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Short Notes

Predation of a Rare Arboreal Land Snail *Euhadra brandtii sapporo* by Introduced Common Raccoon *Procyon lotor*

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Introduced species are one of the primary threats to biological diversity. Their invasion often yields serious negative impacts on endemic biota through competition for resources, habitat alterations, parasitism, disease, and predation (Wonham, 2006; Hunter & Gibbs, 2007). Predation by introduced animals has been a major cause of the decline of land snails. In the Southeast Pacific region, the exotic carnivorous land snail *Euglandina rosea* exterminated 56 of the 61 endemic arboreal land snails after its introduction in a biological control program targeting the giant African snail, *Achatina fulica* (Coote & Loeve, 2003). In the Bonin Islands, Japan, the introduced rat *Rattus rattus* severely preys upon native land snail species, which have extensively radiated throughout a unique evolutionary history (Chiba, 2009). *Platydemus manokwari*, a flatworm originating from New Guinea Island, has spread to many regions in the world, killing native land snails and thereby being listed among the world's 100 worst invasive alien species (Lowe *et al*., 2000).

Although land snails are one of the most diverse and imperiled groups of animals, they tend to draw relatively little attention from researchers and the public (Lydeard *et al*., 2004; Parkyn & Newell, 2013). Especially little information is available on arboreal land snails because it is difficult to observe these species in high forest canopies. *Euhadra brandtii sapporo* is an arboreal land snail that is mainly distributed in southwestern Hokkaido, Japan (Environmental Agency of Japan, 1993). This taxon is designated as near threatened (NT) in the national red list due to its restricted geographic range (Ministry of the Environment, 2012). To gather life-history information on this snail, we were investigating its natural predators in canopies and on the ground by using a manipulative field experiment. During the experiment, we unexpectedly found the exotic common raccoon (*Procyon lotor*) preying on *E. brandtii sapporo*. Here, we report this incident as a reference for future conservation and management.

Materials and Methods

The study was conducted in the Tomakomai Experimental Forest (TOEF), Hokkaido University, Japan. This research station is located at 42.68°N and 141.60°E (20–90 m elevation). The average annual temperature and precipitation are 6.7°C and 1,112 mm, respectively (TOEF, 2016). The site is within the cool-temperate deciduous forest zone. The most dominant tree species is *Quercus crispula* Blume, associated with *Acer pictum* Thunb. subsp. *mono* (Maxim.) H. Ohashi, *Acer amoenum* Carrière, *Magnolia obovata* Thunb., and *Tilia japonica* (Miq.) Simonk.

To investigate predators of *E. brandtii sapporo*, we performed a field experiment. On 7 June 2015, we collected 48 mature individuals of *E. brandtii sapporo* at a natural deciduous forest in TOEF. The collected individuals were immediately brought to a laboratory, and an approximately 50-cm length of cotton string and a number label were attached with glue on the shell of each individual. These individuals were stored in plastic cases at room temperature until the glue dried. The samples were then brought to a natural forest stand in TOEF, and

Fig. 1. Experimental system to monitor predators of *Euhadra brandtii sapporo* in tree canopies (A) and on the ground (B). **A**. Tethered individuals (left, white arrow) and automatic infrared sensor camera (right) were set on the study tree at a 10-m height in the forest canopy. **B**. Tethered individuals on the ground that were placed approximately 5 m from the study tree.

a *M. obovata* (diameter at breast height, 26.8 cm; hereafter tree no. 1), an *A. amoenum* (39.2 cm; tree no. 2), and a *Q. crispula* (85.1 cm; tree no. 3) were selected as study trees. These trees grow naturally with a height range from 15 to 20 m in the approximately 300-year-old natural forest in TOEF. One of the authors (IS) climbed the study trees by using the single rope techniques (Ishii, 2000; Lowman *et al*., 2012), and eight individuals of *E. brandtii sapporo* were tethered on the trunk of each of the study trees at ca. 10-m height (Fig. 1a). Then, an automatic infrared sensor camera (HGC SG-007, Shenzhen Siyuan Digital Technology, China) was set to monitor whether any predation events occurred on the tethered individuals. As a reference, we also tethered *E. brandtii sapporo* individuals on the ground. Eight individuals were secured with the cotton string, short sticks, and clips around each of the study trees (Fig. 1b). These individuals were placed 3 to 5 m from each other, and one sensor camera was set to monitor one individual per study tree.

