Notornis, 2021, Vol. 68: 245-252

Diet of the Floreana mockingbird (*Mimus trifasciatus*) during the dry season on Champion and Gardner Islets, Galápagos Islands, Ecuador

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Abstract: The Floreana mockingbird (*Mimus trifasciatus*) is one of the most endangered passerines in the world, with a global population of *c.* 400 individuals, restricted to two isolated islets: Champion and Gardner-by-Floreana. Due to its rarity and the inaccessibility to these islets, the biology of the Floreana mockingbird has remained poorly documented. Here we present a study on the diversity of food items consumed by Floreana mockingbirds prior to the rainy season. We recorded 269 foraging bouts, from 148 individuals on three independent sampling events. Floreana mockingbirds exhibited a generalist diet, which included flowers, nectar, stamens, sap, fruits, seeds, and seedlings from 12 plant species; larvae, pupae and adults of at least 10 arthropod orders; and small vertebrate prey, carrion, and egg contents. The diversity of food items between months and islets supports the idea of a generalist diet for the species. Our study provides useful information to identify and monitor the abundance of key resources for the species as part of the restoration of Floreana Island.

Wittmer-Naranjo, C.; Reyes, E.M.R.; Jácome, H.E.T.; Rueda, D.; Sevilla, C.; Ortiz-Catedral, L. 2021. Diet of the Floreana mockingbird (*Mimus trifasciatus*) during the dry season on Champion and Gardner Islets, Galapagos Islands, Ecuador. *Notornis 68(4)*: 245–252.

Key words: bird behaviour, conservation, generalist diet, island avifauna, scavenging

INTRODUCTION

Developing management strategies for species of conservation interest requires an understanding of the biology of the target species. For instance, the successful conservation of the kakapo (*Strigops habroptilus*) (a nocturnal flightless parrot from New Zealand) has been fine-tuned since the 1970s as more research on the mating system and dietary requirements of the species is developed (Harper *et al*. 2006). Additionally, an understanding of the food preferences of a species can help managers identify

Received 4 March 2021; accepted 16 May 2021
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suitable areas for reintroduction (Kelle *et al*. 2014). Unfortunately, the biology of many endangered species remains poorly documented. One example is the Floreana mockingbird (*Mimus trifasciatus*), one of four species of mockingbirds endemic to the Galapagos Islands (Arbogast *et al*. 2006).

The mockingbirds (*Mimus* spp.) of the Galapagos Islands played an important role in the development of Darwin's theories about natural selection (Nicholls 2015); however, compared to Darwin's finches (*Geospiza, Camarhynchus, Certhidea*, and *Platyspiza* spp.) they have been the subject of fewer field studies. Four species of mockingbird exist in the Galapagos archipelago, all within the genus *Mimus* (Arbogast *et al*. 2006). Three of these are endemic to a single island, and their near-shore islets, all located in the south-east of the archipelago: the Española mockingbird (*M. macdonaldi*), the Floreana mockingbird (*M. trifasciatus*), and the San Cristobal mockingbird (*Mimus melanotis*). The fourth species, the Galapagos mockingbird (*M. parvulus*) occurs on nine main islands and several islets across the centre, north, and west of the archipelago (Arbogast *et al*. 2006; Hoeck *et al*. 2010a). A subspecies of Galapagos mockingbird (*M. parvulus bauri*) represents a lineage of hybrid ancestry between the San Cristobal mockingbird and Galapagos mockingbird (Nietlisbach *et al*. 2013) indicating temporary co-occurrence of two species on a single island. Lastly, the co-occurrence of two species of mockingbirds on a single island has been reported on Gardner-by-Floreana, where a single San Cristobal mockingbird coexisted in a population of Floreana mockingbirds for at least 10 months (Ortiz-Catedral *et al*. 2021).

