

A reptilian smoking gun: first record of invasive Jackson's chameleon (*Chamaeleo jacksonii*) predation on native Hawaiian species

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Abstract Here we report the first conclusive evidence of an introduced reptile (*Chamaeleo jacksonii*) feeding on Hawaiian taxa, including 11 snails in four endemic genera from two families, including four individuals of an endangered species (*Achatinella mustelina*), and native insects in five genera. Native Hawaiian invertebrates were discovered in the dissected stomachs of wild caught Jackson's chameleons collected from June to November 2009 on the island of Oahu. Although Jackson's chameleons were introduced to the Hawaiian Islands in the early 1970s, ecological impacts have never been documented. Of particular concern is the fact that chameleons have previously only rarely been found in native Hawaiian habitat, although 12 were recently collected in a mid-elevation native forest, an area that is not likely to be suitable for their long-term persistence, but that is adjacent to higher elevation pristine forest where endemic prey are abundant and favorable climatic conditions exist for chameleon persistence. One concern is that Jackson's chameleons may be undergoing a range expansion into upper elevation pristine forests. If chameleons reach and establish populations in these areas, devastating impacts to the native ecosystem are possible. A thorough understanding of the impacts of chameleons on Hawaiian fauna will require additional evaluation and sampling, but dissemination of this discovery in a timely fashion is important as it provides new information regarding this threat. Monitoring and collection of chameleons is ongoing, particularly in native Hawaiian forest habitats at mid and upper elevations (600–1,300 m).

Keywords *Achatinella mustelina* · Oahu tree snails · *Auriculella* sp · Impacts of introduced predators · Conservation · Native Hawaiian insects

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Introduction

Jackson's chameleons, *Chamaeleo jacksonii* (Boulenger 1896) are native to high elevation montane habitats in Kenya and Tanzania (Necas 1999). Optimal foraging strategy studies suggest that chameleons behaviorally maximize the diversity of prey for energetic and nutritional balance (Eason 1990). In their native habitat, Jackson's chameleons prey on flying and crawling insects, centipedes, isopods, millipedes, spiders, lizards, small birds, and snails. In the early 1970s, chameleons became part of the pet trade in Hawaii. In 1972 a licensed pet shop owner in Kaneohe on the eastern side of Oahu imported several dozen chameleons from Kenya. Upon arrival of the shipment, the lizards were in poor condition, appearing dehydrated, and were placed outdoors, effectively releasing them and constituting the first and only known introduction of Jackson's chameleons in the state of Hawaii (McKeown 1996). In subsequent years, chameleons were transported within and among the islands as pets; their inter-island transport remained unrestricted until 1997. Established populations were first documented on Lanai and Kauai in the mid 1990s, and today multiple, self-sustaining and possibly increasing populations are present on all of the main islands, predominantly in wetter habitat from 100 to 1,000 m elevation, with substantial established populations on Oahu, Maui, and the island of Hawaii. Here we present the first documentation of wild Jackson's chameleons preying on native Hawaiian invertebrates.

Materials and methods

We examined stomach contents of Jackson's chameleons captured from mid-elevation endangered tree snail habitat at Puu Kumakalii in the Schofield Barracks Forest Reserve just north of Kolekole Pass in the Waianae Mountains on the western side of the island of Oahu (Fig. 1) in June 2009. The first chance encounter occurred during a survey for rare and endangered native tree snail populations. Subsequent surveys were conducted with the goal of searching for Jackson's chameleons. Chameleons were collected by hand from native trees alongside rare native snails, transported back to Honolulu and were humanely euthanized and dissected. Gut contents were examined under a dissecting microscope.

Results

In total, 12 Jackson's chameleons were collected. The stomach of one of the chameleons (Fig. 2A) contained a single specimen of the endangered Oahu tree snail species *Achatinella mustelina* (Achatinellidae, subfamily Achatinellinae), and four individuals of another endemic Hawaiian achatinellid, *Auriculella* sp. (subfamily Auriculellinae; Fig. 2B). Another chameleon, collected during the same survey, had a single specimen of *Lamellicidea* sp., another endemic achatinellid (subfamily Pacificellinae), in the stomach. During a subsequent survey in the same area, a chameleon was collected, and when dissected was found to contain two *Auriculella* sp., two *Achatinella mustelina*, and a single specimen of a native helicarionid, *Philonesia* sp. In nearly all cases in which snail remains were found, shells were intact with some traces of soft tissues remaining. The fact that shells were not crushed suggests that these snails were swallowed whole.

In addition to snails in gut contents, we identified legs, wings and other body parts of the following five native insect genera: *Banza* sp. (grasshoppers), *Hyposmocoma* sp. (case-bearing caterpillars), *Oliarus* sp. (planthoppers), *Oodemus* sp. (beetles), *Pantala* sp.