This monitoring extended from 11 to 25 June 2015 (15 days). On the ground, we visited the study site every 2 to 3 days and checked the survival of tethered individuals. When the individual monitored by the camera had died, we changed the camera location to monitor another live individual. On the last day of the experiment, we retrieved the tethered individuals and assessed their survival. On the same day, the sensor cameras were removed, and video data were examined. During the experiments, some individuals escaped from the strings, and thus the survival rates were calculated after excluding those individuals. We were able to determine whether the individuals escaped or were predated because when they were predated, the strings were cut or broken shells were left. The proportions of living and dead individuals were compared between the canopy and ground treatments for each study tree by using Fisher's exact test.

All the experiments and collections were performed in accordance with the Institutional Policy on Animal Experimentation of the University of Tsukuba. Based on an earlier population census (Saeki, 2015), we estimated the number of *E. brandtii sapporo* in the entire area of TOEF as about 5 million. Thus, we assumed that our sampling had little effect on the long-term population vulnerability of *E. brandtii sapporo*.

Results and Discussion

In canopies, survival rates at the end of the experiment were 0.83, 1.00, and 0 at trees no. 1, 2, and 3, respectively (Table 1). We found one individual dead in the canopy of tree no. 1. Its shell was partially broken, but we could not determine the cause of death because there were no informative data recorded in the camera on tree no. 1. On tree no. 2, a bird (*Parus minor*) and a squirrel (*Sciurus vulgaris orientis*) were recorded in the video, but they did not prey on *E. brandtii sapporo*. On tree no. 3, all the tethered individuals were missing at the end of the experiment. We examined the video and found that a common raccoon preyed on all the individuals (Fig. 2; Supplemental Material). This finding indicates that common raccoons can climb trees at such a height (*i.e*., 10 m) and prey on native arboreal land snails very quickly.

Table 1. Survival rate of *Euhadra brandtii sapporo* tethered in the forest canopy and on the ground.

Tree no.	Tree species	Canopy			Ground		
		No. of tethered individuals[1)]	No. of surviving individuals[2)]	Survival rate	No. of tethered individuals[1)]	No. of surviving individuals[2)]	Survival rate
1	*Magnolia obovata*	6	5	0.83	7	0	0
2	*Acer amoenum*	6	6	1.00	3	0	0
3	*Quercus crispula*	8	0	0	8	2	0.25
Average		6.7	3.7	0.61	6.0	0.7	0.08

1) The number of tethered individuals was eight at the beginning of the experiment, but three and seven individuals escaped from the strings at tree no. 1 and 2 during the experiment, respectively.
2) The number of surviving individuals after 15 days since the experiment started.

Fig. 2. Predation of *Euhadra brandtii sapporo* by common raccoon in the forest canopy (June 15, 2015, Tomakomai Experimental Forest, Hokkaido University, Japan). Refer to Supplemental Material for movies of raccoon predation events.

On the ground, survival rates were generally low. The survival rate near tree no. 3 was 0.25, and it was 0 for the other trees (Table 1). In total, 16 of the 18 samples were dead at the end of the experiment. By checking the video data, we found that native raccoon dogs (*Nyctereutes procyonoides*) fed on *E. brandtii sapporo*. Such scenes were recorded four times during the experiment (three times at tree no. 1 and once at tree no. 3). Shells of the predated individuals were completely broken, and similar predation marks were found in 7 of the 18 sample individuals. The rest of the dead individuals did not have obvious predation marks, and their causes of death are unknown.

Based on Fisher's exact test, the proportions of living and dead individuals were significantly different between the canopy and ground treatments for tree no. 1 ($p<0.01$) and tree no. 2 ($p<0.02$), but not for tree no. 3 ($p>0.4$).

