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Estimation of Growth Rate, Survival Rate, and Longevity of the Endangered Otton Frog (*Babina subaspera*) Using the Capture-Mark-Recapture Method

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Abstract.—**The Otton Frog (*Babina subaspera*) is an endangered species endemic to Amami-Oshima Island. To obtain fundamental ecological information on this species, I conducted a 6-y capture-mark-recapture survey and made 465 captures of 385 individuals. The growth rate decreased linearly as snout–vent length increased. According to a growth curve, the Otton Frogs appeared to mature in the second year after metamorphosis. Estimated longevity was at least 7 y and the estimated mean annual survival rate was 0.68 ± 0.09 (mean ± standard deviation, 95% CI: 0.51 – 0.88) for females and 0.70 ± 0.08 (95% Confidence Interval = 0.55 – 0.86) for males. These demographic parameters may be useful for the development of conservation measures for this species.**

Key Words.— Amami-Oshima Island; Cormack-Jolly-Seber model; field survey; growth curve; mortality rate

Introduction

Amphibians are among the most threatened groups of animals on the planet (Hof et al. 2011). Habitat degradation, climate change, and amphibian diseases have caused a decline in many amphibian species worldwide (Alford and Richards 1999), highlighting the urgent need for appropriate conservation measures (Semlitsch 2000). To develop conservation strategies for endangered amphibian species, thorough ecological information about the target species, such as growth rate, survival rate, longevity, and home range, is extremely important.

The Otton Frog (*Babina subaspera*; Fig. 1), inhabits the subtropical forests of Amami-Oshima Island, southern Japan (Maeda and Matsui 1999). This species is of great scientific interest from an evolutionary perspective because of its unique pseudothumb, or the so-called fifth finger (Tokita and Iwai 2010; Iwai 2013b). It is endangered owing to habitat degradation (Environment Agency 2000) and introduced predators (Watari et al. 2008). This species is currently listed as Endangered on the Red List of the International Union for the Conservation of Nature (IUCN 2021). The author has previously described the home range and movement patterns of the Otton Frog to inform the effective management of this endangered species (Iwai 2013a); however, demographic parameters have not been obtained. In this descriptive study, I estimated the growth rate, survival rate, and longevity of Otton Frogs using data from a 6-y capture-mark-recapture field survey. These ecological data will contribute to the effective management of this valuable, but endangered, species.

Materials and Methods

Field survey.—I conducted this study in the Sumiyo region of Amami-Oshima Island, which is located in Kagoshima Prefecture, southern Japan (28°12′ N, 129°25′ E). The island is mountainous and covered with subtropical rain forest, and its highest peak reaches an elevation of 694 m. The density of Otton Frogs in the Sumiyo region is relatively high compared with that of the remainder of the island (Iwai and Watari 2006). I conducted the surveys along a 4–5 m-wide paved road (Fig. 1) that connects two villages with fewer than 150 and 30 people each. Traffic volume on the survey road was low, with < 10 vehicles per night travelling at a mean speed of 11.5 km/h (unpubl. data). The survey started at the north end of the road at an elevation of 9 m, continued into the mountains, reaching 380 m elevation at the 6-km point, and then headed down to 190 m elevation at the 12.3-km endpoint. The endpoint was the last potential breeding site and was located to the north of a large river, over which the road crossed via a bridge. Several streams traversed the road, and small dams were constructed at the intersections; some of the pools created by the dams were used as breeding sites by Otton Frogs.

I conducted surveys during the active season of the Otton Frog for 6 y (2010–2015). To identify as many individuals as possible for future recapture, survey effort was large in the first year, with 4–20 nights of surveying every month from April to October (76 nights in total). From the second year on, survey efforts were relatively consistent, 11–17 nights per year during May to August (68 nights in total). Each night, I looked for Otton Frogs