The endangered Floreana mockingbird was historically present on the lowlands of Floreana Island, but became extinct on its namesake island due to the effects on introduced species and large-scale habitat modification by early inhabitants on Floreana Island (Curry 1986; Steadman 1986; Grant *et al*. 2000). Two remnant populations, geographically and genetically isolated on the islets of Champion and Gardner-by-Floreana, represent the last strongholds for the species (Hoeck *et al*. 2010b), with an estimated population of 400 individuals on both islets (Ortiz-Catedral 2018). In order to increase the geographic range and population size of the species, a reintroduction plan to the lowlands of Floreana has been developed (Charles Darwin Foundation 2008; Hoeck *et al*. 2010b), and a range of reintroduction scenarios had been analysed taking into account the genetics of the remnant populations (Bozzuto *et al*. 2017). However, to date there is only limited information on the range of food types and species that Floreana mockingbirds consume (Ortiz-Catedral 2014, 2018; Ortiz-Catedral *et al*. 2017). Prior to the reintroduction of the species to the lowlands of Floreana Island, it is imperative to determine whether their preferred prey items occur at potential release locations, and also how these resources increase in abundance as the restoration of Floreana Island progresses. Nevertheless, the diversity of food items that Floreana mockingbirds consume has not been quantified. We conducted a field study on the diversity of foods consumed by Floreana mockingbirds during the dry season, three months prior to the typical breeding season of the species: November, December (2015), and January (2016) (Ortiz-Catedral *et al*. 2017) in order to characterise the range of food species that need to be monitored on Floreana Island to assess whether their abundance can sustain a reintroduced population of Floreana mockingbirds in the near future.

METHODS

Our study was conducted on two islets: Champion (9.4 ha) (90°21′47′′W, 01°13′55′′S) and Gardner-by-Floreana (80 ha) (90°17′44′′W, 01°20′48′′S). Both islets represent land fragments of Floreana Island, which historically had a much larger area than present (Ali & Aitchinson 2014). Access to these islets is highly restricted and the Directorate of the Galapagos National Park have implemented stringent biosecurity measures in place to prevent the accidental introduction of invasive species. Further, both islets harbour remnant populations of vertebrate species now extinct on Floreana Island, including the Floreana mockingbird (Grant *et al*. 2000) and the Western Galapagos racer (*Pseudalsophis biserialis*) (Ortiz-Catedral *et al*. 2019), and are thus considered islets of high conservation value. Therefore, we visited the islets for two to a maximum of two to four days to conduct observations in November and December 2015 and January 2016. All biosecurity protocols were followed as part of this research. We conducted observations from 0600 h to 1800 h with a recess from 1200 h to 1400 h during the hottest period of the day, when mockingbirds are less active (Ortiz-Catedral *pers. obs.*). Individual observers (2–4) covered the study areas on foot: the total accessible land area of Champion, equivalent to 9 ha, and a 12 ha section of Gardner known as "The Plateau". The Plateau has been a study area for the population of Floreana mockingbirds for previous studies (see Ortiz-Catedral 2014; Hoeck *et al*. 2010b), and represents the only part of the islet that can be accessed safely. Whenever a mockingbird was encountered, the location, time, height to nearest 0.5 m, and only the first food item consumed within 30 seconds from sighting were noted to maximise independence of observations. Birds were observed at an approximate distance of 5 to 15 m using 8 x 42 binoculars.

Table 1. Plant and animal species consumed by Floreana mockingbirds on Champion and Gardner-by-Floreana (Gardner) from November 2015 to January 2016. ND indicates not determined.

