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Population Status of Three Endangered Lizards on Shimojijima Island and Irabujima Island, Ryukyu Archipelago, Japan

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Abstract: The introduced Japanese weasel, *Mustela itatsi*, has had a significant negative impact on indigenous terrestrial vertebrates across several islands in the Miyako Group. The present study aimed to assess the current population status of squamate reptiles by investigating the distributions and abundances of three endangered lizards, *Plestiodon kishinouyei*, *Takydromus toyamai*, and *Emoia atrocostata atrocostata*, on Shimojijima Island and Irabujima Island. Route censuses for these species were conducted in the periods from 30 July to 4 August and 8–13 October 2022. Additionally, opportunistic sightings of lizards outside of the designated censuses were recorded. Eight *P. kishinouyei*, 20 *T. toyamai*, and seven *E. a. atrocostata* were recorded along four out of 101 survey routes, six out of 76, and two out of 39, respectively, with one additional *E. a. atrocostata* sighting at a non-census site. *Plestiodon kishinouyei* and *E. a. atrocostata* exhibited highly restricted distribution: the former was exclusively found in the northwestern part of Shimojijima Island, whereas the latter was confined to the southwestern part, with no presence on Irabujima Island. *Takydromus toyamai* was observed on both Shimojijima Island and Irabujima Island. The frequency of occurrence was low for the two skink populations on Shimojijima Island and *T. toyamai* on Irabujima Island, suggesting a potential population decline. These findings provide baseline data on the population status of these three lizard species. Such data will be crucial for evaluating their prospects for recovery, particularly considering the ongoing extensive eradication project targeting the introduced Japanese weasel on these islands.

Key words: Endemic species; Invasive alien species; Japanese weasel; Miyako Islands; Population decline

Introduction

Invasive species are one of the primary causes of biodiversity loss (Sala et al., 2000),

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and island ecosystems are especially vulnerable to the detrimental impacts of introduced organisms (Bellard et al., 2016; Doherty et al., 2016). Efforts to mitigate the impacts of invasive species have led to eradication attempts worldwide, with recent successes reported on small islands and enclosed areas (e.g., Nogales et al., 2004; Campbell and Donlan, 2005; Howald et al., 2007). In Japan, effective eradication of goats (*Capra hircus*) from most islands in Ogasawara Islands and the near eradication of mongoose (*Urva auropunctata*) from Amami-Oshima Island stand as prominent examples of successful invasive species removal (Japan Wild Research Center, 2019; Watari, 2019). The ultimate objective of such eradication projects is the restoration of reduc native populations. Indeed, the abundance of native endemics on Amami-Oshima, that had once been severely impact because of the introduced mongoose, have apparently recovered along with the elimination of the mongoose population recently (Watari et al., 2008, 2013).

The Miyako Islands Group, located in the southern part of the Ryukyu Archipelago, consists of Miyakojima Island and seven satellite islands (Fig. 1). The terrestrial vertebrate fauna in this island group is unique among other islands of the Ryukyu Archipelago, such as the Okinawa Group and Yaeyama Group. Endemic species in the Miyako Group are often characterized by the unique phylogeographic positions, with their closest relatives found in Taiwan and mainland China rather than other islands of the Ryukyu Archipelago (Ota, 1998; Lin et al., 2002; Ota et al., 2002; Igawa et al., 2006). However, the introduction of several invasive species has negatively impacted the indigenous terrestrial fauna, including endemic species. Among the introduced species in the Miyako Islands Group, the non-native Japanese weasel (*Mustela itatsi*) is widely considered to pose the most significant threat to the region's biodiversity, particularly the indigenous terrestrial fauna (Yamada, 2021). Kawauchi et al. (2018) and Nature Conservation Division of Okinawa Prefectural

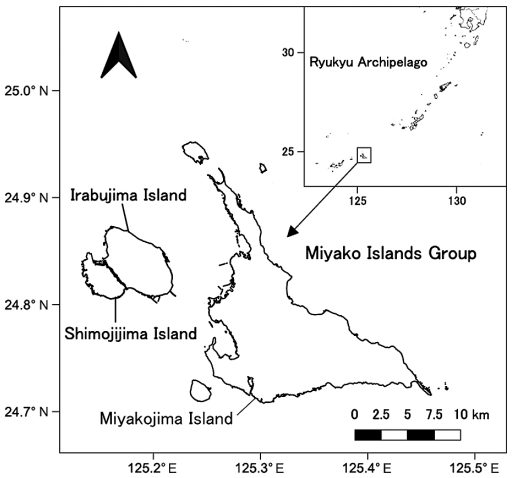

FIG. 1. Map of Shimojijima Island and Irabujima Island of the Miyako Islands Group in the southern part of the Ryukyu Archipelago.

