae |  | 0 | 4 | 2 | 6 |  |
|  |  | Rhizophagidae |  | 0 | 5 | 1 | 6 |  |
|  |  | Melodiae |  | 1 | 3 | 1 | 5 |  |
|  |  | Tenebrionidae |  | 1 | 1 | 0 | 2 |  |
|  |  | Melandryidae |  | 0 | 2 | 0 | 2 |  |
|  |  | Leiodidae |  | 0 | 7 | 15 | 22 |  |
|  |  | Rhysodidae |  | 0 | 2 | 1 | 3 |  |
|  |  | Trogositidae |  | 0 | 2 | 0 | 2 |  |
|  |  | Salpingidae |  | 0 | 0 | 1 | 1 |  |
|  |  | Erotylidae |  | 0 | 0 | 1 | 1 |  |
|  |  | Mycetophagidae |  | 0 | 0 | 21 | 21 |  |
|  |  | Cryptophagidae |  | 0 | 0 | 7 | 7 |  |
|  |  | Derodontidae |  | 0 | 0 | 1 | 1 |  |
|  |  | Pyrochoridae |  | 0 | 0 | 1 | 1 |  |
|  |  |  |  | 14227 | 23625 | 36435 | 74287 |  |