Order/Family	Common name	Scientific name	Champion	Gardner	Part eaten
Boraginales/Boraginaceae	Muyuyo	*Cordia lutea*	0	1	Fruit
Boraginales/Boraginaceae	Heliotrope	*Heliotropium angiospermum*	0	1	Flower
Caryophyllales/Aizoaceae	Galapagos carpetweed	*Sesuvium edmonstonei*	2	0	Flower
Caryophyllales/Cactaceae	Prickly pear	*Opuntia megasperma*	51	14	Stamens, nectar, sap
Caryophyllales/ Nyctaginaceae	Wartclub	*Commicarpus tuberosus*	0	1	Seedling
Caryophyllales/Portulacaceae	Galapagos purslane	*Portulaca howellii*	0	13	Flower
Caryophyllales/Portulacaceae	Common purslane	*Portulaca oleracea*	1	0	Flower
Euphorbiales/Euphorbiaceae	Chala	*Croton scouleri*	1	3	Seed, seedling
Solanales/Convolvulaceae	Lava morning-glory	*Ipomoea habeliana*	5	0	Flower
Solanales/Solanaceae	Galapagos ground cherry	*Physalis galapagoensis*	13	2	Fruit
Solanales/Solanaceae	Galapagos shore petunia	*Exedecomus miersii*	0	4	Fruit, seeds
Lamiales/Verbenaceae	Galapagos lantana	*Lantana peduncularis*	0	1	Flower
Araneae/Araneidae	Garden orb-web spider	*Argiope trifasciata*	2	0	Adult
Araneae/Lycosidae	Wolf spider	*Hogna albemarlensis*	1	1	Adult
Blattodea/Kalotermitidae	Termite	*Incisitermes sp.*	1	2	Larvae
Diptera/Syrphidae	Fly	*Ornidia obesa*	0	3	Adult
Hymenoptera/Vespidae	Yellow paper wasp	*Polistes versicolor*	1	0	Adult
Neuroptera/Myrmeleontidae	Galapagos antlion	*Galapagoleon darwini*	0	1	Adult
Orthoptera/Acrididae	Large panted locust	*Schistocerca melanocera*	12	15	Adult
Scolopendromorpha/ Scolopendridae	Galapagos centipede	*Scolopendra galapagoensis*	1	0	Adult
Solifugae/Ammotrechidae	Sun spider	*Neocleobis solitarius*	0	1	Adult
Columbiformes/Columbidae	Galapagos dove	*Zenaida galapagoensis*	0	1	Egg contents
Pinnipedia/Otariidae	Galapagos sealion	*Zalophus wollebaeki*	10	0	Carrion
Squamata/Gekkonidae	Floreana gecko	*Phyllodactylus baurii*	0	1	Adult
Squamata/Tropiduridae	Floreana lava lizard	*Microlophus grayii*	1	1	Adult, carrion
Suliformes/Sulidae	Nazca booby	*Sula granti*	0	4	Egg contents
Araneae	Spider	ND	7	3	Adult
Lepidoptera	Moth, butterfly	ND	0	3	Adult, caterpillar, pupae
Blattodea	Cockroach	ND	1	1	Adult
Excoetidae	Flying fish	ND	0	1	Carrion
Coleoptera	Beetle	ND	1	4	Adult
Diptera	Fly	ND	11	6	Adult
Formicidae	Ant	ND	1	7	Adult
Gryllidae	Cricket	ND	0	7	Adult
ND	Arthopod	ND	17	29	Adult
-	Pebble	-	1	0	Non-dietary

Efforts were made to identify food items to species or at least major taxonomic groups (i.e. family or order for invertebrates). Plant food types were assigned to the following categories: flower bud, stamens, nectar, fruit, seeds, seedling, sap. Animal food types were classified as either invertebrate or vertebrate. Invertebrate food items were assigned to the following categories: larvae, pupae, adult. Vertebrate food items were classified as: carrion, egg contents, adult, or juvenile. Whenever possible we classified the foraging behaviour for each feeding bout according to the proposed terminology by Remsen & Robinson (1990). However, in over 30% of cases we could not clearly classify the type of foraging behaviour. Foraging behaviours are thus presented only for descriptive purposes. We analysed our data, as absolute frequency of occurrence (Wright 2010) per month, between populations, using Fisher's exact test in R (R Core Team 2020). We excluded the ingestion of sap (two observations) and pebbles from statistical analyses due to the low number of observations of these items. We also contrasted foraging heights per islet per sampling period using a two-sample t-test.

