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Sticks and stones: notes on the ecology and conservation of an endemic stick insect (*Apterograeffea marshallae*) and the restoration of an island ecosystem

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Abstract: The Mascarene Islands (Mauritius, Rodrigues, and Réunion) of the western Indian Ocean are home to a diversity of endemic flora and fauna, often linked through close evolutionary and ecological relationships. Owing to a turbulent history of anthropogenic exploitation, contemporary research and habitat restoration efforts are underway on Mauritius and numerous surrounding islets, notably Round Island. The Round Island stick insect, *Apterograeffea marshallae* (Phasmatodea: Platycraninae), was described in 2002 and information about the species' biology has been wanting. In this short communication we confirm the importance of the endangered Blue Latan Palm (*Latania loddigesii*) in the diet of the Round Island stick insect and include observations on reproduction and predation of this insect species. These observations are relevant for informing ongoing habitat restoration and conservation efforts in the Mascarenes, as well as the biology of the stick insect *A. reunionensis* on Réunion. Despite their roles as prey, predators, and pollinators, insects are disproportionately overlooked as conservation priorities. We suggest that conservation projects would greatly benefit from directed study of oft-neglected insects to supplement knowledge of species biology, reconstruct ecological histories, re-establish lost ecological interactions, and restore integrity of ecological communities.

Keywords: conservation; ecological restoration; island biogeography; Mauritius; natural history; Phasmatodea (Phasmida); plant-animal interactions.

Introduction

In the western Indian Ocean, laying approximately 900 km east of Madagascar, the Mascarene Islands (Mauritius, Rodrigues, and Réunion) represent a crucible of biological evolution. Boasting an astonishing array of biodiversity and a turbulent history of human-induced environmental destruction, the island of Mauritius is an exemplary case study of ecological research, species conservation, and habitat restoration (Cheke and Hume 2008; Florens 2013). Among biologists, Mauritius is best known for its biogeography, species endemism, and as the former home of the dodo (*Raphus cucullatus*), among a host of other extinct and imperiled species (Cheke and Hume 2008). Round Island (19°51'01"S, 57°47'15"E; Fig. 1), located approximately 22 km from the north shore of Mauritius and measuring 219 ha in area, is one of over a dozen islets under the protection and ongoing ecological restoration of the Mauritian government's National Parks and Conservation Service, Mauritian Wildlife Foundation (MWF) and Durrell Wildlife Conservation Trust (Durrell). The poaching of nesting