Government (2018) conducted fecal analysis of the Japanese weasel and found remains of the Miyako grass lizard (*Takydromus toyamai*) and Kishinoue's giant skink (*Plestiodon kishinouyei*), both representative endangered species endemic to the Miyako Group and to the Miyako and Yaeyama Groups. Ota (2014a, b) and Takenaka (2014) also pointed out that the Japanese weasels might pose negative impact on these lizards in this region.

The Japanese weasel densities are highest on Shimojijima Island and Irabujima Island among the Miyako Group (NCDOP, 2018), raising concerns about potential severe declines of lizard populations on these islands. In response to this threat, NCDOP initiated a weasel eradication project on Shimojijima Island and Irabujima Island in 2020 to protect native lizard populations (NCDOP, 2018). Regarding *P. kishinouyei*, Toda et al. (2013b) failed to find any individuals on these two islands despite their presence on other islands of the Miyako Group. This observation, coupled with the absence of recent records for this species on these two islands, suggests the possibility of local extinction. However, definitive confirmation of this status requires further surveys. Indeed, although there are several obser-

vational and specimen-based records for other species of lizards in the islands of the Miyako Group (Nohina et al., 1998; Kikukawa, 2019; Toyama, 2019), these records are insufficient for accurately evaluating the current status of the lizard populations on each island. There is another endangered lizard, the littoral skink, *Emoia atrocostata atorocostata* (Scincidae), on both islands, but no comprehensive surveys have been conducted to assess its population status.

In this study, we evaluated the population status of native lizards on the islands and provide a baseline for evaluating the effectiveness of the weasel eradication project on these lizards' population. To achieve this objective, we conducted intensive surveys of the three endangered lizards, *P. kishinouyei*, *T. toyamai*, and *E. a. atorocostata*, on Shimojijima Island and Irabujima Island and determined their current distributions and abundances.

Materials and Methods

Study sites and species

Shimojijima Island and Irabujima Island, located west of Miyakojima Island, are uplifted limestone islands surrounded by coral reefs, with areas of 9.68 km^2 and 29.07 km^2, respectively. These two islands are adjacent, separated by a narrow and shallow channel partially exposed at the lowest tide (Fig. 1). In addition to the tidal flat areas, several bridges and paved roads connect these islands. The farmland, mainly fields of sugarcane, occupies nearly 50% of the islands' areas (Miyakojima City Office, 2022).

Approximately 100,000 Japanese weasels were introduced to many islands of the Ryukyu Archipelago between the late 1950s and early 1970s to control rat populations in the sugarcane fields, and 732 weasels were released on Irabujima Island in 1966 and 1967 (Uchida, 1969; Miyara, 1972; Uchida and Miyara, 1972). Later, Uchida and Miyara (1972) reported that the control of rats by the Japanese weasels was not as effective as expected and rat-related sugarcane damage continued on some islands, including those within the Miyako Group. These weasels have persisted until today in several islands, including Shimojijima Island and Irabujima Island.

This study focused on three diurnal lizard species, *P. kishinouyei*, *T. toyamai*, and *E. a. atorocostata*. *Plestiodon kishinouyei* is the largest skink in Japan, and some of the males exceed 400 mm in total length. This species is frequently encountered in relatively open environments, such as grasslands, farmland, coastal scrublands, and the edges of secondary forests (Ota, 2014a). *Takydromus toyamai*, a green-colored grass lizard endemic to the Miyako Group, inhabits grassy areas within diverse environments, including forest edges, farmlands, and even villages (Saiki et al., 2018; Toda and Takahashi, 2018). *Emoia atorocostata atorocostata*, which is widely distributed across subtropical to tropical East and Southeast Asia and western Pacific islands (Ota, 2014b), exhibits a restricted distribution within Japan, solely inhabiting the Miyako Group. This skink has a unique habitat, being found almost exclusively on rocky shores or within mangrove forests (Richmond et al., 2021).