RESULTS

We recorded a total of 269 incidental foraging bouts by Floreana mockingbirds during November 2015 to January 2016 on 26 species of plants, invertebrates and vertebrates (Table 1). Floreana mockingbirds ingested invertebrate prey (larvae, pupae, adult insects), flowers (including petals, stamens, nectar, whole flowers), fruits, seeds, and seedlings, and vertebrate matter including carrion, small vertebrate prey, and contents of bird's egg. (Table 1). We also recorded a single instance of a non-dietary item ingestion, small pebbles (Table 1). In general, Floreana mockingbirds fed on similar food types in November and December (Fisher's exact test November $P = 0.06$, $n = 32$; Fisher's exact test December $P = 0.71$, $n = 124$). In January, Floreana mockingbirds on Champion fed predominantly on flowers, while on Gardner-by-Floreana, they consumed primarily invertebrates (Fisher's exact test January $P < 0.001$, $n = 113$) (Fig. 1). Floreana mockingbirds on Champion and Gardner-by-Floreana foraged on resources at the same height in November, but as our sampling progressed, individuals on Champion foraged at significantly higher strata than on Gardner-by-Floreana (Table 2). Floreana mockingbirds captured invertebrate prey using a variety of methods including: glean (flies, ants, spiders), flush pursue (Galapagos painted locust *Schistocerca melanocera*, yellow paper wasp *Polystes versicolor*), flake (termites), leap (Galapagos painted locust), lunge (Galapagos centipede *Scolopendra galapagoensis*, sun spider *Neocleobis solitarius*), and peck (termites). Floreana mockingbirds captured small vertebrates using lunge (Floreana lava lizard *Microlophus grayii*) and flake (Floreana gecko *Phyllodactylus baueri*). Floreana mockingbirds pulled pieces of carrion for ingestion, drank egg contents (Nazca booby *Sula granti*, Fig. 2; Galapagos dove *Zenaida galapagoensis*) and drank sap (prickly pear *Opuntia megasperma*). Fruits, and flowers were foraged by reach (Uvilla *Physalis peruviana*; purslane *Portulaca howellii*) and stamens and nectar by probe (prickly pear). With the exception of the yellow paper wasp, all species registered in our study are native species to the Galapagos Islands.

DISCUSSION

The diversity of food types and species consumed by Floreana mockingbirds during our study indicates that it is a generalist species, like the Galapagos mockingbird (*M. parvulus*) which feeds on a variety of invertebrates (Grant & Grant 1979; Curry 1986), booby (*Sula* spp.) blood (Curry & Anderson 1987), and even introduced mice (*Mus musculus*) (Gotanda *et al*. 2015). Similarly, another island species, the Socorro mockingbird (*Mimoides graysoni*) endemic to Socorro Island, Mexico consumes arthropods and fruits of at least seven plant species (Martínez-Gomez *et al*. 2001). Prior to our study, preliminary information on the breeding season diet of Floreana mockingbirds showed the consumption of nectar, pollen, and invertebrates (Ortiz-Catedral 2014). Our observations thus expand the list of known dietary items for the species. The consumption of carrion from sea lions (*Zalophus wollebaeki*), Floreana lava lizard (*Microlophus grayii*), and flying fish (Excoetidae) are of interest as these have not been documented for the species before. The

Table 2. Monthly changes in foraging height (m) of Floreana mockingbirds on Champion and Gardner Islets. *Significant differences.

