Agriculture, Ecosystems and Environment 232 (2016) 190–198

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Azteca chess: Gamifying a complex ecological process of autonomous pest control in shade coffee

Luis García-Barrios, Dr.[a,*], Ivette Perfecto[b], John Vandermeer[c]

[a] El Colegio de la Frontera Sur, San Cristóbal de las Casas Campus, Chiapas, Mexico
[b] School of Natural Resources, University of Michigan, Ann Arbor, MI, USA
[c] Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor, MI, USA

ARTICLE INFO

Article history:
Received 13 April 2016
Received in revised form 5 August 2016
Accepted 7 August 2016
Available online xxx

Keywords:
Ecological complexity game
Shade cofee
Educational board-game
Autonomous pest control
Trait mediated interactions

ABSTRACT

Science-based board games can help people grasp the ecological complexity of autonomous pest control (APC) in the shade-coffee agroecosystem. Azteca Chess is a board-game that captures in a stylized way the fascinating natural history and the dynamics of a complex network of direct, indirect and cascading trait-mediated interactions among five species of arthropods dwelling in shade coffee bushes (a coffee-scale, an ant, an adult and larval lady beetle, a parasitoid wasp and a parasitoid fly). In exchange for honey-dew, the Azteca ant protects scale-insects that help control the devastating coffee-rust disease. The ant repels the adult ladybeetle but inadvertently protects its larvae, which devour scales to local extinction. The head-hunting fly paralyzes Azteca and opens a window of opportunity for the adult beetle to oviposit under scales, but also for a parasitoid wasp to kill the beetle larvae. Interactions can cascade or not towards APC. Experimental test-driving shows Azteca Chess meets good modeling and game-design standards and is proved statistically to enhance understanding and application of relevant complex ecological processes.

1. Introduction

Capturing the inherent complexity of ecological systems has long been a perplexing problem for pedagogy. Massive networks of interactions, so commonly displayed in nature centers and power point presentations, do not really convey what most professional ecologists understand about ecological complexity. The reality is that ecology is complex and therefore is difficult to teach, learn and apply (Leiba et al., 2012; Proctor and Larson 2005). This is more so when those that are supposed to use the knowledge to solve practical problem, have not been trained in the formal science of ecology, which is the case of most stakeholders involved in natural resource management, including the millions of farmers in the world. “Preaching” to local impoverished farmers about the “ecological services” provided by the local nature preserve is not, in our experience, effective.

One pedagogical tradition that has seen many science classroom applications is gaming (e.g. Honey and Hilton, 2011; Stevenson et al., 2014), where students play either board or computer games designed to represent various natural phenomena, most frequently physical principles or human behavior (e.g., classical economics). We propose that such an approach could be useful in an extension outside of the classroom also, especially with the purpose of teaching an appreciation of some basic principles of ecological complexity with very practical consequences for shade-coffee and other agroecosystem management involved. Indeed, board-games have recently emerged as participatory education tools that facilitate communication and reflection among those involve in resource management, and promote a common knowledge ground from where to build effective management and governance (Sandker et al., 2010; Etienne, 2014; García-Barrios et al., 2015). To this end we have taken a particular ecological system with which we are intimately familiar (Perfecto and Vandermeer, 2015), developed a set of rules that capture the central essence of the interactions involved, and cast it as a two-person board game called “Azteca Chess.” We here report on the game itself and on the results of test-drive “tournaments” we have organized in Mexico.

Shade-coffee grown by Mesoamerican farmers in tropical mountains has been claimed as an archetypical example of a complex ecosystem capable of sustaining a significant proportion of the local biodiversity (Perfecto and Vandermeer, 2015). Unfortunately, the farmers who construct and manage these

* Corresponding author.
E-mail addresses: luisgarciabarrios@gmail.com (L. García-Barrios), perfecto@umich.edu (I. Perfecto), jvander@umich.edu (J. Vandermeer).

http://dx.doi.org/10.1016/j.agee.2016.08.014

systems are riddled with livelihood problems, most recently due to the coffee rust epidemic (*Hemileia vastatrix*) (Vandermeer et al., 2014; McCook and Vandermeer, 2015). Such dramatic moments are perhaps not as rare as thought when considering a longer time frame and more extensive area (e.g., only a few years earlier, it was the coffee berry borer that created the drama and the coffee leaf miner, a trivial problem in Mexico, is currently a major problem in Puerto Rico). There is, of course, an important message here – populations of agriculturally relevant organisms in general explode to pest levels only occasionally. This is due, at least in part, to the emergence of self-organized (and therefore autonomous) networks of organisms, including natural enemies of the pests, that are interacting directly and indirectly resulting in oscillating populations that are kept within certain bounds (e.g. autonomous pest control; APC). Small-scale coffee farmers have sophisticated ecological knowledge of many processes occurring in their farms (Valencia et al., 2015) but are rarely aware of the subtle yet critical interactions among the smaller inconspicuous organisms that contribute to APC (Perfecto and Vandermeer, 2015).

