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Changes in the dynamics of functional groups in communities of dung beetles in Atlantic forest fragments adjacent to transgenic maize crops

Renata C. Campos *, Malva I.M. Hernández

Department of Ecology and Zoology, Center of Biological Sciences, Federal University of Santa Catarina, Florianópolis, SC 88040-900, Brazil

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ABSTRACT

We investigated the composition and structure of dung beetle communities (Coleoptera, Scarabaeidae, Scarabaeinae) inhabiting areas of forest fragments next to either conventional or Bt-transgenic maize crops. The purpose of the study was to examine possible impacts of transgenic plants on non-target organisms associated with mammals through their food chain. In February 2011, we collected a total of 1502 beetles belonging to 33 species in Campos Novos, Santa Catarina state (SC), Brazil. Beetles were captured using 200 pitfall traps distributed among 20 forest fragments, 10 fragments in each site type (adjacent to conventional vs. Bt crops). In the fragments adjacent to conventional maize, 805 dung beetles from 27 species were collected. In the fragments adjacent to Bt-transgenic maize, 697 dung beetles from 27 species were caught. Dung beetle community composition was affected by fragment size and environmental complexity, and by distance between fragments. However, it did not explain the differences related to the two crop types, i.e., the functional group of dwellers was significantly over-represented in the fragments surrounded by transgenic maize. Hence, the dweller species *Eurysternus francinae* and *Eurysternus parallelus* were more frequent and abundant in fragments located near the transgenic maize, while the tunneler species *Onthophagus tristis*,*Uroxys terminalis*, *Ontherus sulcator* and the roller species *Canthon lividus seminitens* were more frequent and abundant in fragments surrounded by conventional maize. This observed impact of transgenic crops on functional group dynamics within dung beetle communities could potentially lead to impaired capacity for feces removal, seed dispersal, edaphic aeration, and incorporation of organic matter in the soil in these areas, as such ecosystem services are not performed by the dominant functional group (i.e., dwellers).

1. Introduction

Insects play a role in many ecological processes and are key dietary components of numerous fauna. They are involved in several trophic interactions in the ecosystem, which makes them important for nutrient cycling within food webs (Miller, 1993; Godfray et al., 1999; Wall and Moore, 1999). Beetles of the subfamily Scarabaeinae (Coleoptera, Scarabaeidae) are extremely important organisms for tropical ecosystem function, since they actively participate in nutrient cycling, with both larvae and adults feeding on decomposing organic matter. Most species feed on feces (coprophagous) or carcasses (necrophagous) (Halffter and Mathews, 1966; Halffter and Edmonds, 1982), both primarily from mammals.

Dung beetles are divided into three functional groups according to their behavior when processing decomposing organic matter. Rollers, or telecoprid, roll balls of food across the surface of soil some distance away from the initial resource location; tunnelers, or paracoprid, burrow tunnels near or below the food resource in order to carry the food underground; dwellers, or endocoprid, they do not move or store food, but rather only consume it at the initial discovery site (Halffter and Edmonds, 1982; Cambefort, 1991). Dung beetles are detritivores that promote soil removal and incorporation of organic matter in nutrient cycling, helping to clean the environment and to regulate and improve physical and chemical properties of soil (Halffter and Edmonds, 1982; Cambefort and Hanski, 1991; Slade et al., 2007; Simmons and Ridsdill-Smith, 2011). Furthermore, the building of tunnels by some beetles allows soil aeration and hydration, as well as the incorporation of nutrients present in feces, animal carcasses and fruits that are buried in these tunnel spaces (Halffter and Edmonds 1982; Cambefort and Hanski, 1991; Slade et al., 2007; Nichols et al., 2008 and references therein). In neotropical dung beetle communities, tunneler species are found in larger quantities, and contain the greatest diversity of the three functional groups. They are also better resource competitors than other functional groups. Dwellers

* Corresponding author. Tel.: +554837214735.
E-mail address: recalixtocampos@gmail.com (R.C. Campos).

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are the least common functional group in most studies (Halffter et al., 1992; Feer, 2000; Scheffler, 2005; Hernández and Vaz-de-Mello, 2009).

Environmental degradation causes changes in dung beetle community structure and composition, resulting in a decrease in species diversity compared to preserved areas (Klein, 1989; Davis et al., 2001; Gardner et al., 2008a). The generally rapid response of dung beetle communities to the effects of destruction, fragmentation and isolation of tropical forests has lead to their recognition as ecological indicators (Favila and Halffter, 1997; Davis et al., 2001; McGeoch et al., 2002; Nichols et al., 2007; Gardner et al., 2008b; Herrnández and Vaz-de-Mello, 2009). In addition to community-level changes, some species tend to have increased or decreased abundance in areas with particular characteristics caused by environmental change (Halffter and Favila, 1993; Viegas et al., 2014). The use of dung beetles to assess the ecological consequences of ecosystem disturbances is both practical and efficient, combining low cost of collection with relative ease of species identification (Gardner et al., 2008a).

Fragmentation is one of the most commonly occurring environmental changes in tropical forests, defined as the process by which a large area of habitat is transformed to a number of smaller patches, isolated from each other by an array of habitat types different than the original type (Wilcove et al., 1986). Continued agricultural expansion, increased fragmentation and subsequent loss of biodiversity is currently a problem in Atlantic forests (Galindo-Leal and Câmara, 2003). The vast majority of Scarabaeinae have highly specific habitats in forest ecosystems (Halffter, 1991; Campos and Hernandez, 2013), and are unable to extend their populations to open areas (Klein, 1989; Spector and Ayzama, 2003). These species are strongly affected by fragmentation and habitat loss, which can both restrict distribution and cause species loss in some locations (Davis and Philips, 2005; Hernández et al., 2014).