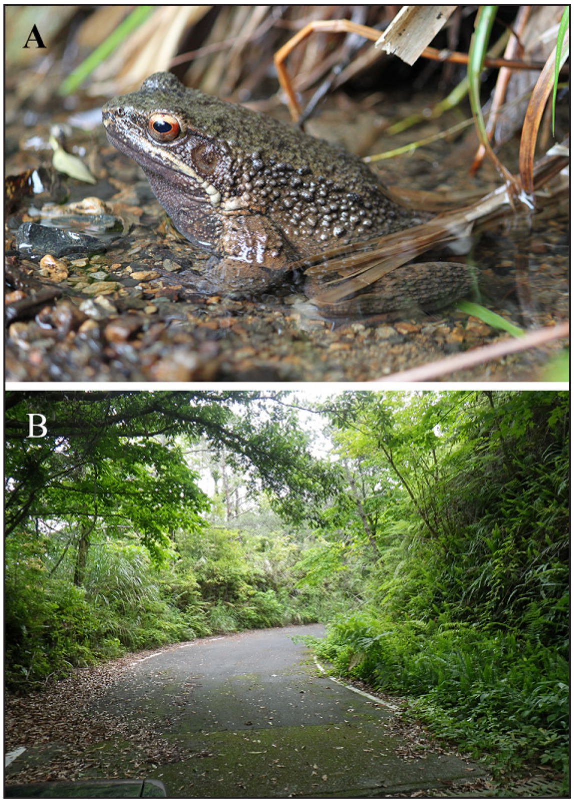

Figure 1. (A) An adult Otton Frog (*Babina subaspera*) from Amami-Oshima Island, Kagoshima, Japan. (B) General view of the survey road. (Photographed by Noriko Iwai).

on the road while slowly driving a car (10–15 km/h) as well as by checking 16 potential breeding sites (artificial pools) along the road. When found, I captured Otton Frogs by hand and weighed them with a portable balance (model HL-3000WP; A&D, Tokyo, Japan) to 1 g, and determined their sex based on the presence of vocal openings, which only occur in males (Maeda and Matsui 1999). I placed individuals on the ground holding one hind limb to let them pull themselves up to their full length, and measured their snout–vent length (SVL) with callipers to 0.1 mm. I categorized individuals with SVL < 86.1 mm as juveniles because this was the SVL of the smallest male with vocal openings. I marked individuals by toe clipping a unique combination of digits, but I did not clip the pseudothumb or more than one digit from each limb to minimize any effects of toe clipping (Grafe et al. 2011). I then photographed individuals. If an individual was already toe clipped, I recorded the ID number. If an individual was recaught during the same season, I only recorded the first capture event. Regrowth of toes was limited, and injury did not occur in a way obscuring the identification, so I was confident I could identify all individuals.

Data analysis.—To calculate the growth rate, I used data from individuals captured in two successive years. I divided the difference in SVL between years by the number of interval days (mm/day). To examine the relationship between growth rate and body size, I constructed a General Linear Model with the growth rate as a dependent variable and the SVL of the earlier capture event and sex as independent variables. This gives a linear function of growth rate:

$$\text{Growth Rate} = a \times \text{SVL} + b.$$

where a = slope of the regression line and b = the intercept. When an individual has a growth curve expressed as the size on time t as f(t), its growth rate is f′(t). By solving ordinary differential equation, $f'(t) = a \times f(t) + b$, we can obtain $f(t) = -b/a + c \times \exp(at)$ as a growth curve. Coefficient c can be calculated with the initial size $f(0) = -b/a + c$.

Because I did not measure all population vital rates (e.g., birth, death, immigration, emigration) during the study period, I chose the Cormack-Jolly-Seber model as an open population model for the estimation of survival rate (Cormack 1964; Jolly 1965; Seber 1965). In capture-recapture studies, temporary emigration can be an issue in some cases (Kendall et al. 1997). Because adult Otton Frogs show high site-fidelity (Iwai 2013a), I assumed they have low rates of leaving the study site. Breeding season and active season of Otton frogs are almost equal, and I looked for the frogs both on the road and at breeding sites. Accordingly, I assumed that the temporary emigration issue would be negligible in this study.

I applied Bayesian Population Analysis to estimate the survival rate and recapture probability. As no events that could affect the survival rates of Otton Frogs (such as clear-cutting or large typhoons) occurred during the survey period, I assumed that the survival rate was constant throughout the survey period. Meanwhile, I estimated recapture probability for each year because survey efforts differed among years. I estimated survival rate and recapture probability for each sex separately. A detailed description of the model and R code is provided by Kéry and Schaub (2012) and I used a modified version of their model (Chapter 7.6.1). I ran the model in WinBUGS version 1.4.3, accessed through R version 4.1.2 (R Core Team 2021) using the R2WinBUGS package (Sturtz et al. 2005). I ran five independent chains of 100,000 iterations after a burn-in of 10,000 iterations, with chains thinned by a factor of 10 to produce a final posterior of 45,000 samples.