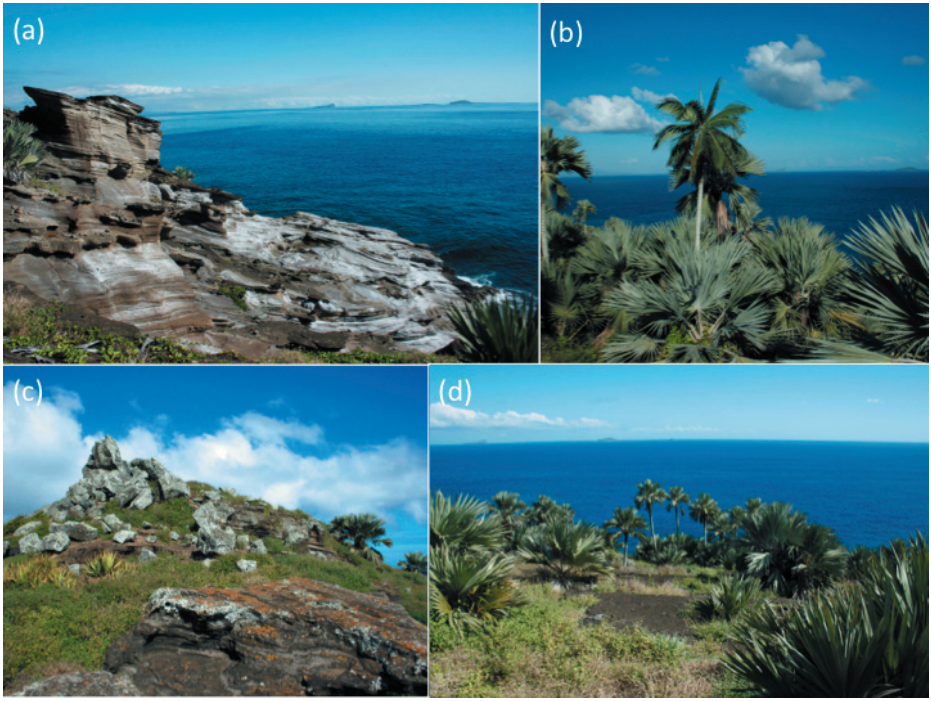

Fig. 1 Landscapes of Round Island, Mauritius: (a) Basaltic coastal rock carved by wind and rain with neighbouring Gunner's Quoin (left), Flat (center), and Gabriel islets (right) on horizon; (b) Hurricane Palm (*Dictyosperma album* var. *conjugatum*), the lone *in situ* survivor, stands above a group of endemic Blue Latan Palm (*Latania loddigesii*); (c) rock outcroppings on the northeastern summit; (d) regenerating lowland palm savanna, home to the Round Island stick insect (*Apterograeffea marshallae*). Photos by PD Moldowan

seabirds and now extinct giant tortoises (*Cylindraspis* spp.), introduction of invasive plants, and the release of rabbits (*Oryctolagus cuniculus*) and goats (*Capra hircus*) to the island as food for early mariners resulted in accelerated erosion, extensive destruction of native vegetation, and the loss of native fauna of Round Island (Bullock 1986; Tonge 1989; Tatayah 2010). Today, Round Island is among the few remaining population strongholds, for an unique reptile assemblage consisting of one extant endemic snake (in addition to one snake species now presumed extinct) and six extant endemic lizard species, of which four had become confined to Round Island until recent efforts to reintroduce them back to other islets (Bullock 1986; North et al. 1994; Cole *et al.* 2009); a native palm community representing the last individuals of their species and varieties (North *et al.* 1994); and is critical nesting habitat for several seabird species (Tatayah 2010). Temple (1974) emphasized that Round Island "probably has more species of threatened plants and animals per acre than any other piece of land in the world", earning the island status as a nature reserve in 1957 (Merton 1987). Natural and assisted

recovery of the native vegetation and endemic reptile fauna is beginning to restore the island system towards its pre-anthropogenic state, following the eradication of exotic mammals (North *et al*. 1994; Bullock et al. 2002). Attention is now shifting from the recovery of endemic and native plant and vertebrate taxa towards the re-establishment of lost ecological roles. For example, Aldabra Giant Tortoises (*Aldabrachelys gigantea*) and Radiated Tortoises (*Astrochelys radiata*) were introduced to Round Island in 2007 following trials on a smaller Mauritian islet, Île aux Aigrettes (Griffiths *et al*. 2010). These 'ecological replacements' are now assisting the management of remaining exotic plants through grazing as well as establishment of native plants through seed dispersal (Griffiths *et al.* 2011, 2013).

In contrast to the extensive effort invested in the recovery of the native plant and vertebrate biota of Mauritius (and elsewhere), the biology and status of native insects remain largely unknown (Motala *et al.* 2007). Over the past decade, entomological research has uncovered a diversity of new species in the Macarenes with many taxa showing a high degree of endemism and endangerment (eg, Cliquennois and Brock 2004; Hugel 2009, 2010; Hugel *et al*. 2010; Smith and Fisher 2009), and many more likely already extinct. In 2002, a new genus of stick insect (Phasmatodea: Platycraninae: *Apterograeffea*) was described from the Mascarenes with *A. marshallae* described on Round Island (Cliquennois and Brock 2002). Recent molecular research has demonstrated that *A. marshallae* is a member of an ancient lineage originating from Australasia, pre-dating the volcanic origin of Mauritius itself (Bradley *et al*. 2015). The