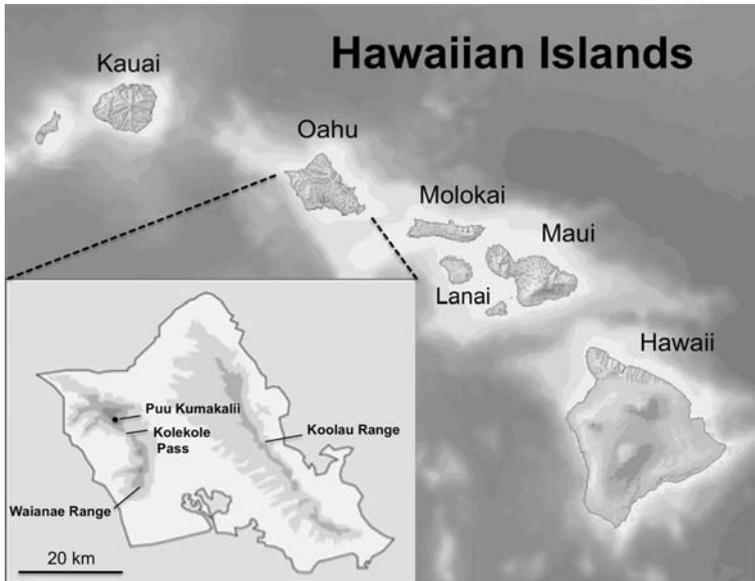


Fig. 1 Map of the Hawaiian Islands with detail of Oahu inset, showing sampling location of Jackson's chameleons. On Oahu, endangered tree snail habitat is indicated by the *darkest shading* in both Koolau and Waianae mountain ranges, representing elevations of about 900 m and higher. The elevation of the Puu Kumakalii locality is about 850 m

(dragonflies). The presence of dozens of wings of *Oliarus* indicates that planthoppers comprise a major dietary component in this area.

Discussion

Although Jackson's chameleons are classified by the State of Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife as "injurious wildlife", and export as well as inter-island transport has been prohibited since 1997 (Hawaii Administrative Rule Section 13-124-3), published studies demonstrating their impact on native Hawaiian fauna are lacking. However, this has not prevented speculation on the ecological impacts of these predators, ranging from claims that they have beneficial effects by controlling invasive pest arthropods, to theories that they are harmful by directly preying on threatened native fauna. Until now such threats remained unsubstantiated. Meanwhile no restrictions have been imposed on selling and or keeping chameleons as pets, and they can readily be found in pet stores throughout the islands. A noted local herpetologist summarized his assessment of the threat to native Hawaiian fauna as follows: "In Hawaii the versatile but low density Jackson's chameleon feeds on a wide variety of primarily introduced species of insects and other invertebrates including, but not limited to grasshoppers, crickets, flies, bees, butterflies, moths, beetles, cockroaches and spiders." He went on to state, "During hundreds of hours of field observations of this species in Hawaii, the author has seen nothing to indicate it will negatively impact endemic species of invertebrates" (McKeown 1996).



Fig. 2 (A) Closeup of adult male Jackson's chameleon collected in the Waianae Mountains on the Hawaiian island of Oahu, showing endemic snail shells for scale. (B) Hawaiian land snail shells removed from chameleon stomachs: the three smaller shells to the left are endemic *Auriculella* sp., not shown are one additional *Auriculella* sp. shell that had deteriorated further than the other three, and one minute shell of *Lamellidea* sp. (~1 mm shell length); these shells were all from the same individual. The larger shell on the right is a subadult specimen of *Achatinella mustelina*, an endangered Oahu tree snail. During a subsequent survey in the same area, a chameleon was collected and found to contain two *Auriculella* sp., two *Achatinella mustelina*, and a single specimen of a native helicarionid, *Philonesia* sp

The Oahu tree snail genus *Achatinella*, which once comprised 41 endemic species, has been listed as endangered since 1981 (USFWS 1981), and all extant species in the genus are currently categorized as Critically Endangered on the IUCN Red List (2009). At present 10 of the original 41 tree snail species are extant. Factors leading to the high extinction rate in Hawaiian tree snails include historical shell collecting, habitat degradation and loss, and predation by intentionally released, failed biocontrol species (Hadfield 1986; Holland et al. 2008). These factors coupled with the particularly slow growth, development, and fecundity of *Achatinella* spp. lead to nearly non-existent recovery potential when populations crash. Topping the list of modern day threats are invasive predators such as the rosy wolf snail (*Euglandina rosea*), rats (*Rattus exulans*, *R. norvegicus* and especially *R. rattus*), and the predatory triclad flatworm (*Platydemus manokwari*). In light of the discovery presented in this paper, an additional species should be added to this list.

Much remains to be determined in terms of making an accurate assessment of the threat posed by Jackson's chameleons in Hawaii, and further work is planned. For example, little is known about their precise range, elevation preference, reproductive season and rate, desiccation tolerance, and prey preference. Jackson's chameleons occur in lower to mid-elevation non-native forests on Oahu, and have rarely been reported from tree snail habitat, which tends to be upper elevation dominated by native flora beginning around 600 m above sea level. The observations presented provide conclusive evidence that when chameleons are present in native forest where tree snails and other endemic invertebrates occur, they pose a threat.

It is possible that due to a number of factors, such as prey availability and distribution, changing climatic conditions, recent population establishment due to pet release or escape, Jackson's chameleons are undergoing a range expansion into upper elevations. This is a concern for a variety of threatened and endangered invertebrate species, including tree snails (*Achatinella* spp.), pomace flies (*Drosophila* spp.), rare damselflies (*Megalagrion* spp.), and rare amastrid and succineid land snails, all restricted to upper elevation forests such as Mt. Kaala Natural Area Reserve adjacent to the sampling locality. Prior to this discovery, as part of an ongoing collaborative study, one author (BSH) has collected several hundred chameleons, and gut contents are being examined from populations in the Round Top/Tantalus area of the Koolau Mountains, Honolulu, on eastern Oahu (Whiting et al. in prep). Endangered Oahu tree snail species have not been observed in this region in several decades. It is conceivable that predation by Jackson's chameleons may have played a role in the local extinction of *Achatinella* spp. in this area.

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