Field survey

Route censuses were conducted from 30 July to 4 August 2022, and 8 to 13 October 2022. Although all three target species are diurnal, *T. toyamai* is more easily detected at night when the lizards sleep on vegetation (Asato et al., 2021). *Plestiodon kishinouyei* is expected to be most efficiently detected in midsummer after the emergence peak of new hatchlings in late June to early July (Toda et al., 2013a). Thus, the censuses for *P. kishinouyei* were conducted during the daytime in July to August. The censuses for *E. a. atorocostata* were conducted in October during the day, while those for *T. toyamai* were performed at night during both survey periods. The daytime surveys for the two species of skinks were conducted during sunny condition because they are heliothermic, using sunlight to regulate body temperature (Toda et al., 2013a).

Survey routes were established across both

islands, encompassing the maximum possible areas while considering the specific habitat preferences of each species, as outlined above. Survey routes incorporated previously documented lizard occurrence sites to the greatest extent possible. Each census route was designed to encompass only one habitat type to minimize habitat bias. This resulted in the establishment of 101, 76, and 39 census routes for *P. kishinouyei*, *T. toyamai*, and *E. a. atorocostata*, respectively (Table 1), with route lengths of 20–325 m. In each census, one or two persons walked along the census routes at a consistent pace (approximately 8.5 m per min) and carefully looked for active or resting lizards. When the individuals of the target species were found, their geographical coordinates and growth stage (adult or juvenile) were recorded. The growth stage was determined by estimating body size visually or, in some cases, by directly measuring the snout-vent length (SVL) for lizards temporarily captured for another study. Following the criteria established by Toda et al. (2013a), individuals of *P. kishinouyei* exceeding SVL of 95 mm were provisionally identified as adults. The smallest SVL of female *T. toyamai* with well-developed follicles or oviductal eggs was 46 mm, and hemipenal bulges in males become evident at the same size (Asato and Toda, unpublished), and thus individuals with this SVL or larger were defined as adults. For *E. a. atrocostata*, Okada et al. (1992) reported 18 adult specimens they handled ranging from 72 to 80 mm in SVL. Thus, individuals with SVL clearly below 72 mm were considered juveniles. Lizards that promptly evaded observation after detection and therefore prevented size estimation were recorded as individuals of unknown size. The environment of the census routes and the microhabitats at the point of encounter were also recorded. Records of lizards sighted outside of the designated censuses periods were treated in the same manner.

Data analyses

To assess the distribution and relative abundance of the lizard species across the two islands, we calculated the frequency of occurrence routes and observation frequency. For each species, the frequency of occurrence routes was calculated as number of the occurrence routes divided by total number of surveyed routes. Observation frequency for each target species was estimated by calculating the average number of individuals observed per minute across all survey routes where at least one individual of that species was encountered. The frequency of occurrence routes for each species was calculated by including non-census records of lizards encountered along any census route but outside of the designated census period. However, these data were excluded from the calculation of observation frequency.

Results

Results of the field survey are presented in Table 1. While all three species were observed during the surveys, the frequency of occurrence routes was notably low for each species. *Plestiodon kishinouyei*, *T. toyamai*, and *E. a. atorocostata* were encountered on only four (4.0%), six (7.9%), and two (5.1%) of all surveyed routes, respectively. *Takydromus toyamai* was found on both Shimojijima Island and Irabujima Island, but its frequency of occurrence routes was considerably lower on Irabujima Island (Fig. 2B, Table 1). *Plestiodon kishinouyei* and *E. a. atorocostata* were found only on Shimojijima Island (Figs. 2A, C). Even within Shimojijima Island, the occurrences of both species were highly localized, with *P. kishinouyei* exclusively found in the northwestern part of the island and *E. a. atorocostata* in the southwestern part. The numbers of recorded individual were limited across all three species, with the maximum count being 20 individuals for *T. toyamai*. Both adults and juveniles were observed for all three species. Juveniles of *P. kishinouyei* were observed on all four routes where the species was encountered. For *T. toyamai*, juveniles were found on four out of the six routes where the species was detected. Juveniles of *E. a. atorocostata* were

TABLE 1. Comparison of relative abundances of the three endangered lizards on Shimojijima Island and Irabujima Island with those on Miyakojima Island. Data for the Miyakojima populations were taken from previous studies by Toda et al. (2013b) and Sasai et al. (2021), as well as unpublished studies by Toda and collaborators in 2016. The number of sites where a lizard was opportunistically sighted outside of the designated census routes is provided in parentheses following "No. of observed routes". Similary, the number of individuals observed outside of the designated census timeframes and non-census sites is indicated in parentheses following "No. of individuals".

