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Biological controls of intensive agroecosystems: Wanderer spiders in the Langa Astigiana

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ABSTRACT

Spiders are typical terrestrial predators that show a high degree of diversity in agroecosystems according to prey capture strategies. Their role as biological controllers constitutes a challenging topic in applied ecology. Confronted with prey shortages wanderer spiders actively search for more productive habitats. In this paper we model the population dynamics of wanderer spiders and their prey in an almost homogeneous agricultural landscape. The effect of human intervention through insecticide spraying is also considered.

1. Introduction

Spiders are abundant and ubiquitous predators in terrestrial ecosystems. Wise (1984) proposed the spider as a model terrestrial predator and specified that some spider families differ so much in how they forage and utilize their surroundings that it may prove risky to generalize about their role in terrestrial communities. Competitive interactions, impacts upon prey population and susceptibility to natural enemies may differ so much between web builders and wandering spiders that the role of these two groups in ecological webs would have to be considered separately (Wise, 1993).From a general point of view it can be assessed that both web builders and wandering spiders frequently face a shortage of prey in nature. Confronted with prey shortages, web builders generally choose the sit-and-wait strategy, remaining still and waiting for an increase, while wanderers search for more productive microhabitats. Many wandering spiders, in fact, select microhabitat on the basis of prey abundance (Edgar, 1971; Kronk and Riechert, 1979; Morse and Fritz, 1982). As confirmed by several laboratory–field comparisons (Edgar, 1969; Hagstrum, 1970; Anderson, 1974), an increase in prey abundance may favour their growth rate and fecundity. If increases in one or more of these parameters cause the average population to increase, it can be assumed that (wandering) spiders are theoretically food limited. An increase of the population would consequently increase competition among adults (territoriality) and could favour dispersal behaviour. These hypotheses have been tested by researchers showing that spiders did not result constantly being food limited. However, limitations in experimental design in these experiments mean that food limitation cannot be ruled out for most of the species. Accumulating evidence, both direct and indirect, makes it clear that spiders are frequently hungry, to the point of exhibiting rates of growth and reproduction considerably below what is physiologically possible (Wise,

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1993). Several studies suggest that spiders actively select prey in a manner to optimize the proportion of essential amino acids in the diet (Miyashita, 1968; Greenstone, 1979). Even if it seems that this behaviour evolves in environments with low prey diversity, it is proved that a mixed diet is necessary for normal growth and reproduction. The degree of satiation of spiders together with the rejection of certain types of prey could explain the proportion of different type of prey in the diet and, consequently, the need for searching for new microhabitats.

In Piedmont (NW Italy), and similarly in other countries, vineyards agroecosystems are nowadays subject to relevant transformations due mainly to two apparently opposite causes, land abandonment and agricultural intensification. Intensification implies the progressive removal of all small natural landscape elements not strictly related to the production process, thus increasing the overall loss of heterogeneity with its consequences on biotic communities (Ruthsatz and Haber, 1981; Harms et al., 1987; Agger and Brandt, 1988). Landscape heterogeneity is mainly obtained by the presence of woods. It seems to be the most important environmental factor to enhance spider diversity (Isaia et al., 2006). Diverse landscapes, including in particular wood habitats, can be considered a refuge and a source of spider populations for habitats like vineyards. Agricultural land is a virtually continuous shifting mosaic of land types, in which organisms are repeatedly disturbed by farming operations (Halley et al., 1996). Indeed, most agroecosystems provide no permanent habitats for many species. Hence, for the thriving of the latter, the presence of refuge areas, such as relatively undisturbed woods, is fundamental. As pointed out by Halley et al. (1996), the effect of introducing a second land type source in a very homogeneous landscape making it less homogeneous can lead to dramatic consequences, supporting more diverse species and increasing their population sizes. The presence of a herbaceous layer also plays an important role. These factors influence both the community structure and species composition of spider assemblages. The maintenance of semi-natural patches allows a greater diversification of specialized predators, which could be important for the control of various pests in agroecosystems (Marc and Canard, 1997).

In this paper we want to model the situation of the Piedmontese Langhe, where the landscape is dominated by vineyards and the only diverse elements are small residual patches of wood. We describe a system in which predators, the spiders, can move around among vineyards and woods, in which two different prey, the insect populations, thrive. In addition since vineyards largely predominate on woods we suppose that the spiders experience a kind of feeding satiation effect, in view of the abundance of the same kind of prey in vineyards. Since they are able to move around and seek other food sources, we model this ability for finding other food sources by accounting also for the insect population living in the nearby territories. The analysis of the system shows that periodic cycles in the three populations are possible, under suitable parameter values. We then investigate the effect of human activities in this ecosystem, by considering also insecticide spraying and its effects.

2. Model formulation

The ecosystem we consider consists of the spiders populations $s(t)$ and the insects on which they predate, which we account for in dependence on the territory in which they live. More specifically let $f(t)$ be the insects population living in the woods and the green patches bordering the cultivated land, and let $v(t)$ denote the insects having the vineyards as habitat. The model in which all the parameters are assumed to be nonnegative, is the following one

$$\dot{f} = rf\left(1 - \frac{f}{W}\right) - csf, \quad \dot{s} = s\left(-a + \frac{kbv}{H+v} + kcf\right), \\ \dot{v} = v\left[e - \frac{bs}{H+v}\right]. \tag{1}$$

The first and third equations describe the evolution of the wood insects and the growth of the insect population in open fields, respectively.

The equation for the wood insects accounts for logistic growth, first term, while the last term represents the predation these insects are subject to by the spider population, modeled via a mass action law. As already mentioned in the landscape of the Langa Astigiana the woods and green patches are very small compared to the extension of the cultivated land, so that their corresponding carrying capacity W is small.

The third equation instead models the growth of the insect population in open fields, and then also the predation activity to which they are subject by spiders. Notice that these two terms have different functional forms from the corresponding ones of the first equation. This is a basic assumption of this system, to faithfully model the situation in the Langa Astigiana. Recalling the discussion on the ‘‘almost homogeneous agricultural’’ landscape of the Langhe described in the introduction, the vineyard insects are indeed assumed to follow Malthus law in view of the huge extension of vineyards and cultivated land compared to the small size of the green patches and bordering wood areas. This is then reflected in the fact that the carrying capacity of the vineyards is very much larger than the one of the wooden patches, so that it could be modeled by a parameter V with $V \gg W$ as done for instance in (Venturino et al., 2006). In order to deal with one less parameter in the model, safely enough it is here assumed to be $V = \infty$. The last predation term is instead modeled on the basis of the spiders behaviour described below.

The dynamics of spiders is given in the second equation, in which a negative Malthus growth describes their mortality. The two nonnegative terms account for the growth due to predation on the two insect populations, where the constant $k < 1$ models the conversion factor of prey into new spiders. Notice again that we expressly take two different predation functional forms on the two different kinds of prey since as discussed in the introduction the almost absolute homogeneity of the vineyard cultivation implies that the insects living in it are extremely abundant, while the marginal wooden patches host very small populations of different insects. The latter constitutes an alternative food source for the spiders, appetible especially when the monotonous diet consisting of the abundant vineyard insects makes the spiders