Over the past twenty years various research teams have combined to provide an appreciation of the complex ecology of neotropical shade coffee (Perfecto et al., 1996; Greenberg et al., 1997; Perfecto and Vandermeer, 2008, 2015; Philpott et al., 2009; Vandermeer et al., 2010; Karp and Daily, 2014; Perfecto et al., 2014). In southern Mexico, where many of the studies have been conducted, they have unraveled the fascinating natural history and the qualitative dynamics of a self-organized network of at least 21 interacting species of fungi, ants, beetles, parasitoid wasps and parasitoid flies capable of exerting autonomous pest control over coffee-berry borers (*Hypothenemus hampei*), leaf miners (*Leucoptera coffeella*), scale insects (*Coccus viridis*) and rust fungus (Vandermeer et al., 2010; Perfecto and Vandermeer, 2015). Our two-player strategic board-game, Azteca Chess, deals with a keystone subset of this community involving a scale insect pest and a fungal rust disease and the purported autonomous pest control (APC) therein (Fig. 1). A full accounting of the system is found elsewhere (Vandermeer et al., 2010; Perfecto and Vandermeer, 2015), and Supplementary Online Materials (Appendix A in Supplementary materials) presents a synthesis.

The APC in this system emerges from direct and indirect interactions and from the cascading effects of the mere presence and behaviors of some species (trait-mediated interactions). The following is a list of those interactions shown in Fig. 1 and how they contribute (or not) to APC:

In shade coffee plantations, high-density colonies of the green coffee scale (*Coccus viridis*) – a minute sessile insect – are found sucking the sap out of twigs, leaf and fruits of a few coffee bushes. Why? Swarms of the tree-nesting ant *Azteca sericeasur* (Azteca hereafter) actively patrol these bushes tending the scale insects. This is a typical ant-hemipteran mutualism where the ant protect the scales by harassing and chasing away scale parasitoids and predators, in exchange for energy-rich honeydew that the scale insects extrudes. High-density scale colonies harbor its "predator" the white halo fungus (*Lecanicillium lecanii*), an entomopathogen known to also attack other fungi. *Lecanicillium* proliferates on these scale colonies, which provides spores that disperse from these nuclei to attack the coffee rust. The scale helps exert prevention and partial control on rust at the farm level.

The lady beetle, *Azya orbiguera* is a major predator on the scale. *Azteca* harasses the adults and sometimes kills them. However, the beetle larvae are protected from ant predation by abundant waxy filaments that cover their soft bodies and deter the ants from biting them. Furthermore, *Azteca,* by chasing away all the parasitoids that come close to the general area where the scales are located,

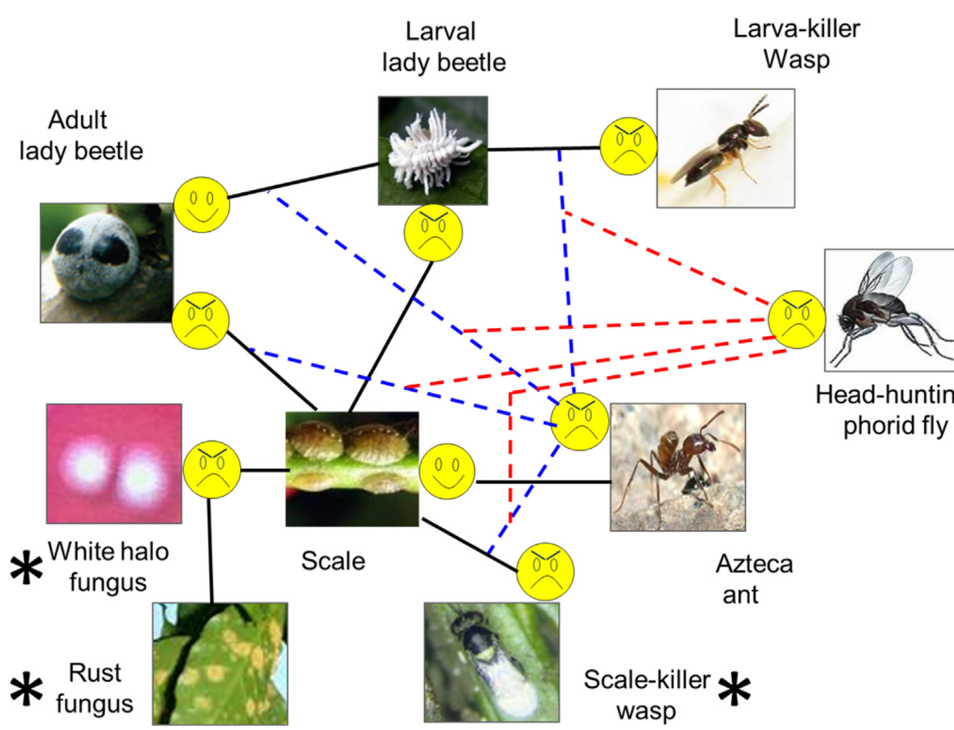

Fig. 1. Each organism projects an action (face) through a line directed towards another organism(s) or interaction(s) which it affects. An angry face signifies harm and a happy face benefit. Solid lines mean predation or parasitism (eating the prey or laying eggs that will hatch and eat the prey). For example: the larval lady beetle projects a harmful face towards its prey, the scale. Trait-mediated interactions are represented by dashed lines. The capacity of the ant to change the behavior of predators is represented by dashed blue lines projected upon predation interactions. The capacity of the fly to change the behavior of the ant is represented by dashed red lines. Happy faces in the figure represent the capacity of the scale to provide honey-dew to the ant and of the adult lady beetle to oviposit and produce its larvae. (Figure modified after Fig. 5.14 in Perfecto and Vandermeer, 2015. In the latter, standard ecological symbols (dot and arrow) are used to denote consumer-resource relations. Species marked with an asterisk are included in workshop lectures but not in the game.). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)