Species	Island	No. of census routes	Research efforts (min)	No. of occurrence routes (non-censes)	Frequency of occurrence routes	No. of inidviduals (non-censes)				Observation frequency per min (range)	Reference
						Adult	Juvenile	Unknown	Total		
Plestiodon kishinouyei	Irabujima	68	458	0	0	—	—	—	—	—	present study
	Shimojijima	33	230	4 (0)	0.12	0 (2)	4 (2)	0 (0)	4 (4)	0.20 (0.12–0.27)	present study
	Miyakojima	43	—	3	0.07	—	—	—	—	0.04	Toda et al. (2013b)
Takydromus toyamai	Irabujima	56	471	2 (0)	0.04	4 (0)	5 (2)	0 (0)	9 (2)	0.21 (0.09–0.33)	present study
	Shimojijima	20	236	4 (0)	0.20	6 (0)	2 (0)	1 (0)	9 (0)	0.13 (0.05–0.24)	present study
	Miyakojima	117	—	23	0.20	—	—	—	—	0.08	Toda et al. (unpubl. data)
Emoia atrocostata atorocostata	Irabujima	23	164	0	0	—	—	—	—	—	present study
	Shimojijima	16	183	2 (1)	0.13	4 (0)	1 (1)	1 (0)	6 (1)	0.32 (0.13–0.50)	present study
	Miyakojima	46	—	11	0.24	—	—	—	—	0.15	Sasai et al. (2021)

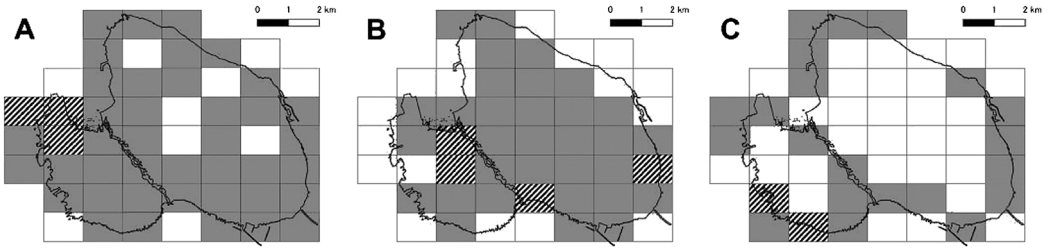

FIG. 2. Maps of Shimojijima Island and Irabujima Island, highlighting locations of the census route (grey grids) and the locations where the three endangered lizards, (A) *Plestiodon kishinouyei*, (B) *Takydromus toyamai*, and (C) *Emoia atrocostata atrocostata*, were encountered (hatched grids). To safeguard these species from potential illegal collection (Janssen and Shepherd, 2019), the precise details of the census routes have been obscured by using 1 km grid squares.

recorded on one of the two routes where the species was found and another site outside of the established census routes. This additional site where juvenile *E. a. atorocostata* was observed was located relatively close (<800 m) to the nearest census route where other conspecific individuals were recorded.

The observation frequencies across all three species were similar, with 0.20 individuals observed per minute for *P. kishinouyei*, 0.21 for *T. toyamai* on Irabujima Island, 0.13 for *T. toyamai* on Shimojijima Island, and 0.32 for *E. a. atorocostata*. These values were comparable to the densities reported for Miyakojima Island (Table 1). *Plestiodon kishinouyei* was primarily observed around a single large secondary forest in a large geographic scale, and environments of the occurrence routes were forest edge bordering paved roads, trails within the forest, and coastal vegetation adjacent to the forest. *Takydromus toyamai* was sighted in grassy habitats, primarily along forest edges and rarely within areas dominated by grasses. *Emoia a. atorocostata* was found exclusively on rocky coasts characterized by the presence of boulders and cliffs behind the shoreline. Active individuals were observed in both the intertidal and supratidal zones. A juvenile *E. a. atorocostata* was also observed outside of the designated census routes, on a fence situated between the shoreline and a paved road.

