Ecological Infrastructures May Enhance Lepidopterans Predation

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Ecological infrastructures (EIs) are considered relevant components in agricultural landscapes to support biodiversity and ecosystem services. The EI typologies influenced differently the predator groups and the overall predation rate. Major differences were observed for bird predation, being higher in woody EIs. A positive correlation between predation rate and EIs area of the surrounding landscape, as well as a negative correlation with the distance to the nearest riparian and woody EIs, was observed for birds. The observed dissimilarities in the predators' response may be related to habitat differences and its functional connectivity. The overall monthly low predation rates are possibly related to the intensive agricultural system and the small area occupied by EIs.

artificial sentinel prey dummy caterpillars ecosystem services predators

1. Introduction

The agriculture intensification observed after the Second World War has been pointed out as the main cause of biodiversity and related ecosystem services (ES) decay in rural areas [1][2][3]. A sharp reduction in habitat heterogeneity has been associated with the intensification of agricultural landscapes [4]. This intensification has caused the loss and fragmentation of natural and seminatural habitats responsible for supporting ES providers, such as pollinators and natural pest enemies. Intensive agriculture also brought soil overexploitation, crop monocultures, and the use of pesticides, further limiting pollination and pest regulation [5]. In addition, natural and seminatural habitats, such as riparian buffer strips, road verges, hedgerows, and isolated mature trees, located on the boundaries of agricultural land have often been removed to facilitate mechanization or converted to crops [3][6][7][8][9]. The management of agricultural landscapes to support biodiversity and ES, and consequently, more sustainable food and fibers production systems is thus a real scientific and political challenge [10].

The intersection of agricultural land use with landscape elements, i.e., ecological infrastructures (EIs), creating landscape heterogeneity, discontinuity in agricultural fields, and connectivity with other agroforestry ecosystems, can contribute to overcoming negative impacts and disservices caused by intensive farming systems [11]. According to Boller et al. [12], EIs consist of any infrastructure existing within a farm or in a range of about 150 m, with ecological value to a farm and capable of enhancing functional biodiversity. They include: (1) permanent habitats, such as forests, ruderal areas, meadows, and pastures; (2) temporary habitats, such as small woodland, patches of trees and shrubs, puddles, stone piles, stone walls, and timber piles; and (3) ecological corridors, such as riparian vegetation, hedgerows, cover crops, and flower strips, connecting permanent and temporary habitats [12].

These noncrop habitats are considered key elements in maintaining and enhancing biodiversity and underlying services [13][14][15][16].

The typology and configuration of EIs, defined by size, shape, vegetation structure, and patch distribution, have been suggested as key factors in determining biodiversity and associated ES in agricultural systems [8][17]. However, there is still a lack of information on the role of different types of EIs on the abundance and diversity of natural pest enemies and the extent they will favor pest control in crops [5].

Predators are important biocontrol agents of insect pests, influencing their population dynamics [18][19]. The predation of herbivorous insect larvae is one of the most beneficial ES provided by the animal communities in agricultural lands and associated EIs [20]. Still, quantifying predation activity is difficult. Many predators leave no signs or consume the entire prey without leaving traces. This is probably one of the reasons why relatively few studies have been published quantifying insect pest predation [5][21]. Predation activity may be estimated using artificial sentinel prey or dummies [22][23][24][25][26]. Dummy caterpillars are artificial larvae made of molding clay and mimicking the size and shape of real lepidopteran larvae. The exposure of dummy caterpillars is a relatively simple and efficient method to assess predation rates [27][28]. Predators attack dummy caterpillars as if they were real prey, leaving marks on the clay. The exposed artificial caterpillars, once attacked, may further allow distinguishing predator signs left by teeth, mandibles, or birds’ beaks and thus identifying different groups of predators, including insects, birds, mammals, and reptiles [23][28].

Dummies have been increasingly used to estimate predation on lepidopteran larvae [27][28][29]. The method has been applied in ecological studies in different ecosystems, such as agricultural [30], forest [24][25][29], and urban (e.g., [22]).

Lepidoptera is a highly diverse insect order, with over 157,000 recognized species distributed among 133 families [31]. Lepidopteran species are mostly herbivores and may feed on a wide range of hosts, being pests of different agricultural, forest, and ornamental plants [32]. They are common insects in different ecosystems, including anthropogenic, semi and natural habitats [33][34][35]. Lepidoptera larvae are the prey of different guilds of predators, such as birds, mammals, spiders, and insects (e.g., ants, social wasps, carabids, neuropterans, crickets, pentatomids, reduviids) [23][28][33].

2. Overall Predation Pressure

Artificial caterpillars have been used as prey sentinels to estimate predation rates of both vertebrate and invertebrate predators in multiple studies [25][36][37]. Due to its simplicity in relation to real prey, the method has been proposed for assessing the invertebrate predation service [38][39].