Results

Over the 6-y study period, I made 465 captures of 385 individuals (Table 1). Of these 385 individuals, 55 were captured twice, 11 were caught three times, and one was caught four times, for a total of 147 recaptures.

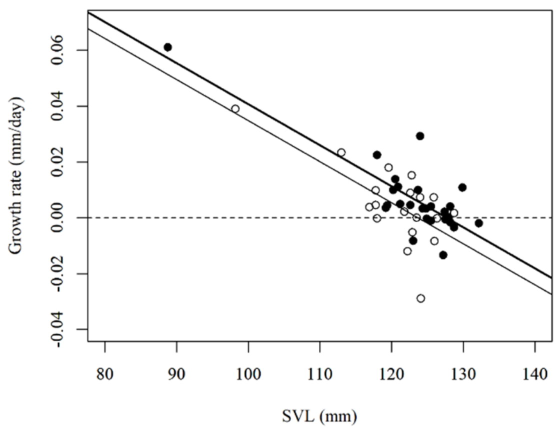

Figure 2. Relationship between snout-vent length (SVL) at first capture and growth rate (mm/day) of the Otton Frog (*Babina subaspera*) from Amami-Oshima Island, Kagoshima, Japan. Open circles with a thin regression line denote females and solid circles with a thick regression line denote males. The dotted line is where the growth rate equals zero.

For the following analysis, I excluded eight juveniles and one sex-unknown individual (all caught only once).

I obtained 19 data points for 16 females and 25 data points for 21 males for the growth rate calculation. The growth rate (mm/day) significantly decreased as the SVL at the first capture increased (t = -7.90, P < 0.001; Fig. 2). For females, Growth Rate = -0.00147 × SVL + 0.182, and for males, Growth Rate = -0.00147 × SVL + 0.188 (Table 2). Considering that individual size at metamorphosis, f(0), was 25.9 ± 2.8 mm (mean ± standard deviation, n = 7; unpubl. data), the body size (mm) on day t was expressed as f(t) = 123.7 – 97.8 × exp(-0.00147 × t) for females and f(t) = 127.7 – 101.8 × exp(-0.00147 × t) for males (Fig. 3). According to the obtained growth curve, predicted age of the smallest sized adults (SVL = 86.1 mm) was 650 d (95% Confidence Interval [CI] = 524.6–853.0 d) for females and 608 d (95% CI = 474.2–847.4 d) for males.

I observed the longest intervals between captures at 5-y, 11 d (1,836 d) for a female and 5 y, 58 d (1,883 d) for a male. These individuals were full-grown adults at their first capture (female: SVL = 120.4 mm; male: SVL = 122.3 mm). From the obtained growth curves, female and male Otton Frogs reach SVLs of 120.4 mm and 122.3 mm at 2,302 d (95% CI = 1,931–2,868 d) and 1,994 d (95% CI = 1,459–3,280 d) after metamorphosis, respectively. The estimated annual survival rate was 0.68 ± 0.09 (mean ± standard deviation, 95% CI = 0.51–0.88) for females and 0.70 ± 0.08 (95% CI = 0.55–0.86) for males. Recapture probability was 0.10–0.17 for females and 0.13–0.22 for males (Table 3).

Table 1. Number of captures of the Otton Frog (*Babina subaspera*) from Amami-Oshima Island, Kagoshima, Japan, during each survey year.

Group	2010	2011	2012	2013	2014	2015	Total
Female	75	23	35	30	41	27	231
Male	68	17	41	32	32	35	225
Juvenile	2	1	0	1	0	4	8
Unknown	1	0	0	0	0	0	1
Total	146	41	76	63	73	66	465

Table 2. Mean, standard error (SE), and 95% confidence interval (LCL = lower confidence limit, UCL = upper confidence limit) for the estimated coefficients in the linear model explaining growth rate with snout-vent length (SVL) and sex of the Otton Frog (*Babina subaspera*) from Amami-Oshima Island, Kagoshima, Japan.

