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Population status of the Floreana racer (*Pseudalsophis biserialis biserialis* (Günther, 1860)) on islets off the coast of Floreana Island, Galápagos Islands, Ecuador

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Abstract

The Floreana racer (*Pseudalsophis biserialis biserialis*) is a subspecies of the Eastern Galápagos racer, formerly present in the lowlands of Floreana Island but confined to only two localities since the late 1800s: Champion Islet and Gardner-by-Floreana, both free of introduced rodents and cats. We conducted the first population assessment for the subspecies by using a capture-mark-recapture method of tagged individuals. We captured and measured 123 individuals, and estimated an approximate density of 12 adult and subadult individuals per ha on Champion Islet, and 14 per ha on Gardner-by-Floreana. Based on our results, we calculate that the global population of this subspecies is approximately 1000–1500 individuals. The current population on Champion Islet is likely to be very small, possibly fewer than 100 individuals. Strict quarantine to prevent the accidental introduction of invasive alien species to both islets is paramount. Our results indicate that both islets hold sufficient numbers of Floreana racers to assist in the translocation plans for the species back to the lowlands of Floreana Island as part of the ecological restoration in the Galápagos Islands.

Keywords

Terrestrial snake, endemic, translocation, ecological restoration, reptile survey, Galápagos Islands, *Pseudalsophis biserialis biserialis*

Introduction

The Floreana racer (*Pseudalsophis biserialis biserialis* (Günther, 1860)) (Figure 1) is the nominal subspecies of the Eastern Galápagos racer, described from a single specimen collected by Charles Darwin on Floreana Island in the Galápagos archipelago, Ecuador, in 1835 (BMNH 1946.1.4.56) (Thomas, 1997). Although this specimen has long been considered the *only individual* of a terrestrial snake species seen on Floreana Island at the time of Darwin's visit, Captain Fitzroy wrote in his narrative for Floreana Island, "there are a few small snakes, but those we caught were not venomous" (Fitzroy 1839), indicating more sightings of snakes on the island at the time. The 1905–06 California Academy of Sciences Expedition did not encounter Floreana racers on Floreana Island (Fritts & Fritts 1982). There is subfossil evidence of Floreana racers from the caves in the lowlands near the coast (Steadman 1986), but recent surveys have not encountered terrestrial snakes on Floreana Island (Jiménez-Uzcátegui & Ortiz-Catedral 2020). At present, the Floreana racer is restricted to only two islets: Champion and Gardner-by-Floreana, and it is considered extinct on Floreana Island since the late 1800s (Steadman 1986; Christian 2017). The current IUCN assessment for the species includes the populations of Champion Islet and Gardner-by-Floreana as well as the population of San Cristobal Island, and considers the species as "Near Threatened" (Márquez et al. 2017). Little is known about the San Cristobal subspecies (*Pseudalsophis biserialis eibli* (Mertens, 1960)). Williams et al. (2019) report that it is found from 350 to 358 m asl, and that it feeds on geckos (*Phyllodactylus* spp.).

The Floreana racer is one of several extinct or locally extinct vertebrate species on Floreana Island. Large-scale habitat modification by introduced browsers such as donkeys (*Equus asinus*) and goats (*Capra hircus*), and depredation by introduced rats (*Rattus rattus*) and feral cats (*Felis catus*) of the native fauna during the early 20th century are considered critical factors in the disappearance of the Floreana racer and other vertebrate species from the lowlands of Floreana Island (Van Denburgh 1912; Steadman 1986; Dvorak et al. 2017).

Floreana Island (17,300 ha) has long been

Figure 1. The Floreana racer (*Pseudalsophis biserialis biserialis*).

considered a priority for island restoration via eradication of introduced species (Brooke et al. 2007; Nogales et al. 2013). Significant progress has been achieved, with the eradication of donkeys and goats between 2006 and 2009 (Carrion et al. 2011), and a recent feasibility assessment for rodent and feral cat eradication (Hanson & Campbell 2013), as well as the development of preliminary scenarios for reintroduction of locally extinct species (Bozzuto et al. 2016). In recent years, the potential reintroduction of Floreana racers to the lowlands of Floreana Island has been discussed (Hanson & Campbell 2013). However, the biology of the species remains poorly known. Floreana racers, like other members of the genus *Pseudalsophis* (see Altamirano 1996), exhibit a bimodal pattern of activity during the day. Field observations indicate that they are more active around 8:00 h and 17:00 h (Christian 2017). They are found in grasslands, arid scrub, seabird colonies and rocky outcrops (Christian 2017; Arteaga et al. 2019). Nothing is known about their reproduction, but courtship and copulation have been observed in January on Gardner-by-Floreana (Sollis 2020). Their diet consists of geckos, lava lizards and birds (Ortiz-Catedral et al. 2019). To assist in the development of a reintroduction plan for the Floreana racer, we conducted a capture-mark-recapture (CMR) study on Champion and Gardner-by-Floreana. Our aim was to estimate the population size of the Floreana racer on these islets, and to better understand their size classes as well as proportions of males and females.

