Controlling invasive species with biologically-inspired robots

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Abstract

Robotics is emerging as a promising approach to study animal behavior. Biologically-inspired robots can manipulate the behavior of live animals and are increasingly employed to uncover the underpinnings of sociality and mate choice in the animal realm. But behavioral variation between animals plays a critical role for their ecology and evolution, and ultimately it determines variation in the survival, growth, and reproduction of individuals. While the study of behavioral responses of animals toward their robotic counterparts dominates the literature, it remains largely untested whether the life-history strategies of live animals can be artificially manipulated with biologically-inspired robots. Recently, predator-mimicking robots allowed to successfully study antipredator responses of highly invasive fish in detail, revealing that costs of behavioral alternations induced by robotic predators can impact the health and survival of invaders. The evidence that biologically-inspired robots can undermine the ecological success of invasive animals opens the door to novel experimental analyses at the interface between robotics, ecology, and invasion biology.

Invasive species: a serious environmental problem

Human activities have offered unprecedented opportunities to some animals for crossing geographical barriers and invading new habitats (Elton, 2000; Richardson, 2011). As a result, nowadays invasive species are spread across the planet, driving native species to extinction (Clavero and García-Berthou, 2005), compromising ecosystems (Lockwood, 2013), and costing our economy billions of dollars every year (Pimentel at al., 2005). Freshwater ecosystems host more than 25% of the world's vertebrates and are particularly vulnerable to competitive and aggressive invaders (Leprieur at al., 2008; Su et al., 2021). Despite the urgent environmental challenge that invasive species represent for freshwater ecosystems, methods to eradicate invasive species are largely unsuccessful (Byers et al., 2002).

The invasive mosquitofish (*Gambusia holbrooki*, Figure 1A) is a major threat to freshwater fish and amphibians (Pyke, 2008). Its impact on biodiversity has been recognized by the *International Union for Conservation of Nature*, which lists mosquitofish as amongst the world's top hundred worst invasive species (Lowe at al., 2000). For example, the presence of mosquitofish is causing the extinction of the red-finned blue eye (*Scaturiginichthys vermeilipinnis*) and the Edgbaston goby (*Chlamydogobius squamigenus*)—two of the most critically endangered fish species in Australia (Faulks at al., 2017; Kerezsy and Fensham, 2013; Nicol et al., 2015). To date, no successful procedure exists for eradicating mosquitofish and mitigating their impact on native fauna (Brookhouse and Coughran, 2010; Westhoffet al., 2013; Willis and Ling, 2000).

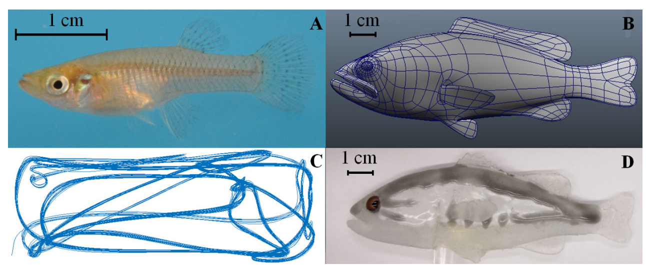

Figure 1 (A) Mosquitofish and (B) the body morphology and (C) swimming features that we measured in the native mosquitofish's primary predator (*Micropterus salmoides*) and that we integrated into the design of (D) the biologically-inspired robotic predator presented in Polverino et al. 2019a. A is adapted from Polverino and Porfiri 2013a, B is from Adicaza 3D models, and C and D are prepared by Polverino and Porfiri for this article.

Harnessing cutting-edge technology to understand animal invasions

New technologies have offered invaluable tools for studying the ecology and evolution of living creatures (Aguilar et al., 2014) and addressing the seemingly intractable problem of invasive species (Kerr et al., 2017; McCann at al., 2019). In particular, robotics is emerging as a promising approach to studying animal behavior (Krause et al., 2011; Romano et al., 2018; Webb, 2000) and animal invasions (Dufour et al., 2020; Polverino et al., 2019). State-of-the-art robots can move autonomously (Butail et al., 2013; Butail et al., 2014; Gribovskiy et al., 2018; Katzschmann et al., 2018), simulate specific characteristics of live fish (Landgraf et al., 2016; Phamduy et al., 2014; Polverino et al., 2012; Romano et al., 2017a), infiltrate social groups (Bierbach et al., 2018; Butail et al., 2013; Marras and Porfiri, 2012), and interact with live animals in real time (Bonnet et al., 2019; Kopman et al., 2013; Polverino et al., 2019a).

Recent studies underscore the extraordinary opportunity of using robots inspired by live predators to control the behavior of pests such as locusts (Romano et al., 2017b, 2019) that pose a threat to human agricultural economies. Similarly, falcon-like robots are a powerful tool to deter other birds from flying in the vicinity of aircrafts (Folkertsma et al., 2017). Robots are inherently safer to use than live agents in the wild, since robots can be finely controlled and cannot breed.

Efforts from our group have shown that biologically-inspired robotic predators can repel invasive mosquitofish (Polverino and Porfiri, 2013a), undermine their health (Polverino et al., 2019a), and simultaneously attract non-invasive fish species (Polverino and Porfiri, 2013b).

Advancing the field

The unparalleled control offered by biologically-inspired robotics to successfully manipulate animal behavior leads to new exciting questions. We know that small behavioral adjustments have relatively large effects on the survival and reproduction of animals (Réale et al., 2007) and can determine the ecological success of invaders, including mosquitofish (Brodin et al., 2019; Rehage and Sih, 2004). What we do not know is whether and how the behavior of invasive animals can be artificially manipulated to undermine their ecological success.

Our previous analyses have demonstrated that variation in behavioral, physiological, and life-history traits in fish is associated at the individual level—individuals that are more active grow faster and have higher metabolic rates than less active ones (Polverino et al., 2018). We have uncovered the association between individual variation in risk taking and fertility, where males that take more risks have high number of sperm over risk-averse males (Gasparini et al., 2019). We also found empirical evidence that manipulating social experience during development alters the mating acquisition of fish in adulthood and, hence, their reproductive success (Polverino et al., 2019b).

The knowledge that altering the behavior of fish has repercussions on their physiology, growth, fertility, and reproduction is central for studying the developmental and evolutionary consequences of behavioral manipulation. Yet whether exposure to biologically-inspired robots has effects that extend beyond the behavior of animals remains unexplored (but see Polverino et al., 2019a).

We believe that state-of-the-art robots inspired by live predators offer an extraordinary opportunity to alter the behavior of invasive species and study the detrimental consequences of fear and anxiety on their survival and reproduction. World-leading experts in ecology and evolution indeed advocate for expanding the conceptual underpinning and practice of biological control (Culshaw-Maurer et al., 2020). In this vein, cutting-edge technologies can play a key role in revealing the evolutionary vulnerabilities of invasive and pest species, and transfer the fundamental knowledge from predator-prey ecology to inform a new generation of biocontrol practices.

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