Month	n	Champion	Gardner	t value	*P*
November	33	0.10 ± 0.34	0	1.28	0.21
December	125	0.37 ± 0.81	0.11 ± 0.39	2.25	0.03*
January	106	1.06 ± 0.92	0.27 ± 0.56	5.32	<0.001*

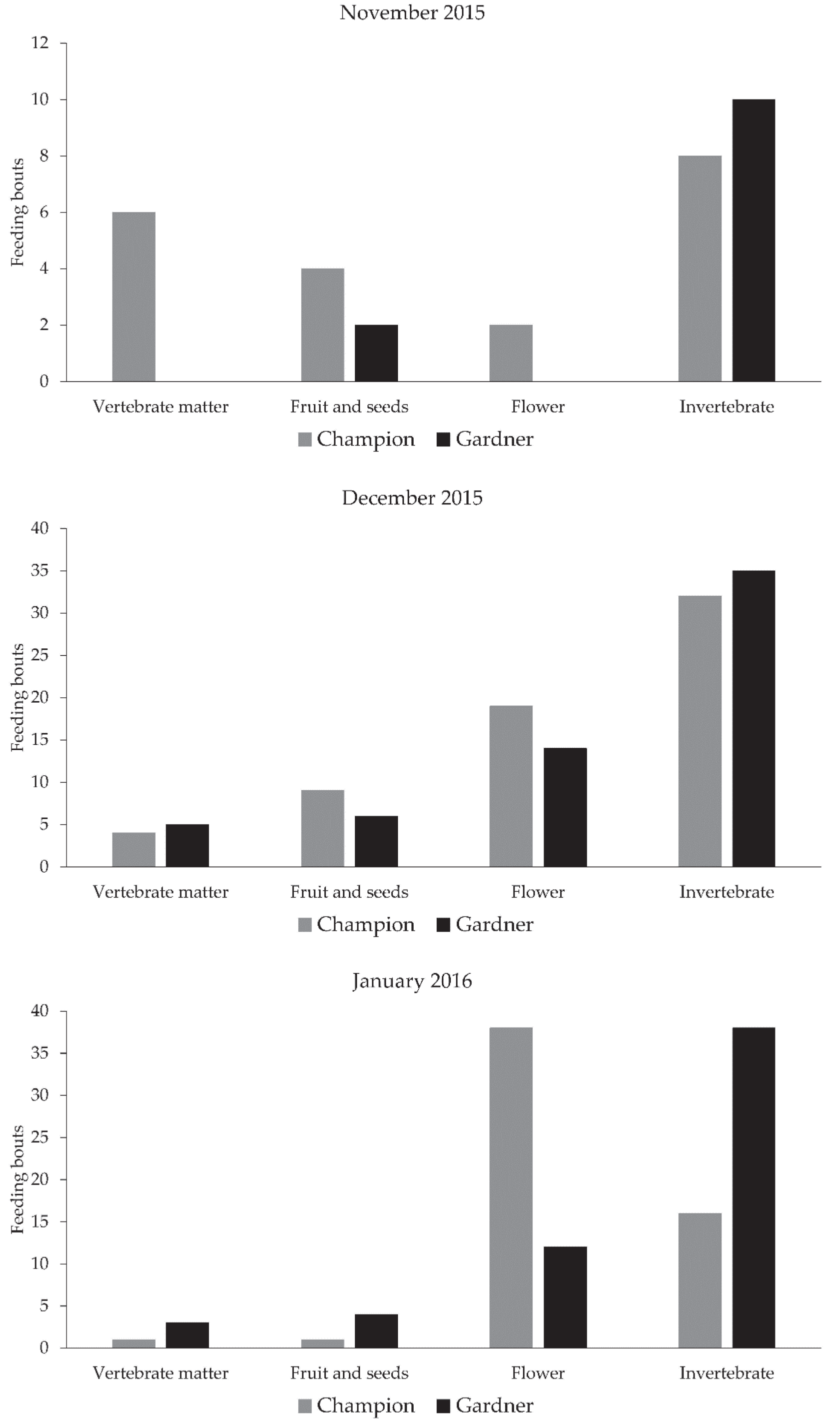

Figure 1. Monthly changes in proportion of food types in Floreana mockingbirds on Champion and Gardner-by-Floreana ("Gardner").

