Conservation Biology

Diversity

The conservation paradox of endangered and invasive species

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Invasive and Endangered

Conservation professionals are increasingly likely to encounter competing conservation priorities surrounding individual species, namely endangered species that also have non-native populations. This overlap arises when a non-native species is established in a novel location but is at the same time endangered within its native range. This creates a difficult philosophical paradox in which efforts to protect the endangered species conflict with the protection of the invaded ecosystem and its compliment of native taxa.

Interest in the phenomenon arose from our work on *Palea steindachneri* (wattle-necked soft-shelled turtle) in Hawaii (Fig. 1). *P. steindachneri* is a large omnivorous freshwater turtle native to Vietnam and China (Ernst & Lovich 2009). In its home range it has been hunted close to extirpation largely due to its high cultural value as food and as a source of medicine. It is listed as endangered by the International Union for Conservation of Nature (IUCN) and threatened by the Convention on International Trade in Endangered Species (CITES). The Turtle Conservation Fund considers *P. steindachneri* one of the 48 most endangered turtle species on the planet (Bonin 2006). The few remaining wild populations of this turtle face uncertain survival prospects because the extreme rarity of the species has increased the cultural and market value of the remaining individuals (McKeown & Webb 1982).

The cultural importance of the species led to its introduction by Chinese laborers to Mauritius, Hawaii, and the Sacramento River, California (Radford 2011), in the 1800s. The species is currently established on the Hawaiian island of Kauai, and there have been reports of individuals on nearby Oahu and Maui. These extralimital populations clearly represent a substantial conservation opportunities for this species. For example, a novel habitat is likely exempt from some of the forces precipitating decline in a species' native range and may represent the last or most reasonable hope for a species' survival. Eventually, an introduced population may become the only extant population. In a sense, ex situ populations can serve as insurance for the species' survival. The non-native populations also present unique research opportunities for taxa that are too rare or too heavily protected by law to be effectively studied in their home ranges. Ecological studies of these extra-range individuals can generate life-history data that can be used to assist future captive propagation or management without harming the remaining native individuals. For some endangered species, even a little life-history or population data can go a long way toward effective protection. The extralimital populations may also harbor genetic diversity missing from remaining native populations (Bradshaw et al. 2006; Garzon-Machado et al. 2012). These non-native individuals could therefore play a role in future restoration efforts.

Effects on Native Species

Despite the positive aspects of extralimital populations, they also have clear negative conservation aspects. For example, it is likely that *P. steindachneri* is contributing to the severe alteration of the native freshwater ecosystems on the island. Across Hawaii non-native species and habitat degradation together pose the greatest danger to the islands' unique freshwater communities (Brasher 2003). Due to its isolation, many of Hawaii's freshwater taxa are endemic and the islands' aquatic communities have characteristically low diversity

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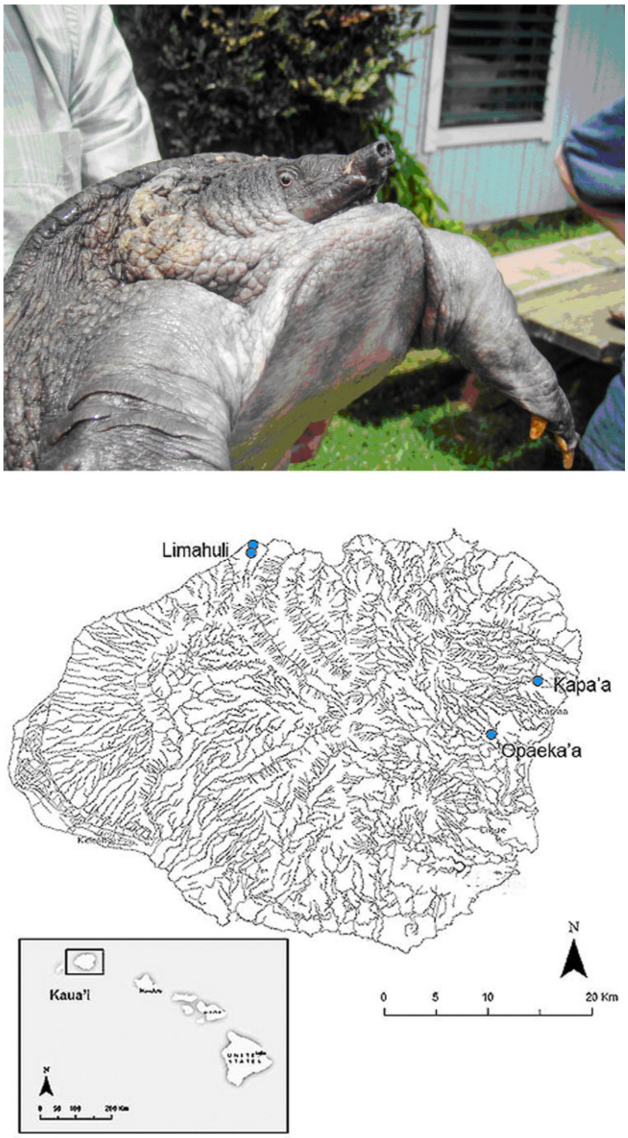

