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Long-term Changes in Age Structures of a Naturalized Population of Freshwater Turtle, Red-eared Slider *Trachemys scripta elegans*

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Abstract: The red-eared slider turtle, *Trachemys scripta elegans*, is an invasive species, that may potentially induce negative impacts on native turtle communities and freshwater ecosystems. Effective control of invasive species requires knowledge of the process of invasion and the long-term dynamics of an introduced population. However, such studies are scarce. We investigated temporal changes in the species composition of a freshwater turtle assemblage including density and age structure of the red-eared slider turtle at the Kahokugata lagoon of Ishikawa Prefecture in central Japan over 15 years (2001–2003, 2013 and 2015). The number of red-eared sliders increased over time, whereas that of Reeves' pond turtle, *Mauremys reevesii*, remained flat for 15 years from 2001 to 2015. Data on morphological measurements in the red-eared slider population showed that the proportion of old individuals increased whereas juveniles decreased. Moreover, the body condition index decreased in all age classes. These results suggest that juvenile recruitment was limited in the recent years and thus breeding efficiency was lowered in the red-eared slider population at this lagoon perhaps due to high population density.

Key words: Age structure; Invasive species; Juvenile recruitment; Population density; Red-eared slider

Introduction

Invasive species artificially introduced outside their natural range frequently induce negative impacts on the native flora, fauna, and ecosystem. Numerous cases of these impacts through various processes have been described previously including predation on native species, competitive exclusion of native species, hybridization with native species, introduction of new diseases and parasites, and alteration of the ecosystem (Mooney and Cleland, 2001). In freshwater ecosystems, negative impacts of invasive species have been reported following introductions of large-mouth bass, *Micropterus salmoides*, and cane toads, *Rhinella marina*, in many regions of the world (Maezono and Miyashita, 2003; Christopher et al., 2015; Hamamura et al., 2016; Han et al., 2016; Uditha et al., 2016).

The red-eared slider turtle, *Trachemys*

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scripta elegans, is a famous invasive species of freshwater turtle (Lowe et al., 2000) that has been introduced to many aquatic regions of the world via the pet trade (Luiselli et al., 1997; Chen and Lue, 1998; Polo-Cavia et al., 2011). Populations established in the wild and semi-natural wetlands can displace native freshwater turtle populations (Cadi and Joly, 2004; Polo-Cavia et al., 2010, 2011; Taniguchi et al., 2017). In Japan, red-eared sliders were imported from the United States (Yasukawa, 2002). Since then, they have been released to ponds, lakes, rivers, and other wetlands (Kamezaki, 2015). Originally, Japanese pond turtles, *Mauremys japonica*, and Reeves' pond turtles, *Mauremys reevesii*, occupied wetland habitats in Japan, though the latter species is suggested to have been introduced from China a few hundred years ago (Suzuki et al., 2011). Native turtle species may have been threatened by the invasion of red-eared slider (Taniguchi and Kamezaki, 2010; Kamezaki, 2015). In western Japan, the red-eared slider is dominant and the densities of native turtles are low at many ponds (Taniguchi et al., 2015). Additionally, Kato et al. (2014) reported that the red-eared slider comprised 55.8% of freshwater turtles captured in wetlands around Shizuoka City of Shizuoka Prefecture. These studies suggest that red-eared slider populations could be displacing native freshwater turtle populations in wetlands of Japan.

For the conservation of the native turtle communities and freshwater ecosystems, it is important to examine the process of invasion and range expansion, and the population dynamics of the red-eared slider. Specifically, information of population growth over a long time period may provide useful suggestions for effective control program. However, little is known about the long-term dynamics of red-eared slider populations in Japan. In Ishikawa Prefecture, freshwater turtle communities are dominated by the red-eared slider (Noda and Kamata, 2004). In the present study, we investigated species composition of freshwater turtles and age structure in each species at the Kahokugata lagoon in 2001–2003, and 2013 and 2015, to identify long-term changes in species composition and characteristics of the red-eared slider population. We then propose an effective method for control of the red-eared slider population.

Materials and Methods

Animals

The red-eared slider, *Trachemys scripta elegans*, is a semiaquatic turtle belonging to the family Emydidae. The maximum carapace length of adults is 30.2 cm (Tucker et al., 2006) for females but males are smaller. The conspicuous small red dash marking on each side of their head is one of the specific characteristics. The turtle is widespread in lakes, ponds and marshlands all over Japan, potentially disturbing native turtles and other freshwater animals (Yasukawa, 2002). Moreover, agricultural damages, such as predation of lotus, water shield, and water caltrops, have been reported (Arima et al., 2008; National Institute for Environmental Studies of Japan, 2015). In many ponds of western Japan, efforts are underway to eradicate this turtle (Kamezaki, 2015).

