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Effects of environmental and agronomic factors on soil-dwelling pest communities in cereal crops

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ABSTRACT

Characterizing the composition of pest communities across variable cropping landscapes is critical for developing integrated management programs due to variation across species in their ecology and impacts on crops. Wireworms, the soil-dwelling larvae of click beetles, have resurged as major pests of cereal crops in the Pacific Northwestern United States, but knowledge of the composition of wireworm communities across cereal-growing landscapes remains limited. Here, we conducted a large-scale field survey of wireworms across a broad region in the Pacific Northwest. We identified a total of 13 wireworm species across samples taken from 160 fields in Washington, Oregon, and Idaho. The most common species were *Limonius infuscatus*,*L. californicus*, and *Selatosomus pruininus,* which together represented approximately 90% of collected larvae. Wireworm communities were more abundant and diverse in spring wheat and conservation reserve program compared with winter wheat fields. Interestingly, *L. californicus* was the only species that was more abundant in cultivated wheat crops than in native grass fields, suggesting that this species persists in crop habitats throughout its life cycle and thus might exert stronger impacts on winter crops compared to other species. Our results indicate that *Limonius* species are distributed mostly in the intermediate and higher precipitation zones or in irrigated fields, while *S. pruininus* is confined to drier regions. As the dominant wireworm species, the diversity of wireworm communities, and total wireworm abundance varied across crops, landscapes, and climatic regions, management practices should vary across regions for maximum effectiveness.

1. Introduction

The distribution and abundance of pest species in agro-ecosystems are governed by many environmental and agronomic factors (Pedigo and Rice, 2008; Ehrlén and Morris, 2015). Understanding which factors mediate the persistence of pest species and their population dynamics is in turn an essential principle of sustainable pest management (Pedigo and Rice, 2008; Price et al., 2012). Agricultural landscapes often vary considerably in terms of habitat composition and other environmental conditions, and characterizing which environmental factors and management practices promote abundant and diverse pest communities is critical for the development of effective control tactics (Pedigo and Rice, 2008; Price et al., 2012).

Wireworms, the soil-dwelling larvae of click beetles (Coleoptera: Elateridae), have re-emerged as economically significant pests of cereal, vegetable, and legume crops in the Pacific Northwestern United States (PNW) (Higginbotham et al., 2014; Esser et al., 2015; Milosavljević et al., 2016). Wireworms were considered severe crop pests in the early 20th century (Comstock and Slingerland, 1891), but dwindled in importance beginning in the 1950's due to the effectiveness of potent broad-spectrum insecticides used for their control (Vernon et al., 2008). Reliance on these chemicals created a false sense of security and decreased growers' awareness of wireworms (van Herk and Vernon, 2007; Vernon et al., 2009), resulting in scant research on the biology and ecology of wireworms for nearly 40 years (Traugott et al., 2015). When several broad-spectrum pesticides were removed from the market and replaced by less effective second-generation toxins, however, wireworms resurged as problematic pests of many field crops (Parker and Howard, 2001; Hermann et al., 2013). Unfortunately, producers are faced with this challenge without the basic knowledge to develop efficient management plans. This has threatened the productivity of agricultural systems in the PNW and globally.

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Substantial temporal and spatial variability in the composition of wireworm communities has made sampling and identification difficult, hampering the development of management strategies (Blackshaw and Vernon, 2006; Willis et al., 2010). Recognizing which wireworm species of economic significance are likely to occur in a given region, or which factors might promote outbreaks in a given field, are thus extremely important (Traugott et al., 2008, 2015; Benefer et al., 2012; Barsics et al., 2013). Within fields, food availability, crop rotations, and agronomic conditions mediate the abundance of wireworms (Furlan, 2004; Jung et al., 2014). Soil characteristics are also important, with studies showing that factors such as texture, moisture, pH, temperature, bulk density, and organic matter impact wireworms (Thomas, 1940; Lefko et al., 1998; Kovács et al., 2006; Hermann et al., 2013; Staudacher et al., 2013).

At broader landscape scales, the availability of habitats that are suitable for oviposition, reproduction, and overwintering, such as grasslands, can impact wireworm abundance (Lefko et al., 1998; Furlan, 2004; Kovács et al., 2006; Keiser et al., 2012; Hermann et al., 2013).The proximity of grasslands to crop fields can also affect dispersal into crops and overall wireworm abundance, although impacts have been shown to be species-dependent (Toepfer et al., 2007). In Europe, predictive models have been developed that relate factors such as cropping landscapes and soil characteristics (i.e. moisture, temperature, type) to wireworm abundance. These models have been shown to predict up to 89% of the variability in wireworm abundance in given fields (Hermann et al., 2013; Jung et al., 2014). As the distribution of wireworm species varies across the PNW (Lane, 1925; Glen, 1950; Toba and Turner, 1983; Toba and Campbell, 1992), such models would help identify areas where damaging wireworm species are likely to occur. Previous research has shown that different wireworm species have variable responses to control treatments, such that economic thresholds vary across species (Furlan, 2004, 2014; Esser et al., 2015). In turn, models that predict wireworm abundance, when combined with knowledge of particular species occuring in a given region, could substantially improve wireworm IPM.