*Figure 1. Wattle-necked softshell turtle (*Palea steindachneri*) from Opeaka'a 2009 and locations of the 3 streams sampled for stable isotopes on the island of Kauai, Hawaii (U.S.A.).*

(McDowall 2003). The freshwater systems contain 7 native fish species, no native freshwater turtles, and no large aquatic predators. Because of its size (carapace ≤450 mm in length) and omnivorous diet, *P. steindachneri* has the potential to play a negative and potentially dominant role in Hawaii's aquatic food webs. Most streams across Kauai have also been colonized by a host of other non-native species, including Tahitian prawn (*Macrobrachium lar*), smallmouth bass (*Micropterus salmoides*), western mosquitofish (*Gambusia affinis*), cane toads (*Bufo marinus*), and red-eared sliders (*Trachemys scripta elegans*). *Palea* is by far the largest among this suite of introduced predators (Yamamoto & Tagawa 2000).

We studied *P. steindachneri* on Kauai from 2007 to 2014 and collected 17 turtles along the island's eastern coast. We captured adults of both sexes and juveniles, the presence of which indicates reproductive populations. In 2009, we took tissue samples from 2 *Palea* for stable isotope analysis (carbon and nitrogen). At the same time, we collected tissue from all aquatic organisms across 3 streams that spanned a range of disturbance from nearly pristine (Limahuli, *Palea* absent), to moderately disturbed (Kapa'a, *Palea* present), to highly disturbed and heavily invaded (O'paeka'a, *Palea* present). Our findings indicated that in streams where the turtle is present it either occupied the same position in the food web as the native fishes in terms of both trophic level and carbon usage (Kapa'a) or added an entirely new top-predatory trophic level to the food web (O'paeka'a) (Layhee et al. 2014) (Fig. 2). The isotope analyses indicated an ecological interaction between the turtles and native fish (competition, predation, or both). Although none of the endemic freshwater fishes in Kauai are currently listed as endangered, there is significant decline among many populations (Yamamoto & Tagawa 2000) suggesting that the turtle may pose a conservation threat.

Kauai has an endemic freshwater snail (Newcomb's snail [*Erinna newcombi*]) that is listed as threatened by the U.S. Fish and Wildlife Service (USFWS) and vulnerable by the IUCN (USFWS 2006). This snail currently occurs in remote areas of 6 streams, 3 of which (Makaleha, Kealia, and Wailua streams) are upstream of locations where we collected *P. steindachneri*. Our data indicated that snail species are a major component of the turtle's diet. If the populations of either Newcomb's snail or the turtle expand, there is the potential for interactions between the 2 species. Likewise, conservation efforts to reintroduce the snail to parts of its former range would be affected by the presence or absence of turtles in those sites. This would create a paradoxical situation where 2 noncompatible endangered species are brought into contact, one in its native range and one as a non-native predator.

Other Invasive and Endangered Species

We have studied a single example of an invasive and endangered species, but conservation situations such as this are likely to become more common as non-native species become established and additional native taxa become imperiled. A number of diverse species are in similar situations: Bermuda cedar (*Juniperus bermudiana*), invasive on some oceanic islands and endangered in Bermuda (Adams 2008); Monterey pine (*Pinus radiata*), invasive in Australia and New Zealand and endangered in California and Mexico (Rogers et al. 2005); arapaima (*Arapaima gigas*), invasive in Bolivia and endangered in Brazil (Miranda-Chumacero et al. 2012); European wild rabbit (*Oryctolagus cuniculus*), invasive in many places and endangered in Iberia (Lees & Bell 2008); banteng