Reeves' pond turtle, *Mauremys reevesii*, is also found at our study site. This species belongs to the family Geoemydidae. Although it has been long regarded as native to Japan, recent research suggested that it was introduced from China and Korea in the past (Suzuki et al., 2011). The distribution of this species ranges from Hokkaido to the Kyusyu as well as to Taiwan and the eastern part of Asian continent. It is typically found in marshlands, relatively shallow ponds, streams, and canals with muddy or sandy bottoms (Ernst and Barbour, 1989).

Methods

Field collection of the turtles

Research was conducted at the Kahokugata lagoon (area: 4.2 km^2), located in the Kana-

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zawa City of Ishikawa Prefecture, Japan (36°41'45"N, 136°41'6"E). In the western area of the lagoon, we collected turtles at three sites along the watercourse to the sea, that were 0.5 km apart. Metal cage traps (20 cm×60 cm×45 cm) with 10 mm mesh were placed in the water with floats to prevent captured turtles from drowning. In each trap, a few slices of fish were put as bait, and the traps were placed in the morning and checked after 24 h to see whether or not turtles had been captured. From 2001 to 2003, five traps were used at each trap site more than five times from spring through summer. In 2013 and 2015, three traps were used, and traps were set 12 times during the same seasons.

Morphological measurements

Species, sex, age, and color of all captured turtles were recorded. Sex was determined based on the position of cloacal opening and claw length. Young turtles that were difficult to determine sex were regarded as juveniles. Age was estimated by counting the number of annual rings on scutes. In cases where the annual rings were worn down, turtles were recorded as "older individuals". Dark-colored turtles were recorded as melanistic individuals, that are possible indication of old age (Ernst and Barbour, 1989). The following morphological characteristics were measured using a caliper and an electronic scale; straight-line carapace length (CL: mm), plastron length (PL: mm), and body weight (BW: g). To evaluate the overall condition of individuals, a body condition index (BCI: BW/CL^3) (Pearson et al., 2015) was calculated. Turtles were marked individually by drilling holes on their marginal scutes. After these treatments, all turtles were released at the original sites of capture.

Results

Species composition of freshwater turtles from 2001 to 2015

From 2001 to 2003, 34–48 red-eared slider and 4–15 Reeves' pond turtle were collected annually. In 2013 and 2015, a total of 157 and 105 red-eared slider and 8 and 23 Reeves' pond turtle were collected annually, respectively (Table 1). None of the individuals marked in 2001 to 2003 were recaptured in 2013 and 2015. In the following analyses, turtles collected in 2001–2003 and 2013 and 2015 were pooled because of small sample sizes in each year. The relative abundance (individuals/trap/day) of both species was significantly higher in 2013 and 2015 (χ^2-test: red-eared slider turtles, $\chi^2=143.1$, $P<0.01$;

Table 1. Species composition and relative abundance of freshwater turtles at the Kahokugata lagoon from 2001 to 2015.

Year	2001	2002	2003	2013	2015
T. s. elegans					
Total collected number	34	41	48	157	105
Number of individuals/trap/day	0.25	0.27	0.64	1.45	0.97
Sex ratio (males/total number of adults)	0.34	0.29	0.31	0.38	0.37
% of juveniles	11.8	26.8	14.6	0.03	0.05
M. reevesii					
Total collected number	10	15	4	8	23
Number of individuals/trap/day	0.07	0.1	0.05	0.07	0.21
Sex ratio (males/total number of adults)	0.7	0.33	0.25	0.5	0.34
% of juveniles	0	0	0	0	0
% of *T. s elegans* in overall captures	77.3	73.2	92.3	95.2	82.0

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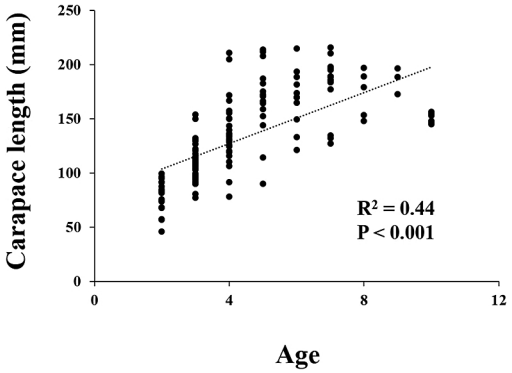


FIG. 1. Relationship between the carapace length (CL) and the age estimated by counting the number of annual rings on scutes based on 140 individuals. CL was positively correlated with the age ($Y=11.7X+80.5$, $R^2=0.43$, $P<0.001$).

