Impacts of Invasive Species on Ecosystem Energy Flow on the Big Island of Hawai'i: Excuse Me, But Are You Going to Eat That Cane Toad?

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ABSTRACT: Worldwide, it has been estimated that invasive species have negative economic impacts in the billions of dollars, with impacts to island ecosystems being among the most devastating. While it is estimated that the most costly and destabilizing impacts are upon ecosystem functions, such impacts are difficult to quantify monetarily, and exact mechanisms are poorly understood. In particular, the role invasive species play in altering energy flow through ecosystems, specifically regarding the recycling of nutrients associated with carrion, is poorly elucidated for most invasive vertebrates. How invasive amphibians and reptiles, which comprise the majority of the invasive species biomass in island ecosystems, may be affecting energy flow within the scavenging pathway is virtually unknown. By setting out camera traps associated with carcasses of 3 taxa (coqui frogs, geckos, cane toads), this study has identified the dominant scavenging vertebrates on the Big Island of Hawai'i, as well as the fate of sequestered energy that is available to be scavenged upon the death of invasive amphibians and reptiles. These data contribute to our understanding of the functional mechanisms through which invasive species alter energy flow and stability of insular ecosystems.

KEY WORDS: amphibians, camera traps, energetics, Hawai'i, mongoose, reptiles, rodents, scavenging

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INTRODUCTION

The threat of invasive species is of worldwide concern, and currently, Hawai'i is experiencing a serious invasion crisis. Although the direct and indirect impacts of invasive species on ecosystems can be qualitatively described, for example predation on and extinction of native species, it is difficult to quantitatively determine the impacts of invasive species on energy flow. It is especially difficult, and thus understudied, to determine the differential role of invasive species as both potential scavengers and as sources of scavengable energy. It is theorized that invasive species could feed off of each other, creating a synergistic effect that promotes the success of certain invaders (Wilson and Wolkovich 2011). In the short term, such a synergism could decrease the pressure that invasive species place on native species, but the demographic boosts that invasive species gain via such a strategy could result in long-term negative impacts (Zavaleta et al. 2001). The potential for invasive, facultative, vertebrate scavengers to destabilize energy flow networks of insular systems is significant, given that there is considerable evidence that scavengers play critical roles in governing rates of energy flow in their native ecosystems. For example, a review of 22 studies conducted worldwide that were focused on the efficiency of facultative vertebrate scavengers indicated that vertebrate scavengers utilize 13-100% of experimentally placed carcasses (DeVault et al. 2003). This suggests that the influence of scavenging upon energy flow within ecosystems varies in importance for different organisms and ecosystems.

Within the Hawaiian island ecosystem, coqui frogs (*Eleutherodactylus coqui*), geckos (various species), and cane toads (*Bufo marinus*) represent a prominent subset of the established invasive amphibian and reptile species. Adults of these species are small (~3-200 g) but often occur at high densities (e.g., >2,000 adult coqui frogs per acre) (Woolbright et al. 2006), and thus the energetic resources represented by these species could be large but available to vertebrates for only a short time after death. The objective of this study was to determine the composition and diversity of vertebrate scavengers that take advantage of the small, fleeting, and novel resources provided by invasive amphibians and reptiles in an insular habitat. This information can be used to construct energy flow models for the Big Island of Hawai'i, as well as to make predictions concerning the impact of disease die-offs and eradication efforts upon stability within insular ecosystems.

METHODS

Approximately 16 carcasses from each of 3 taxa (coqui frogs, geckos, and cane toads), were placed at each of 6 sites within Hawai'i Volcanoes National Park and Pu'u Maka'ala Natural Area Reserve on the Big Island of Hawai'i (n = 287). Animals were collected from the Big Island of Hawai'i and euthanized following our Institutional Animal Care and Use Committee (IACUC) protocol approved through the University of Georgia (A2013 04-007-Y1-A0). The fates of carcasses were recorded by wildlife trail cameras (model: PC900, RECONYX, Inc., Holmen, WI) using motion and external pressure-sensitive triggers. Cameras were attached by cable locks to trees facing the carcass, and an electrical cable connected the external trigger, on which the carcass was placed, to the camera. Each camera trap remained in place for a 5-day experimental trial: If no clear outcome was recorded for a 5-day trial, a make-up trial was conducted for that carcass species and habitat combination. Camera images were analyzed to determine carcass fate (e.g., vertebrate scavenger, invertebrate scavenger, not scavenged), and if applicable, the species of vertebrate scavenger that took the carcass was determined. A trial was deemed successful if it recorded the fate of the carcass.

RESULTS

Of our 287 trials, 107 carcasses (37%) were removed by vertebrates (Table 1). Vertebrates removed 21 coqui frogs (22%), 38 geckos (39%), and 48 cane toads (51%). Mongoose (*Herpestes javanicus*) and rats (*Rattus rattus* and *R. exulans*) dominated the vertebrate scavenging community, taking respectively 74 (69%) and 24 (22%) of carcasses. Invertebrates took the majority of carcasses: in total, 62 coqui frogs (65%), 51 geckos (53%), and 32 cane toads (34%). Only 13 coqui frogs (14%), 8 geckos (8%), and 14 cane toads (15%) remained with any flesh on the carcass after completion of the 5-day experimental trial.

Table 1. Number of coqui frog (*Eleutherodactylus coqui)*, gecko (various species), and cane toad (*Bufo marinus*) carcasses removed by vertebrate and non-vertebrate scavengers on the Big Island, Hawai'i. The number of carcasses that were not taken during the scavenging trials (one 5-day trial per individual carcass) is also shown. Trials were conducted over a 5-week period in July/August 2013.

Scavenger	Coqui frog	Gecko	Cane toad
Mongoose	12	17	45
Black and Polynesian rats	6	15	3
Domestic cat	1	3	0
House mouse	1	1	0
Pig	0	2	0
Myna bird	1	0	0
Non-vertebrate	62	51	32
Not Taken	13	8	14
Total Carcasses	***96***	***97***	***94***

DISCUSSION

Our results indicate that a substantial portion of the invasive amphibian and reptile carcasses experimentally placed in the field on the Big Island of Hawai'i are scavenged by invasive vertebrates (37%) and could be subsidizing invasive species (mongoose and rats) that have detrimental impacts on native species. Although there are native bird species on the Big Island [e.g., Hawaiian hawk (*Buteo solitaries*) and Hawaiian short-eared owl (*Asio flammeus sandwichensis*)] that could use this resource, our study documented no occurrences of native species consuming an experimentally placed carcass. Although it is generally accepted that invertebrates and microorganisms utilize the majority of carrion resources, our study contributes to a growing body of literature indicating that the role of vertebrates within the scavenging pathway has been historically underestimated. On Hawai'i, individual amphibian and reptile carcasses represent small, novel sources of energy that are of small caloric value but nonetheless readily scavenged by vertebrates. The observed utilization of this resource within the vertebrate community suggests that invasive amphibian and reptile carcasses could have a large impact on energy flow within this insular ecosystem. Future research should examine how the energy of larger carcasses of mammalian and avian invasive species is utilized within the invaded Hawaiian ecosystem and also compare Hawaiian scavenging rates to scavenging rates where these carcass resources naturally occur (e.g., DeVault et al. 2004). In combination with data on invasive species densities across the Big Island of Hawai'i, our data on scavenging efficiency can be used to create network models that more accurately measure the transfer of energy within insular ecosystems and which quantitatively demonstrate the impact that invasive species can have on ecosystem stability in the Big Island of Hawai'i.

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