Importance of harvest-driven trait changes for invasive species management

Although intraspecific differences between the phenotypes of organisms are an important driver of ecological dynamics (Des Roches *et al.* 2018), research to help integrate phenotypic variation and its drivers with ecosystem management has been limited. For this reason, the novel conceptual framework proposed by Palkovacs *et al.* (2018) – which helps to clarify the ecological implications of harvest-driven trait changes – is timely.

Biological invasions are a key component of the current biodiversity crisis and affect all levels of biological organization. From local to global scales, efforts to control or eradicate invasive species aim to reduce the negative ecological and economic impacts associated with invaders (Kopf *et al.* 2017). Invasive species management commonly relies on methods including harvest (eg hunting and angling), as well as chemical and biological control measures, and can result in non-random removals of individuals from targeted populations (Myers *et al.* 2000; Britton *et al.* 2011). The potential selectivity of these methods therefore has strong ecological and evolutionary implications. Consequently, we suggest that Palkovacs *et al.*'s (2018) framework could be applied to invasive species management. Indeed, harvest-driven trait changes in invasive species might induce unexpected and potentially counterproductive results that may not have been explicitly considered by ecosystem managers.

Recent studies have demonstrated how harvest modifies the traits of invaders and how these changes could modulate their ecological impacts (Figure 1). In populations of invasive lionfish (*Pterois volitans*) controlled by spearfishing, individuals have shifted their behavior to become more crepuscular, potentially increasing their encounter rates with native reef fishes at dawn and dusk (Côté *et al.* 2014). Behavioral changes were also observed in dingoes (*Canis lupus dingo*) controlled by shooting and baiting, which reduced their activity at dusk and increased it at dawn, relaxing their top–down control of invasive feral cats *Felis catus* and increasing the likelihood of encounters between feral cats and native prey (Brook *et al.* 2012). There is also evidence to suggest that harvest-driven trait changes could affect ecosystem functioning. For example, in an experiment on the invasive red swamp crayfish (*Procambarus clarkii*), a modeling approach revealed that a substantial decrease in crayfish population size affected leaf-litter decomposition rate (a key ecosystem process) to a similar degree as did changes in crayfish behavioral, morphological, and life-history traits (Raffard *et al.* 2017). Harvest-driven trait changes might also modify the indirect effects of invasive species on recipient ecosystems. The removal of invasive pumpkinseed sunfish (*Lepomis gibbosus*) by angling leads to changes in sunfish population size distribution and size at maturity (Evangelista *et al.* 2015). As life-history traits affect fish diet composition (Zandonà *et al.* 2011), these harvest-mediated changes can then alter the nutrient-mediated effects of pumpkinseed sunfish on ecosystem processes (Evangelista *et al.* 2017).

The direction and magnitude of harvest-driven ecosystem effects might be expected to differ between native and invasive species. Although harvested native species usually have high economic, nutritional, and cultural values, these attributes are not necessarily linked to their ecosystem role. Conversely, invaders subjected to control methods are targeted due to their strong negative ecological impacts (Kopf *et al.* 2017) and are therefore likely to comprise a higher proportion of functionally important taxa (eg ecosystem engineers) than harvested native species. This leads us to predict that harvest-induced effects on invasive species should result more frequently in strong ecosystem responses. Moreover, invasion is a selective process where individuals pass through a sequence of filters that act on individual phenotypes to determine whether introduction, establishment, and spread are successful (Blackburn *et al.* 2011). Consequently, in populations prior to harvest, the trait distributions of invaders might be limited as compared to the trait distributions of their native conspecifics (Juette *et al.* 2014), modifying the potential for harvesting to subsequently affect trait distribution. In addition, given the high costs of invasion control programs (Myers *et al.* 2000), invaders are often harvested at high intensity but over relatively short time periods. As a result, many invasion control programs are unsuccessful at permanently reducing or eradicating target populations (Britton *et al.* 2011; Pluess