Reeves's pond turtles, $\chi^2=16.4$, $P<0.01$). In particular, the abundance of red-eared sliders drastically increased (Table 1). The red-eared slider was collected more frequently than Reeves' pond turtle in both samples ($\chi^2=237.3$, $P<0.01$, Table 1), but species composition in the two pooled samples was not significantly different between the two periods ($P=0.22$). The proportion of juveniles of red-eared slider significantly decreased in 2013 and 2015 (χ^2-test: $\chi^2=17.40$, $P<0.01$). On the other hand, juvenile Reeves' pond turtles were not collected in any year of the study.

Morphological characteristics of the red-eared slider population

By counting scute rings, age was estimated in 140 of 410 red-eared sliders collected. We could not count scute rings for the remaining 370 and regarded these as older individuals. In the 140 samples, carapace length (CL) was positively correlated with the age (Fig. 1). Table 2 shows the morphological characteristics of red-eared sliders during 2001–2003 and 2013–2015. In both males and females, the average of CL, PL, and BW were larger in 2013 and 2015 than in 2001–2003. In particular, CL was remarkably longer, indicating an

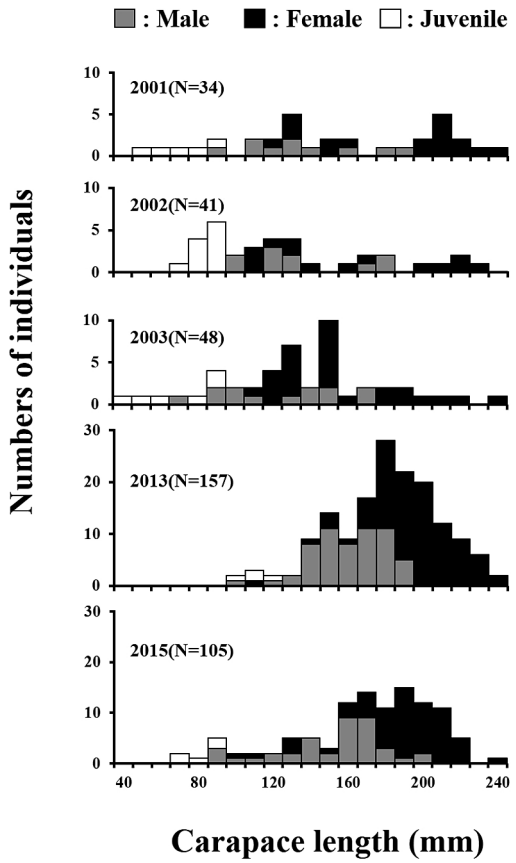


FIG. 2. Frequency distribution of carapace length in the population of the red-eared slider in 2001–2003, and 2013 and 2015.

increase in the mean size of adults. The proportion of adults with a CL of >100 mm increased, whereas that of smaller individuals decreased (Fig. 2). The mean body condition index (BCI) tended to be smaller in 2013 and 2015 (Table 2), and BCI in the individuals with a CL of more 130 mm was significantly different among years, with lower values in 2013 and 2015 (Male: 2001: 1.568±SD 0.803, 2002: 1.416±0.119, 2003: 1.398±0.111, 2013: 1.341±0.105, 2015: 1.374±0.108, $F_{4\,113}=6.60$ $P<0.0001$, Female: 2001: 1.626±0.101, 2002: 1.616±0.097, 2003: 1.578±0.106, 2013: 1.496±0.124, 2015: 1.548±0.107, $F_{4.216}=8.14$, $P<0.0001$, One-way ANOVA). The proportion of melanistic males was remarkably

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Table 2. Morphological measurements of the red-eared slider turtle from 2001 to 2015. CL, carapace length; PL, plastron length; BW, body weight; BCI, body condition index. Average±SD was shown in each variable. All variables were significantly different among years (One-way ANOVA; see text for further details).