DISCUSSION

The present survey offers insights into the current population status of the three endangered lizards on Shimojijima Island and Irabujima Island, coinciding with the early stages of the introduced Japanese weasel eradication project. These data will be essential for evaluating the likelihood of recovery for these endangered lizards, especially considering the ongoing comprehensive project aimed at eradicating the introduced Japanese weasel on these islands. Notably, the discovery of *P. kishinouyei* on Shimojijima Island was worth noting. Contrary to the predictions of local extinction for *P. kishinouyei* on Shimojijima Island and Irabujima Island suggested by Toda et al. (2013b), the present study provides evidence for the continued presence of this species, at least on Shimojijima Island. Toyama (1981) previously remarked on the rarity of *P. kishinouyei* on Shimojijima Island, with sightings primarily based on interview surveys conducted in the 1970s or 1980s. Therefore, to the best of our knowledge, this study represents the first confirmed record of the species on Shimojijima Island.

The rediscovery of *P. kishinouyei* on Shimojijima Island has significant implications for future steps in the weasel eradication project. Species belonging to the genus *Plestiodon* are considered highly susceptible to the predatory pressure of introduced Japanese weasels, as

evidenced by the documented population declines on various islands such as Miyakejima in the Izu Islands (Hasegawa, 2003), Haterumajima Island (Toda, 2017), and Zamamijima Island (Toyama, 2017). On Tairajima and Akusekijima in the Tokara Islands Group, populations of the genus *Plestiodon* appear to have disappeared probably due to the introduction of Japanese weasel before clarification of their taxonomic status (Hikida et al., 1992; Ota, 2003). In this context, the discovery of *P. kishinouyei* on Shimojijima Island in the present survey is promising. However, given the highly localized nature of this population, significant vigilance is necessary to ensure its long-term survival on the island (Fig. 2A).

While *T. toyamai* was observed on both Shimojijima Island and Irabujima Island, its frequency of occurrence routes was markedly lower on Irabujima Island compared to Miyakojima Island (Table 1). This discrepancy stands in contrast to the observation by Takeda and Ota (1996) who stated that "On Miyakojima Island and Irabujima Island, *T. toyamai* seems to be abundant in grasslands and sugarcane fields." An interview survey conducted with residents of the Miyako Group aged 50–100 years revealed that more than one-third of the respondents recalled sighting this grass lizard during their school years, even on Irabujima Island. This suggests that the species was likely common until the 1960s and 1970s (Tatetsu et al., 2022). Considering its putative abundance in the past, the results of the present study suggest a substantial population decline of this species on Irabujima Island in recent years. While the present study observed similar frequencies of occurrence routes for lizard species on Shimojijima Island and Miyakojima Island, it remains unclear whether these populations have increased or decreased in recent years due to the lack of past data in Shimojijima Island.

The present study also reveals that the distribution of *E. a. atorocostata*, similar to *P. kishinouyei*, is restricted to a narrow area within Shimojijima Island. However, it is difficult to conclusively argue about a potential decline in the population of this species due to the lack of previous data. Actually, we cannot rule out the possibility that the absence of *E. a. atorocostata* in many survey routes is attributed to an unsuitability of the habitat rather than solely reflecting population decline. Compared to the two survey routes where *E. a. atorocostata* was recorded, the absence routes appeared to be characterized by more solid limestone surfaces and a significantly lower abundance of bouldering stones, or their complete absence. While habitat requirements may play a significant role in the low frequency of occurrence routes for *E. a. atorocostata*, the possibility of a partial population decline cannot be entirely dismissed. Japanese weasels have occasionally been observed on the Miyako Islands even around the coast, and Ota (2014b) suggested their predatory pressure is a potential factor contributing to the suspected decline of *E. a. atorocostata*. Toyama (1981) previously recorded *E. a. atorocostata* from a location on the southern coast of Irabujima Island. We also conducted a survey at exactly the same site but failed to find any individuals at all. The observation of a seemingly unaltered natural coastal landscape at the survey site suggests that the decline in of *E. a. atrocostata* may be primarily attributed to the impact of weasels. The low frequency of occurrence could also be attributed to excessive exploitation of coastal areas for tourism, particularly in the southern region of Irabujima Island.

The ongoing Japanese weasel eradication project initiated on Shimojijima Island and Irabujima Island in 2020 has shown promising initial results. A recent report indicates a decline in weasel density within at least one area of Shimojijima Island (NCDOP, 2022). Fortunately, the presence of both adults and juveniles in several surveyed sites confirmed successful reproduction for all three lizard species. In addition, observation frequencies on Shimojijima Island and Irabujima Island were comparable to or exceeded those on Miyakojima Island for all three species. It is hoped that the findings of this study will be utilized as a basis for evaluating the ongoing

weasel eradication program. This will contribute to effective development and implementation of future eradication project aimed at protecting native species and ecosystems.

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