Fig. 2 Copulating pair of endemic stick insects (Phasmatodea: Platycraninae: *Apterograeffea marshallae*) on the underside of a Blue Latan Palm (*Latania loddigesii*), Round Island, Mauritius. Photo by PD Moldowan

holotype and paratype of the species were collected on the endemic Blue Latan Palm (*Latania loddigesii*), IUCN Red-Listed as Endangered (IUCN 2016). Cliquennois (2007) suspected the palm to be part of the diet of *A. marshallae* but to date this relationship has not been confirmed. Thus, the objective of this research is to share previously undescribed aspects of *A. marshallae* natural history (diet, reproduction, predation) to inform continued habitat restoration and conservation efforts on Round Island and other islands of the Mascarenes.

Observations

During night surveys between 21:00-00:00 from 08-15th July 2015, pairs of *A. marshallae* were observed mating on the underside of live *L. loddigesii* leaves (Fig 2). Ongoing monitoring by MWF researchers suggests that *A. marshallae* breed year around. In addition, individuals were observed feeding on live leaves of *L. loddigesii,* including a female whilst copulating. In total, 576 *A. marshallae* feeding observations were collected over a 12-month period from July 2006 to June 2007. Feeding observations show that *L. loddigesii* constitutes approximately 90% of the diet of *A. marshallae*, making the palm an important food source. Other food plants included: *Hyophorbe lagenicaulis* (6% of observations), *Elaeodendron* (*Cassine*) *orientalis* (2%) and *Dracaena concinna* (2%).

Discussion

Our *A. marshallae* feeding observations confirm dietary speculations by Cliquennois (2007) that the insect feeds on *L. loddigesii* and illustrate an interesting ecological relationship between an endangered plant, a little known insect, and the insular community at large. Among the six lizard species found on Round Island, invertebrates constitute >75% of their diet, by-far the largest contribution of any dietary item (Zuël 2009), suggesting that insects are an integral prey species in this island food web. Furthermore, *A. marshallae* forms approximately 11% of the diet of the endangered Günther's gecko (*Phelsuma guentheri*; N. Zuël unpublished). Large-bodied insects, such as *A. marshallae,* may be especially important links in this insular food web given the extirpation of other invertebrate species, such as the giant tenebrionid beetle (*Polposipus herculeanus*; Cheke and Hume 2008) from Round Island. Also, following extinction of the endemic Mauritian giant tortoises (*Cylindraspis* spp.) and considering the wholly or largely insectivorous diet of all Round Island lizard species, insects such as *A. marshallae* are the only native herbivores that remain on Round Island (notwithstanding the introduction of non-native tortoises as ecological analogues; Griffiths *et al*. 2010).

The only previous record of reproduction in *A. marshallae* reported a mating pair collected in May 2002 (Cliquennois and Brock 2002). Our observations of year around breeding suggest that *A. marshallae* has an extended reproductive period. *Apterograeffea marshallae* is known to glue its eggs to vegetation (Cliquennois and Brock 2002, 2004), however the host plant species is currently unknown. We suggest that in addition to being an important food plant, *L. loddigesii* may be a nursery plant important for reproduction.

As prey, predators, and pollinators, insects can exert top-down and bottom-up trophic interactions, yet insects are disproportionately overlooked as conservation priorities (Motala *et al*. 2007). It is not known if the feeding relationship between *A. marshallae-L. loddigesii* is facultative or obligate, the latter of which may be due to food scarcity on Round Island following the destruction of the native plant community. Co-evolved plant-animal interactions, providing ecosystem function, connectivity and services, are particularly vulnerable to extinction in insular ecological communities (Fordham and Brook 2010). The biotic community of Mauritius has experienced the erosion of ecological relationships through the extinction of co-evolved plant-animal species (Griffiths *et al.* 2011). Understanding the biology and conservation of insects is of particular importance in Mauritius, for example, where translocation and habitat restoration projects on surrounding islets (eg, Île aux Aigrettes) are ongoing to establish assurance plant and vertebrate communities that ultimately depend on insect counterparts.