Methods

We captured Floreana racers on Champion Islet (9.5 ha) (1°14'7"S, 90°23'8"W) and Gardner-by-Floreana (85 ha) (1°19'52"S, 90°17'20"W) on five occasions: 1–8 December 2015; 7–14 January 2016; 26–30 November 2016 and 1–5 December 2016 and 7–11 January 2017 (total of 407 field days). Due to safety concerns and accessibility, we only accessed the only flat area of Gardner-by-Floreana, known as La Meseta (The Plateau) (17 ha). The terrain on both islets is irregular and rocky. The vegetation on Champion Islet and Gardner-by-Floreana consists of arid scrub with prickly pear (*Opuntia megasperma*), muyuyo (*Cordia lutea*) and chala (*Croton scouleri*). Near the coast and cliff edges of both islets there are open areas used as nesting sites by nazca (*Sula granti*) and blue-footed (*S. nebouxii*) boobies. Both islets are free of introduced rodents and feral cats. We searched for racers, covering the entire area of Champion Islet and The Plateau, during their peak activity periods and captured them by hand. We weighed each individual inside a cotton bag to the nearest 0.5 g, using a portable Pesola® scale, and measured (SVL and TL) to the nearest mm using string and a vinyl measuring tape. The sex of individuals was determined retrospectively by calculating the proportional tail length. In a separate study, sub-adult and adult male and female individuals sexed by manual probing differed significantly in their proportional tail length: mean proportional tail length females: 0.273 ± 0.018 SD (n=9); males: 0.302 ± 0.039 SD (n=13); Welch's t = -2.34, p = 0.031, d.f. = 17.9 (Christian 2017). To identify Floreana racers individually we inserted a Passive Integrated Transponder (PIT) (Trovan ID100 mini) subcutaneously along the posterior third of the venter anterior to the cloaca on snakes with a total length greater than 50 cm (97% of individuals). Each snake was released at site of capture approximately 60–75 minutes after capture, or, if snakes were captured after dusk, they were kept overnight in individual cotton bags and released before dawn the following day.

We used Chapman's (1951) modification of the Lincoln–Petersen closed-population CMR estimator. Because this estimator requires two distinct sampling periods, we grouped our quasi-annual field sampling (i.e., 407 days) into two periods: December 2015–January 2016 and November 2016–January 2017, representing effectively a marking period and a subsequent recapture period. We assumed that these two distinct periods were closed (no births, deaths or immigration–emigration) and limited our population analysis to sub-adult and adult snakes (98% of individuals); and excluding the four individuals classified as juveniles reduced the degree of violation of the assumption of population closure. Other estimators, such as Begon's weighted-mean model (Begon 1979), have been used for snakes inhabiting small islands, such as the Antiguan racer (*Alsophis antiguae*) (Daltry et al. 2001). However, after initial examination, our data was better suited to Chapman's estimator. In support of the assumption of low chances of immigration or emigration, recaptures of Floreana racers indicate little inter-annual movements, with individuals recaptured 150–380 m from their original capture location up to 363 days after (n=8) (Christian 2017). Another assumption of the Chapman estimator is that the probability of capture does not differ between individuals. Considering the small areas of the islets, and the thorough searches we conducted, we assume that the likelihood of capture between subadult and

adult individuals is equal. We excluded juveniles from analyses because we considered them too small to tag safely. Analyses were conducted in Minitab (Minitab 17 Statistical Software 2010).

Results

We captured a total of 123 Floreana racers over a total of 1,056 hours worked on both islets. On Champion Islet we captured 20 individuals (352 hours), and on Gardner-by-Floreana, 103 individuals (704 hours). Of these, 17 were recaptures, one on Champion Islet and 16 on Gardner-by-Floreana. Four individuals – two on Champion Islet, and two on Gardner-by-Floreana – were considered too small to tag or accurately sex (SVL 327 mm ± 68.36, *n*=4) and excluded from mark-recapture analyses. Table 1 includes the morphological measurements of Floreana racers per islet. Excluding the four individuals above, on Champion Islet we captured 11 females and 7 males. On Gardner-by-Floreana we captured 62 females and 39 males.

Table 1: Measurements of sub-adult and adult Floreana racers (mean ± SD).