Procyon lotor is native to North America; it was introduced to Japan in 1962 (National Institute for Environmental Studies, 2016). Since its introduction, this species has continuously enlarged its distribution and is now listed as a target species of the Invasive Alien Species Act. The first introduction to Hokkaido Island was in 1979 in Eniwa city (Ikeda, 1999), which is located about 20 km away from the study site. The number of common raccoons on Hokkaido has dramatically increased during the last 10 years (*i.e.*, 1469 trapped individuals in 2004 vs. 6933 in 2014; Hokkaido Government, 2016). The diet of common raccoons is diverse and contains agricultural grain, leaves and fruits of wild plants, fish, amphibians, reptiles, birds, mammals, insects, and aquatic mollusks (Greenwood, 1982; Suzuki *et al*., 2003; Hori, 2014; Takatsuki *et al*., 2014). Yet, to our knowledge, this is the first report describing predation of arboreal land snails in trees by introduced common raccoons.

Our experimental method of tethering eight individuals within a relatively small area on a tree may have increased the predation rate by common raccoons in the canopy, because once one individual was found the others would likely be predated as well. Based on our observations, however, *E. brandtii sapporo* often occurs at high densities on tree trunks. Thus, we expect that the risk of predation by common raccoons is also high under natural conditions in the forest.

Globally, there are numerous species of land snails living in canopies (*e.g.*, Chiba 1999; Schilthuizen & Rutjes, 2001). One of the reasons for such arboreal behavior is the avoidance of predation by terrestrial animals (Shattuck & Williams, 2010). Because trees no. 1 and 2 showed much higher survival rates of *E. brandtii sapporo* than on the ground (Table 1), an arboreal lifestyle may contribute to reducing the risk of predation by ground-dwelling predators. However, our finding implies that the introduction of non-native arboreal predators may render the adaptation ineffective. Because arboreal land snails are widely distributed in the other regions of Japan (Ministry of the Environment, 2012), similar predation risks are likely present where common raccoons were introduced. Programs to eradicate introduced common raccoons have been conducted in many places (Ministry of the Environment, 2011). Our findings show that such efforts are important to conserve not only ground-dwelling but also arboreal endemic fauna, which cannot be easily observed by humans.

Supplemental Material

Movies of predation of *Euhadra brandtii sapporo* by common raccoon.
https://youtu.be/uYHOVh1IVDw; https://youtu.be/0zQ-5-gm-1s; https://youtu.be/3TIOvrN-8zw

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外来生物アライグマによる樹上でのサッポロマイマイの捕食行動

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要　約

陸産貝類は，世界的にきわめて高い多様性をもつ生物種群である。しかし，外来生物の侵入により，その多くは絶滅の危機にさらされている。一方，樹上に生息する陸産貝類については，観察の難しさなどから，生態や外来生物の影響などに関する知見が乏しい。そこでわたしたちは，樹上性カタツムリであるサッポロマイマイ（*Euhadra brandtii sapporo*）の捕食者相を調べることとした。調査は，北海道大学苫小牧研究林にて行った。調査木を 3 本選び，約 50 cm の糸をつけたサッポロマイマイを 8 個体ずつ，高さ約 10 m の樹上と，地表とに固定し，赤外線自動センサーカメラによって 15 日間観察した。樹上では，1 本の調査木において，アライグマがサッポロマイマイを捕食する映像が撮影された。しかしその他の調査木では，捕食による死亡は確認できず，生存率は 80％以上であった。一方，地表に固定したサッポロマイマイの生存率は 0～25％であった。ビデオ映像から，地表ではタヌキによって捕食され死亡したサッポロマイマイが少なくとも 4 個体あることが確認された。これらの結果から，(1) サッポロマイマイが樹上で生活することは，地上の捕食者から逃れ，生存率を高める効果があること，(2) しかしアライグマが侵入すると，樹上にいても捕食され，死亡するリスクが高まることが示唆された。アライグマは，特定外来生物に指定されており，多くの在来種を捕食することが知られている。しかし，観察の難しい樹上性生物への影響は見過ごされやすいと考えられ，注意が必要である。