Figure 2. Floreana mockingbird (*Mimus trifasciatus*) drinking the contents of a Nazca booby (*Sula granti*) egg on Gardner-by-Floreana. Photograph: L. Ortiz-Catedral.

drinking of egg contents of Nazca boobies (*Sula granti*) and Galapagos dove (*Zenaida galapagoensis*) also represent new records on the diversity of foods consumed by the species, a trait shared with Española mockingbirds (Hatch 1965; Harris 1968). Harris (1968) suspected Floreana mockingbirds fed on eggs and nestlings of blue-footed boobies (*Sula nebouxii*), based on the disappearance of an egg and hatchling in a single nest on Gardner-by-Floreana, but did not directly observe mockingbirds. In fact, based on the description provided, we suspect that the predation of an egg and hatchling of blue-footed booby described in Harris (1968) more likely represents scavenging by Western Galapagos racers (*Pseudalsophis biserialis*), an endemic terrestrial snake (see Ortiz-Catedral *et al*. 2017; Ortiz-Catedral *et al*. 2019). Similarly, Bowman & Carter (1971) suspected that the ingestion of bird eggs was a trait shared by all mockingbird species in the Galapagos islands. They observed Floreana mockingbirds pecking at blue-footed booby (*Sula nebouxii*) eggs without breaking them, and in controlled experiments they induced starvation on Floreana mockingbirds and offered them broken chicken eggs, which the mockingbirds consumed (Bowman & Carter 1971). Therefore, our observations of consumption of egg contents of Nazca booby (Fig. 2) and Galapagos dove represent the first confirmed record in the wild of ingestion of this resource by Floreana mockingbirds.

The Galapagos Islands have suffered large-scale habitat modification prompted by the settlement of humans on the islands in the last 200 or so years (Watson *et al*. 2009), and the introduction of invasive species (Mauchamp 1997; Wikelski *et al*. 2004; Tye 2006; Wiedenfeld *et al*. 2007). This in turn has been associated with reductions in population size, and local extinction of vertebrate species on human inhabited islands, like Floreana Island (Grant *et al*. 2005; Dvorak *et al*. 2017). Nevertheless, since the late 1960s there have been numerous efforts to control or eradicate introduced species from various islands across the archipelago (Cruz *et al*. 2009; Carrion *et al*. 2011), in an effort to restore populations of endemic species (Donlan *et al*. 2007) and more recently, to holistically restore island ecosystems and species' function via reintroductions of locally extinct taxa, such as the Floreana tortoise (*Chelonoidis nigra*) (Hunter *et al*. 2019). The Floreana mockingbird is one of the bird species identified for reintroduction to the lowlands of Floreana Island in coming years (Charles Darwin Foundation 2008; Hoeck *et al*. 2010b; Bozzuto *et al*. 2017).

At this stage however, there is uncertainty about how long after the eradication of introduced species, the lowlands of Floreana will be suitable for reintroducing Floreana mockingbirds. Examples on other systems show that habitat enhancement, for instance via supplementary feeding and targeted restoration of food resources can assist in the reintroduction of critically endangered species (Maggs *et al*. 2019). Our study provides information on the diversity and temporal changes in diet composition of the remnant populations of this endangered species prior to the wet season, and can therefore be used to identify species to monitor on Floreana Island as groundwork for the eventual reintroduction of this endemic species to its namesake island. Future studies should aim to characterise the diet of the species immediately after the breeding season and explore the relationships between group size and territory quality.

ACKNOWLEDGEMENTS

We thank the numerous park rangers who have assisted in the field: Johannes Ramirez, Walter Chimborazo, Christian Pilamunga, Ángel Ramón, and El Burro. We also thank Jessica Hiscox, Eli

Christian and Jenny Daltry for useful discussions on our study and earlier drafts of the manuscript. We also thank Charlotte Causton and Alejandro Mieles for assistance identifying invertebrate prey. Funding for this research was generously provided by the Galapagos Conservation Trust and Mohamed bin Zayed Species Conservation Fund. Data collection and access to sites was conducted under permit PC-33-14 from the Ministry of Environment, Ecuador and Directorate of the Galapagos National Park.

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