Year	N	CL (mm)	PL (mm)	BW (g)	BCI×10^4
Male					
2001	10	141.7±29.6	129.6±25.4	500.5±280.2	1.604±0.124
2002	10	139.0±30.0	130.9±28.7	441.0±265.4	1.498±0.145
2003	13	129.7±29.6	119.1±26.6	358.5±200.3	1.489±0.139
2013	58	166.1±18.5	150.6±18.0	637.0±198.8	1.345±0.109
2015	40	157.4±27.8	142.1±25.1	586.2±258.7	1.412±0.134
F		7.6	6.2	4.66	12.03
P		<0.001	<0.001	0.0015	<0.001
Female					
2001	19	186.9±39.4	174.7±36.7	1192.1±638.8	1.632±0.101
2002	14	165.2±44.4	153.9±43.1	903.2±664.9	1.654±0.156
2003	28	159.0±33.1	148.3±30.9	719.3±484.2	1.587±0.102
2013	95	200.1±21.7	185.6±19.4	1237.8±383.6	1.494±0.126
2015	63	193.2±27.1	180.8±25.3	1182.6±436.5	1.552±0.108
F		13.82	13.22	7.88	10.66
P		<0.001	<0.001	<0.001	<0.001

Table 3. Number and percentage of melanistic males in the red-eared slider population.

Year	2001	2002	2003	2013	2015
N	10	10	13	58	40
Number of melanistic males	2	2	1	34	19
Percentage	20.0	20.0	7.7	58.6	47.5

higher in the pooled sample of 2013–2015 than in 2001–2003 (χ^2-test: $\chi^2=59.2$, $P<0.01$, Table 3).

Discussion

At the Kahokugata lagoon, the red-eared slider was the dominant turtle species both in the 2001–2003 and 2013–2015 samples, indicating its long persistence there. However, our long-term research revealed that age structure of the red-eared slider populations changed over 15 years. In 2013–2015, it mainly consisted of older individuals, with a relatively smaller number of juveniles. This may be due to decreased reproductive output and limited juvenile recruitment. Taniguchi et al. (2017) reported that adult body size of red-eared slider populations in Japan was relatively smaller than those in the native populations in the USA, perhaps because of earlier maturation in the former country. This implies that population growth of red-eared sliders can be affected by biotic and abiotic factors in the sites where they have been introduced, resulting in differences in the population characteristics.

One plausible factor causing a potential decrease of juvenile recruitment and low reproductive output in Kahokugata lagoon is

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intraspecific competition. In general, resource competition among individuals is likely to occur in a high-density population (Krebs, 1994). In the case of invasive species, explosive population growth can lead to lower reproductive potential and higher mortality of individuals because of the carrying capacity of a species in an environment. For example, in the northern snakehead, *Channa argus*, also introduced into Japanese wetlands, population growth was limited despite its wide range expansion (Maehata, 2002). At our study site, the number of turtles collected in the recent years was comparable to many other populations in central and western Japan (Taniguchi and Kamezaki, 2010; Kato et al., 2014). The extreme high-density may have enhanced intraspecific competition. Competition for food resources may have had impacts on the population. In red-eared sliders, juvenile mainly consume small animals, although they shift to a diet with more plant materials as they grow (Clark and Gibbons, 1969; Hart, 1983). The growth and survival rates of juveniles may be limited due to the competition for living prey among juveniles. The decline in BCI over time further supports enhancement of the competition for food resources among old individuals.

The effects of other organisms appear to be a factor limiting juvenile recruitment and the reproductive output. In the Point Pelee National Park of Ontario, Canada, the size structure for populations of Blanding's turtles, *Emydoidea blandingii*, and snapping turtles, *Chelydra serpentina*, shifted toward larger individuals dominated by older turtles during the period from 1972–1973 to 2001–2002 (Browne and Hecnar 2007). Juvenile recruitment at this site was limited over the past 30 years due to frequent predation of eggs in turtle nests by a dense population of raccoons, *Procyon lotor*. Predation on the nests of red-eared sliders and other turtles has also been reported in Japan (Noda, 2004; Shimada and Togari, 2008). In Ishikawa Prefectures, raccoons have extended their range to Kanazawa City near the Kahokugata lagoon (Ishikawa Prefecture Natural Environments Section, 2014). We consider that the change in age structure in our red-eared slider population may be also caused by raccoon predation but further research is necessary to confirm our hypothesis.

The population dynamics and stability of red-eared sliders can be affected by various factors, especially when they are widespread at introduced sites. Therefore, for effective control, it may be important to accurately understand the present conditions of the population. In Japan, the control of red-eared sliders has been attempted by public administrations and citizen groups (Kamezaki, 2015). However, control activities can often be costly, and it is uncertain yet whether red-eared sliders can be effectively reduced. Our long-term data suggest that the age structure of populations changes over time and it should be understood before control activities are started. If a population is composed of many juveniles, it may be effective to remove more juveniles than adults to restrict the population growth. On the contrary, if it is mainly composed of older turtles, all individuals of any size classes should be collected. Thus, the data of our study can be applied for the planning of control efforts.

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