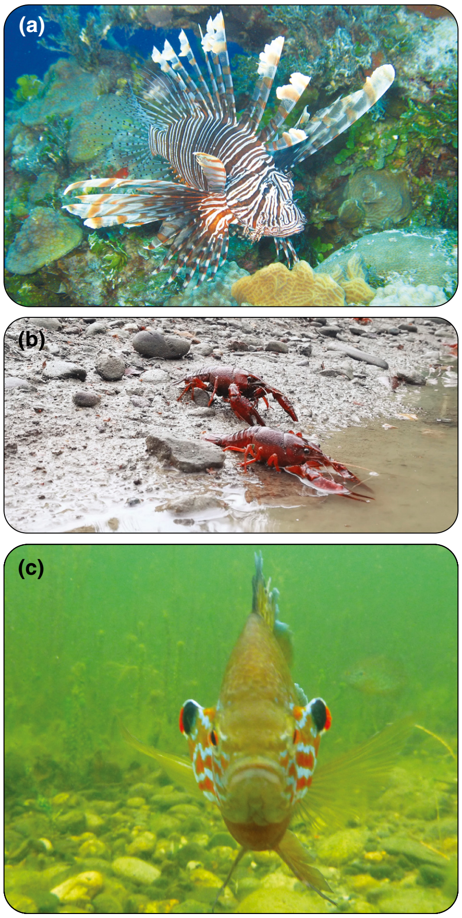

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Figure 1. Examples of effects on community structure and ecosystem functions induced by changes in the traits of invasive species targeted by selective invasion control techniques. (a) Elevated crepuscular activity in lionfish (*Pterois volitans*) increases the chance of the predator to encounter native reef fishes. (b) Changes in behavioral, morphological, and life-history traits of red swamp crayfish (*Procambarus clarkii*) affect the leaf-litter decomposition rate in invaded lakes. (c) Changes in life history and diet of pumpkinseed sunfish (*Lepomis gibbosus*) alter nutrient-mediated effects on ecosystem processes.

et al. 2012), and the remaining individuals can re-establish populations (or colonize previously unoccupied habitats) from a pool of individuals with strongly harvest-biased phenotypic traits.

Invasive species control remains an essential management tool with reported successes (Britton *et al*. 2011; Kopf *et al*. 2017). However, when complete eradication is not achieved through control efforts, re-established populations may contain individuals with traits different from those observed during the precontrol period. By extending the framework of Palkovacs *et al*. (2018) to invasive species, practitioners of ecosystem-based management would be able to explicitly consider ecological impacts of harvest-driven trait changes when assessing the net efficiency of invasion control techniques, by comparing the benefits of population size reduction versus the risks of harvest-driven trait changes.

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Wind energy and wildlife: 20 years of translational ecology in action

Frontiers' Special Issue on translational ecology (TE) focused on the urgent need for "effective translation between good science and informed practice". As scientists, practitioners, and conveners dedicated to facilitating wind energy development while protecting wildlife, we read that issue with the exciting ring of recognition. We commend such work that advances TE and would like to offer a few supporting observations, based on over 20 years of multi-stakeholder collaboration in the area of wind energy and wildlife.

Energy production presents a complex resource management challenge, given its association with habitat degradation, public-health impacts, and greenhouse-gas emissions. Energy production may now also be the largest driver of land-use change in the US, with biofuels – as well as mining and drilling for fossil fuels – having the heaviest footprints (Trainor *et al*. 2016).

Standing out in this energy landscape is the dedicated and potentially unique collaboration among stakeholders in the scientific community, conservation organizations, wildlife management agencies, and the wind industry. This collaboration began as wind energy expanded in the US from the early 1990s onward; first led to multi-stakeholder groups, such as the National Wind Coordinating Collaborative Wildlife Workgroup (www.nationalwind.org); and continued to expand and deepen over time. For example, in 2003, when a wind project in West Virginia was associated with large numbers of bat fatalities, it became apparent that research was needed to understand bat interactions with wind turbines. Bat Conservation International and stakeholders from the wind industry, scientific community, and government agencies subsequently created the Bats and Wind Energy Cooperative (BWEC; www.batsandwind.org). As a result, wind industry companies offered operational