The life history observations of *A. marshallae* may also be relevant to informing the biology of its sister species, *A. reunionensis* on Réunion, and vice versa (Cliquennois and Brock 2002; Bradley et al. 2015). Despite search efforts, Cliquennois (2007) was unable to find *A. reunionensis* in association with Réunion's endemic and endangered Red Latan Palm (*Latania lontaroides*; IUCN 2016). However, observations of *A. marshallae* breeding and feeding on Blue Latan Palm on Round Island suggest that continued searching on Réunion's Red Latan Palm is warranted. In captivity, *A. reunionensis* has fed on the rare Hurricane Palm (*Dictyosperma album*; Cliquennois 2007), but on Round Island only one *in situ* wild *D. album* var. *conjugatum* remains (Critically Endangered; IUCN 2016), which may severely limit *A. marshallae*. If the *Dictyosperma* palm is an important dietary item for *Apterograeffea* stick insects, then this palm should be a conservation priority not only for its own persistence but also the support of the these endemic stick insects and, perhaps, the ecological interactions of these unique insular communities.

The vegetative community of Round Island has experienced a dramatic change over the past two centuries. In an early description of Round Island, Lloyd (1845) described ravines crowded with *Latania* and areas of the island with a deep, rich soil supporting "the most powerful vegetation" (North and Bullock 1986). By this time, rabbits had already been introduced to the island for at least three decades (ca. 1810) and were reported to be in "immense numbers", even "swarms" (Lloyd 1845; North and Bullock 1986). Goats were introduced later (ca. 1844-1865) and acted in synergy with the rabbits to cause an extended period of recruitment failure of *Latania*, among many other plant species. Round Island's palm savannah habitat experienced serious destruction and its hardwood forest was extirpated in the century that followed (North and Bullock 1986; Merton 1987). Populations of these introduced mammals persisted unchecked until eradication efforts began for goats (1976-1979) and rabbits (unsuccessfully 1975-1976, completed 1986; Merton 1987; North *et al.* 1994). Even during periods of reduced grazing pressure (1975-1982), between 73-90% of seedlings *Latania* were grazed (North and Bullock 1986). Still, release from grazing pressure between 1975-76 and after 1989 allowed for the first recruitment in decades for many

of the island's plant species (North and Bullock 1986; North et al. 1994). Vegetation surveys between 1975 and 1982 showed that numbers of *Latania* had been greatly reduced through further habitat degradation and the attrition of mature trees from the population, though this palm remained the most abundant tree species on Round Island (North and Bullock 1986). Follow-up surveys in 1989, three years post-eradication of rabbits, documented a marked increase in *Latania* recruitment and reptile population recoveries (Tonge 1989; North et al. 1994) compared to pre-eradication (1975 and 1982; North and Bullock 1986) showing promise for the recovery of Round Island's severely degraded palm savanna. In the years following eradication of introduced mammals the vegetation on Round Island has made a remarkable recovery. In parallel with the recovery of native vegetation, the biomass of invertebrates was predicted to increase post-eradication of mammals (North *et al*. 1994), although this research remains to be seen. While assessments of the biotic community and habitat restoration are ongoing, major hurdles to the re-establishment of native vegetation on Round Island have included: low number of mature trees to provide seed, seed dispersal limitation, competitive displacement from non-native plants, availability of soil (which eroded under intense grazing pressure), water retention of soil, and the burrowing and uprooting of native vegetation by nesting Wedge-Tailed Shearwaters (*Puffinus pacificus*).

Round Island is a stimulating training ground for conservation scientists and is ripe for further research. This short communication represents a call for biodiversity inventories of the Mascarene Islands and conservation awareness for invertebrate taxa. The Mascarene stick insects can serve as large-bodied and charismatic flagship species for conservation, as the wetas (Anostostomatidae) have in New Zealand (Watts *et al.* 2008) and giant tenebrionid beetle (*Polposipus herculeanus*) for the Seychelles (Gerlach 2008). Ongoing ecological restoration efforts of the Mascarene Islands and elsewhere would benefit from the directed study of oft-neglected invertebrates to supplement knowledge of species biology and their ecological interactions.

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