Here, we conducted a large-scale survey to characterize the distribution and community composition of wireworm species infesting cereal crops and native grasslands in the PNW. Wireworms continue to pose a serious threat to wheat (*Triticum aestivum*) production in the PNW, with up to 70% yield losses (Reddy et al., 2014). First, we examined whether the abundance, diversity, and composition of wireworm communities differed in wheat cropping systems compared with conservation reserve program (CRP) fields that contain native grasses. We also evaluated how wireworm community structure was affected by environmental and agronomic factors across our broad study region. Our goal was to determine the primary factors mediating wireworm abundance and community structure. This could provide a more solid foundation for IPM, because if growers can accurately assess which species will likely be present in their fields, they could incorporate this information into their risk assessment (Furlan, 2014).

2. Materials and methods

2.1. Study sites

In 2013 and 2014, we developed an extensive sampling network to document the distribution of wireworms in commercial wheat fields and native grasslands in the PNW. This network consisted of 160 fields distributed across 20 counties in Washington, Oregon, and Idaho (Fig. 1). Each year we sampled 40 spring wheat (SW) fields, 20 winter wheat (WW) fields, and 20 Conservation Reserve Program (CRP) fields. All CRP fields contained native grasses and had not been planted to crops for over 10 years. We sampled CRP sites in addition to wheat fields because native grasses might serve as sources of wireworms and adult beetles that could migrate into adjacent crop fields. All of the fields were located in 150–750 mm annual precipitation zones (AgWeatherNet, 2015) with soil types ranging from sandy loam to silty clay loams.

All crop fields were managed by participating growers, following practices typical of the PNW region (Camara et al., 2003). Representative wheat growing practices of the region include intensive large-acreage monoculture cropping systems (Schillinger and Papendick, 2008). In areas with lower precipitation, standard rotational practices comprise of two-year rotations of winter wheat-spring wheat or winter wheat-summer fallow. Common rotations in higher rainfall zones include three-year rotations of winter wheat-spring wheat-spring wheat/barley, winter winter-spring wheat-summer fallow, or winter wheat-spring wheat-legume (Schillinger et al., 2006). Fifty of the wheat farms in our study used no-till production methods while the other 70 used conventional tillage practices (Schillinger and Papendick, 2008). Each surveyed farm used seed-applied neonicotinoid insecticides (i.e. thiamethoxam and imidacloprid) at rates between 7 and 12 g active ingredient per 100 kg seed for the control of early-season pests in cereal crops.

2.2. Insect sampling and identification

Wireworm larvae were sampled using modified solar bait traps (Esser et al., 2015). In each field, 10 baits were deployed once in the spring when soil temperatures reached 6 °C. This corresponds with the temperature at which we have observed wireworms start actively feeding on cereal crops in our region (Milosavljević, personal observation). Each bait trap consisted of a nylon stocking filled with 120 cm^3 of wheat and corn seeds in a 50:50 ratio. Traps were kept submerged in water for 24 h prior to deployment to encourage seed germination; germinating seeds produce and emit elevated amounts of CO_2 that are attractive to wireworms (Doane et al., 1975; Doane and Klingler, 1978; Johnson and Nielsen, 2012). A study area measuring 400 m × 250 m (10 ha) was established in each surveyed field (Fig. 2). The first bait was set up 50 m from a field edge to limit edge effects, and subsequent baits were placed in a zig-zag pattern moving into the field, with approximately 50 m between traps (Fig. 2). Each trap was deployed in 20 cm deep hole in the ground, covered with sufficient soil, and flagged to allow easy retrieval. In addition to flags, we covered each trap with a clear and black plastic cover (90 × 90 cm in size) which helped warm the ground and speed up germination. All traps were retrieved after 8 days and transported to the laboratory where they were assessed for wireworms by hand.

Collected larvae were identified to species based on morphological characteristics (Glen et al., 1943; Lanchester, 1946). To ensure that our identifications were accurate, we identified a subset of individuals of each species using DNA barcoding methods (Etzler et al., 2014). This was performed on 5 individuals of the three most prevalent species and 2 individuals of each of the other species from each of several different geographic locations. Each specimen was cut between the second and third abdominal segment to extract DNA. Then, the mitochondrial cytochrome oxidase I (COI) gene was sequenced and compared to existing species (Folmer et al., 1994; Lindroth and Clark, 2009; Staudacher et al., 2011; Etzler et al., 2014).

2.3. Collection of environmental and management data

We recorded data on environmental and agronomic factors at each farm to determine their effects on wireworm communities. These factors were: (1) accumulated rainfall within 30 days of