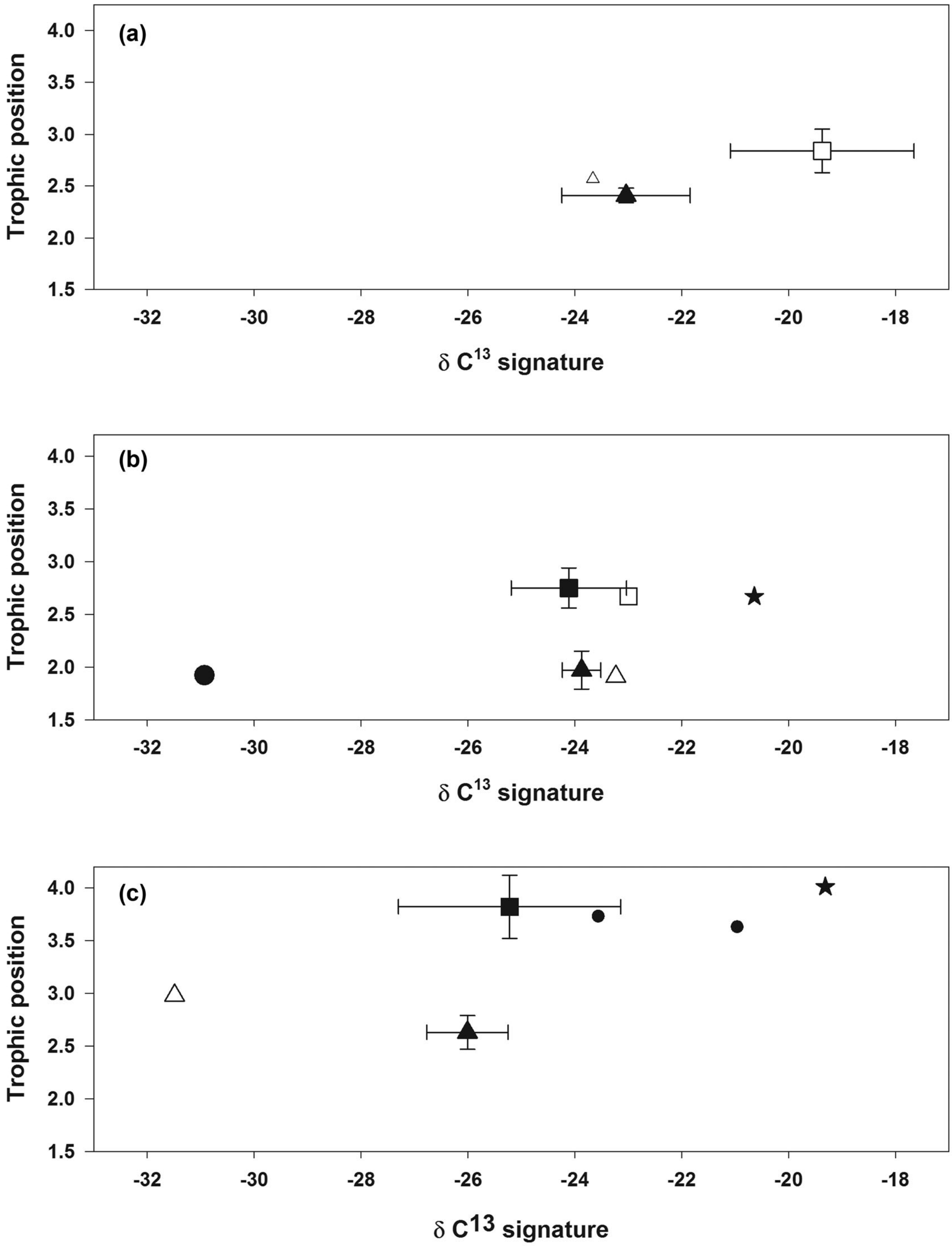

Figure 2. Isotopic biplots of aquatic organisms in (a) Limahuli, (b) Kapa'a, and (c) O'paeka'a streams in 2009 showing δ^{13} carbon signature versus trophic position (filled symbols, non-native organisms; open symbols, native organisms; squares, fishes; triangles, invertebrates; circles, amphibians and reptiles; stars, 2 P. steindachneri *individuals; symbols with error bars, average value in that particular taxonomic group; symbols without error bars, records of a single individual in that taxonomic group).*

(*Bos javanicus*), invasive in Australia and endangered in Bali (Bradshaw et al. 2006); Barbary sheep (*Ammotragus lervia*) and mouflon (*Ovis orientalis*), invasive on the Canary Islands and endangered in their native ranges (Garzon-Machado et al. 2012); and Sacramento perch (*Archoplites interruptus*), non-native throughout the western United States and extinct in its native California range (Crain & Moyle 2011).

Although it may be ethically tenuous to endorse trading one species for another; philosophically, it is hard to decide how to approach these challenging situations. In many cases, it is clearly better to have extant but non-native populations of a species than the alternative, namely extinction. However, this choice is not clear if the non-native populations lead to widespread extinction of native species or collapse ecosystem function in the introduced range. This issue of competing conservation concerns regarding species that are both invasive and endangered and the paradox posed by species such as these is one that will be increasingly wrestled with in the near future. Clearly, these situations are complicated; there are no easy answers and the devil hides in the details of each individual case. As scientists, our job is to evaluate the level of endangerment in the native range; to evaluate the specific impacts of the species in the introduced range; and to predict the resiliency of the affected communities. We have started down this path for *P. steindachneri* in Hawaii. In this, as in most cases, conservation policy will be formed in the absence of perfect data. Plan A is to leave the turtles in place and hope their impacts on native communities are not too great; however, one must be willing to evaluate plans B, C, D, and E, which may involve removal, relocation, captive propagation, or repatriation.

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