Trait	Estimate	SE	LCL	UCL
SVL	-0.00147	0.00019	-0.00184	-0.00110
Sex(Male)	0.00590	0.00028	0.00043	0.01137
Intercept	0.182	0.023	0.138	0.226

Discussion

The growth rate of Otton Frogs correlated negatively with body size. From my growth curves, Otton Frogs mature in the second growing season after metamorphosis. Because small young adults were rarely captured, the growth data for those individuals were limited. This limitation could cause relatively large error, but my data are still valuable for giving rough estimates for this endangered frog species.

The longest interval between capture and recapture was more than 5 y in both sexes. These individuals were full-grown adults when first captured and I estimated that this size would take at least 4–5 y to be reached. As previously stated, Otton Frogs require 2 y to mature. I estimate that the longevity of some Otton Frogs in the field is at least 7 y.

The survival rate of adult Otton Frogs was approximately 0.7 per year for both sexes. Anuran annual adult survivorship varies from 0.15 to 0.94, with lower values observed in the tropics (Wells 2007). Tropical species are susceptible to continuous predation pressure because they are active throughout the year (Duellman and Trueb 1986) and there is a high abundance of tropical predators (Wells 2007). The Otton Frog inhabits a semi-tropical climate and has a long active season (April-October; Iwai 2014). Considering the long duration of the active season, survival rate of Otton Frog was relatively high. Because the Otton Frog is the largest frog species on an island where no large carnivorous mammals exist, there may not be high predation pressure once they grow to large sizes. One possible predator is a large snake *Habu* (*Protobothrops flavoviridis*), but this snake mainly eats mice (Mori and

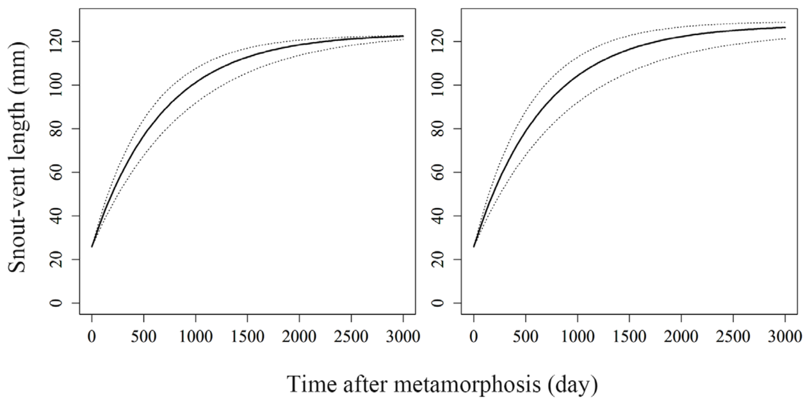

Figure 3. Growth curve calculated from the observed relationship between snout-vent length and growth rate of the female (left) and male (right) Otton Frogs (*Babina subaspera*) from Amami-Oshima Island, Kagoshima, Japan. The dotted line denotes upper and lower 95% confidence limits.

Moriguchi 1988) and thus may not predate much on Otton Frogs.

My study provides fundamental ecological information on the endangered frog species, the Otton Frog. It is often difficult to determine the survival and growth rates of animals in the field because doing so requires labor-intensive efforts (Berven 2009; Schmidt et al. 2012). Field-based studies, such as this investigation, are useful for the development of conservation measures for this endangered species.

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Table 3. Estimated recapture probabilities and the number of survey conducted each year of the Otton Frog (*Babina subaspera*) from Amami-Oshima Island, Kagoshima, Japan. Recapture probabilities are shown with mean, standard deviation (SD), and 95% confidence limits (LCL = lower confidence limit, UCL = upper confidence limit) for each sex. The abbreviation NS = number of surveys.

	Female				Male				
Year	Mean	SD	LCL	UCL	Mean	SD	LCL	UCL	NS
2011	0.17	0.05	0.08	0.28	0.21	0.06	0.11	0.34	11
2012	0.17	0.06	0.08	0.31	0.22	0.07	0.11	0.37	14
2013	0.15	0.06	0.06	0.28	0.19	0.06	0.09	0.32	15
2014	0.17	0.06	0.07	0.32	0.21	0.07	0.10	0.37	17
2015	0.10	0.05	0.04	0.22	0.13	0.05	0.05	0.26	11

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