Lövei and Ferrante [38] reviewed the use of sentinel prey to estimate invertebrate predation. Based on the analysis of 42 articles using artificial caterpillars, they determined a median attack rate of 8.8% per day for predators in general, 3.9% per day for vertebrate predators, and 3.3% per day for invertebrate predators. The estimated attack rates here of the exposed dummy caterpillars were lower than the median values reported by Lövei and Ferrante [38], although within the range of reported values. These results suggest that the predation pressure in the study systems is relatively low. Whereas birds are not affected by prey body size and are more likely to attack larger caterpillars [40], arthropod predators may be in a biased position since they tend to be more successful when attacking smaller caterpillars [41]. Nevertheless, birds dominate in temperate ecosystems, while insects, namely ants and wasps, are the main predators in tropical forests [41][42][43].

3. Effects of Ecological Infrastructures and Landscape Metrics on Predation Rate

EIs have been reported to support functional biodiversity and related ES in agricultural systems [13][14][17][44]. Concerning ES related to regulatory predation, most studies analyze predators’ abundance and diversity supported by EIs in the vicinity of agricultural fields [13][20]. Differences in the composition of predator communities in function to different types of EIs have also been observed [13]. However, the influence of EIs on insect predation is still poorly studied. In addition, the effects of vegetation structure, EIs proportion in the landscape, and other elements, such as the proximity to riverine habitats, have not been comprehensively studied. The effects of EI structure and location may also differ between predatory groups.

Insect predation by birds contributed to the overall differences observed between EIs and the agricultural matrix. Further, the highest predation by birds was observed in trees in the vicinity to the water, i.e., riparian woody, also corresponding to more complex vegetation structural composition. Riparian habitats also provide emergent aquatic insect populations that may constitute an alternative food source for insectivorous birds [45]. It has been shown that riverine structures support high bird diversity, species that are sensitive to riparian vegetation structure and composition [46]. The importance of riparian habitats in supporting regulatory ES, such as pollination and pest control, has been highlighted [16][47][48].

Mammal attack rates were highest in riparian habitats, in particular herbaceous. Other studies showed that riparian habitats may work as shelter areas and result in higher diversity and abundance of small mammals [49][50]. This effect increases in tandem with the greater complexity of vegetation structure [49]. Also striking was to observe that predation by mammals was higher in the agricultural matrix than in most of the EIs, except the riparian herbaceous. It is suspected that this might be associated with the presence of small omnivorous rodents in maize crops, often attracted by seed consumption. For instance, voles abundance may be influenced by crop characteristics such as density and height [51]. The response differences between groups of predators may be related to habitat usage and functional connectivity among habitats.

4. Drawbacks and Strengths of the Method

Dummy caterpillars allow for a standardized and rapid assessment of relative predation rates. They are easy to install and to assess, being also appropriate for citizen science programs [52]. Quantification of invertebrate predation is not easy, as evidence is difficult to obtain [28][53]. In contrast, dummies allow collecting predator's marks and can be implemented on a large scale and diversity of habitats. Dummy caterpillars have been increasingly used with the main purpose of measuring variation in predation pressure. The method has proven to give comprehensible results in different contexts, such as when comparing predator variations between canopy and understory habitats [29], forest gaps, and forest understory [54], variation across different types of forests [25], different agricultural land-uses [30], along urbanization gradients [22], elevation [24] or latitudinal variation [52][53][55]. Still, the interpretation of the results must be considered carefully. Differences in predation activity may be expected when changing the exposition of the caterpillars, such as naturally exposed vs. semiconcealed mimicking leaf-rolling caterpillars [56]. In addition, the presence of particular elements of the microhabitat or avoidance of local predators might influence the results. For example, Dáttilo et al. [57] showed that predators were visually repelled by ants, reducing predation marks on dummy caterpillars near objects resembling ant shapes.

Dummies are inactive and inodorous, which may make them less attractive to predators and thus might not reflect natural predation rates [27][28]. On the other hand, dummies do not run away or hide from threats, which may be considered to create a conservative balance [28]. Still, it is necessary to consider that dummies attract predators merely by visual cues. Different groups of predators are more oriented by visual cues than others and may respond in different ways to the color, size, and shape of the prey. Thus, despite being a similar technique, the results among groups have to be compared carefully. In particular, birds are probably mostly attracted by prey visual cues (color and shape) and less by odors, as birds mainly use vision to perceive information from their environment [58]. On the contrary, for many predator insect species, in particular specialist ones, vibrational and chemical cues play a major role while searching for prey as well as for prey recognition and acceptance. Chemical cues may include semiochemicals emitted directly by the prey (e.g., [59][60]) or associated with the prey, such as feces (e.g., [61]) or plant volatiles [62]. Small mammals are also acoustically oriented to locate and select their prey [63]. The differential response of birds observed here, in comparison to insects and mammals, could be in part due to different prey detection and recognition mechanisms used by these three predator groups. Bird marks are also probably more reliable than insect marks, as they are easier to distinguish even by nonexpert observers [64].

5. Conclusions

Overall, a consistent trend was observed of increasing predation from agricultural matrix to complex and biodiverse systems, such as the riparian woody EIs. However, differences were observed between groups of predators. The birds were the most responsive to the proximity and area covered by woody EIs in the landscape. The presence and proximity to riparian EIs were also important factors for predation by birds. Insects were the least responsive predator group to habitat complexity. The observed differential response of the studied predators is possibly related to the low proportion of EIs in the landscape, with low connectivity levels for the less mobile predator groups, such as insects. Future studies should consider different landscapes with different levels of EIs to test this hypothesis.

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