Champion Islet		
Sex	Female (*n*=11)	Male (*n*=7)
SVL (cm)	53.36 ± 11.13	48.23 ± 8.99
Tail length (cm)	18.84 ± 3.65	21.51 ± 3.96
Total length (cm)	72.20 ± 14.59	69.74 ± 12.83
Mass (g)	54.77 ± 64.23	57.50 ± 47.59
Gardner-by-Floreana		
Sex	Female (*n*=62)	Male (*n*=39)
SVL (cm)	59.89 ± 14.08	55.44 ± 12.18
Tail length (cm)	22.28 ± 5.20	24.79 ± 4.71
Total length (cm)	82.18 ± 18.81	80.23 ± 16.78
Mass (g)	77.84 ± 56.70	68.87 ± 48.59

For our CMR analyses, using Chapman's estimator, we estimated a population size of adults and sub-adults on Champion Islet (9.5 ha) of 110 ± 8 SE based on 18 captures and one recapture over a period of 407 days, excluding two juvenile individuals. For The Plateau (17 ha) on Gardner-by-Floreana, using the same method and excluding two juveniles, we estimated a population of adults and subadults of 240 ± 56 SE based on 101 total captures and 16 total recaptures over a period of 401 days. These mean estimates are equivalent to 12 Floreana racers per hectare on Champion Islet and 14 on The Plateau.

Discussion

Our study represents the first attempt to quantify the population size of the Floreana racer in the only two known localities for this subspecies. The population estimate for Champion Islet must be interpreted cautiously as it is based on a dataset containing two capture sessions one year apart. Estimating accurate population sizes of snakes on small islets can be challenging if recapture rates are low. The Saint Lucia racer (*Erythrolamprus ornatus*) population on Maria Major (9.4 ha) is estimated at fewer than 50 mature individuals, based on a 30-day survey with only five recaptures (Williams et al. 2016). Maria Major is similar in size to Champion Islet, so it is indicative of approximate densities of an ecologically similar colubrid. Thus, we consider the Floreana racer population on Champion Islet to be small, possibly fewer than 100 individuals. Further surveys on Champion will help refine these estimates.

Based on the densities obtained, the Floreana racer population on Gardner-by-Floreana is estimated to be between 920 and 1,480 adult and sub-adult individuals. Although our study was restricted to The Plateau, the vegetation on the rest of Gardner-by-Floreana (ie., 68 ha excluding The Plateau) is similar to that of our study area, albeit across much more rugged terrain. The presence of Floreana racers has been reported during reconnaissance visits to the least accessible parts of the islet. The population of Antiguan racers (*Alsophis antiguae*) on Green Island (45.2 ha) is estimated at approximately 565 adults and subadults (Daltry et al. 2017), a roughly comparable estimate to the corresponding density of Floreana racers in The Plateau (i.e., approx. 17 Antiguan racers per ha as opposed to 12 adult and subadult Floreana racers per ha) (Daltry, unpubl. data).

Our CMR estimates only represent a snapshot of the populations of Floreana racers, and further surveys are necessary to fine-tune estimates and determine inter-annual variability among these. These surveys will also offer an opportunity to collect more information on the

biology of the Floreana racer. Based on our findings to date, however, we consider that the current global population of Floreana racers represents a viable source of individuals for a reintroduction programme to Floreana Island. For the ecologically similar Antiguan racer, successful reintroductions to Rabbit (2.1 ha), Green (45.2 ha) and York (7.0) islands consisted of releases of 14, 46 and 26 individuals respectively (Daltry et al. 2017). Therefore, it is likely that the successful reintroduction of Floreana racers to Floreana Island could consist of releases of small groups of individuals. The estimated area of the lowlands of Floreana Island is approximately 11,000 ha, which suggests that multiple translocation events will be necessary to establish a self-sustaining and genetically diverse population of Floreana racers without endangering the source populations of Champion or Gardner-by-Floreana. On the coast of Floreana, there are several peninsulas that could serve as pilot sites for the reintroduction of small numbers of Floreana racers, subject to the successful eradication of introduced rodents and feral cats. Our study highlights the high conservation value of Champion Islet and Gardner-by-Floreana for the Floreana racer, and illustrates the importance of ongoing stringent biosecurity measures to prevent the establishment of introduced rodents and feral cats on these islets. We recommend further studies focusing on the prey availability on these islets and regular surveys of Floreana racers to better understand the demography of the subspecies, and to provide robust recommendations for the reintroduction of the Floreana racer to the lowlands of Floreana Island.

Author Contributions

Luis Ortiz-Catedral: Conceptualisation; data collection; data curation, formal analysis; methodology; project administration; resources; logistics; validation; writing – original draft; review and editing.
Eli Christian: Data collection; data curation, formal analysis; methodology; writing – original draft; review and editing.
Danny Rueda: Conceptualisation; project administration; resources; logistics; writing – original draft; review and editing.
Christian Sevilla: Project administration; resources; logistics; writing – original draft; review and editing.
Jennifer C. Daltry: Conceptualisation; data collection; formal analysis; methodology; resources; validation; writing – original draft; review and editing.

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