Globally, GM transgenic maize was planted on 55.1 million hectares in 2012, single-trait Bt maize occupied 7.5 million hectares. This represents an increase of 1.5 million hectares from 2011, a 25% growth equivalent to 4% of total global biotech. GM maize was grown in 17 countries in 2012, with the largest increase being in Brazil (i.e., nearly three million hectares more than in 2011) (James, 2012).

The nature of the effects of transgenic plant material or plant-expressed Cry1Ab on non-target organisms is highly controversial. A number of articles have reported no effects, while others have described significant negative effects on various invertebrate species (Duan et al., 2010; Hilbeck and Schmidt, 2006; Hilbeck et al., 2008; Obrycki et al., 2001; Wolfsbarger et al., 2008; Zwahlen and Andow, 2005; Harwood et al., 2005; Obrist et al., 2006; Then, 2010). Recently, a heated debate has arisen concerning such effects (e.g., Wickson and Wynne, 2012; Dolezel et al., 2011; Hilbeck et al., 2011; Hilbeck et al., 2012; Bøhn et al., 2012; Romeis et al., 2013). In one example, a meta-analysis of 42 field experiments took into account location, duration, plot sizes, and sample sizes and concluded that the mean abundance of all non-target invertebrate groups, as well as survival and growth, was greater in GM cotton and maize fields than in non-GM fields managed with insecticides. However, if GM crop fields and insecticide-free fields were compared, certain non-target insects were less abundant in GM fields (Marvier et al., 2007).

Most published studies have been based on conspicuous negative parameters such as mortality. More subtle effects, such as aberrations in behavioral or social competence, have not been studied to a comparable extent. Their importance, however, is underscored by evidence of such effects. For example, one study indicated that when honeybees were exposed to a high concentration of Cry1Ab protein the effects were not lethal, but that behavior and vital learning ability was disrupted (Ramírez-Romero et al., 2008). Furthermore, other factors should be considered in the risk analysis of GM plants, such as their effects on pollen dispersal and on vector dispersal of seed or plant debris (e.g., by wind, insects, animals, humans) which can spread materials up to several kilometers away (Emberlin et al., 1999; Heinemann, 2007; Hoyle and Cresswell, 2007; Reuter et al., 2008).

Negative effects of transgenic crop practices on associated fauna via trophic webs are poorly understood (Obrycki et al., 2001; Lovei et al., 2009). When Bt plants were developed and released, scientists postulated that these toxins were highly specific and would not affect organisms outside of the target insect groups (Schuler et al., 1998; Betz et al., 2000). However this did not hold true (Van Frankenhuyzen, 2013), and currently the mode(s) of action of Bt toxins are subject to more controversy than in the early 1990s when Bt plants were first developed and promoted (Vachon et al., 2012).

The use of dung beetles, a taxon with acknowledged importance for the maintenance of ecological processes, can serve as a tool for finding general patterns related to cascade effects of GM crops on wildlife. It is, for instance, understood that when a feces provider species changes its diet, this may have consequences that result in changes in dung beetle community composition and structure via trophic cascade effects. Hence, a trophic link likely exists between GM maize and dung beetles through the mammals that feed on maize, and this link could potentially be utilized in a risk assessment context.

The present study was based on the working hypothesis that for dung beetles communities, nearby cultivation of GM (genetically modified) transgenic maize may enhance the negative effects of forest fragmentation. Dung beetle collections were performed in agricultural fields with either transgenic or conventional maize varieties and adjacent to forest fragments. Dung beetles may be exposed to plant materials and toxins derived from Bt-transgenic maize via three different routes: (1) from feces of maize-consuming animals, which has the prerequisite that transgenic DNA and proteins pass through mammalian or avian gastrointestinal tracts either intact or in biologically meaningful fragments (Lutz et al., 2005; Paul et al., 2010; Guertler et al., 2010); (2) from carcasses of maize-consuming animals, which has the prerequisite of uptake and circulation of transgenic DNA and protein in the blood, and presence in the internal organs (Grønsberg et al., 2011); and (3) from exposure to cry1Ab DNA and Cry1Ab proteins present in the soil (Stotzky, 2002; Saxena and Stotzky, 2000), as well as in domestic animal manure (Gruber et al., 2011). The aim of the present study was to evaluate differences in dung beetle community composition and structure in forest fragments next to conventional vs. Bt-transgenic maize crops, and to reveal possible impacts caused by these environmental changes in organisms via trophic cascade interactions.

2. Methods

The study was conducted in Campos Novos, Santa Catarina state, Brazil (27°23′S, 51°12′O). This region contains numerous Atlantic forest fragments, originally Araucaria forest formations (Leite and Klein, 1990), surrounded by soybean and maize crops. The region has a mild mesothermal climate according to the Köeppen classification system (Pandolfo et al., 2002) with altitude ranging from 710 to 950 m.

Twenty sample areas were established in the forest fragments, 10 areas surrounded by a matrix of transgenic maize crops, and 10 areas surrounded by conventional maize crops. Farms were chosen with assistance from the Integrated Agricultural Development Company of Santa Catarina (Companhia Integrada de Desenvolvimento Agrícola de Santa Catarina – CIDASC) and the