

Rapid Communication**Report of *Sternotherus carinatus* (Gray, 1856), an invasive species traded as a pet, observed in the wild in South Korea**Seung-Min Park¹, Seung Ju Cheon², Jae Hyeok Choi², Han-Woong Na², Md Mizanur Rahman¹ and Ha-Cheol Sung¹¹Department of Biological Sciences, Chonnam National University, 61186 Gwangju, South Korea²School of Biological Sciences and Biotechnology, Chonnam National University, 61186 Gwangju, South KoreaCorresponding author: Ha-Cheol Sung (shcol2002@jnu.ac.kr)

Citation: Park SM, Cheon SJ, Choi JH, Na HW, Rahman MM, Sung HC (2024) Report of *Sternotherus carinatus* (Gray, 1856), an invasive species traded as a pet, observed in the wild in South Korea. *BioInvasions Records* 13(3): 647–654, <https://doi.org/10.3391/bir.2024.13.3.07>

Received: 3 February 2024**Accepted:** 24 July 2024**Published:** 19 August 2024**Handling editor:** Thomas Evans**Thematic editor:** Tim Adriaens**Copyright:** © Park et al.

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OPEN ACCESS**Abstract**

The razor-backed musk turtle (*Sternotherus carinatus*) is native to the Southwestern United States and is traded as a pet. Currently, turtle species that are traded as pets have been observed in the wild with increasing frequency, and *S. carinatus* is among them. To effectively manage an invasive species, it is necessary to know its distribution. Therefore, in this study, we report a new observation of *S. carinatus*. We captured the turtle in a reservoir in Gwangju, South Korea, and confirmed it to be *S. carinatus* through morphological characteristics and genetic analysis. Our results show that, despite extensive efforts in the management of invasive species, species traded as pets continue to be observed in the wild.

Key words: razor-backed musk turtle; World distribution; management of invasive species; pet trade

Introduction

The razor-backed musk turtle (*Sternotherus carinatus* Gray, 1856) is a species belonging to the family Kinosternidae (Iverson 1979), which includes mud turtles and musk turtles. The musk turtles are named for the foul odor they emit from behind the shell when disturbed (Moll and Dazet 2014). *Sternotherus carinatus*' morphological characteristics include a weakly serrated posterior end of the carapace (Lindeman 2008) and it is a small turtle with an average length of 13–16 cm (van Dijk 2011). Its major habitats are rivers, lakes, and swamps with sandy, gravelly, or pebbly bottoms, and the dead wood in these habitats influences their distribution (Lindeman 2008). While the native range of this turtle is the southern United States (van Dijk 2011), they are traded as pets, and juveniles are particularly popular in East Asia (van Dijk 2011). In 2019, online pet shops in South Korea traded approximately 60,000 won worth of this species (Koo et al. 2020a).

According to the Global Biodiversity Information Facility (GBIF), *S. carinatus* has been confirmed in several regions outside of its native range (GBIF 2024). Therefore, this species is treated as an invasive species (IUCN 2022). Invasive species can pose many problems, including ecosystem disturbance and disease (Jo et al. 2017; Angoh et al. 2021; Martínez-Ríos et al. 2022;

Park et al. 2022a), and recently, substantial economic losses have been confirmed (Cuthbert et al. 2021). To address these challenges, invasive species require management. In South Korea, legal designations and management measures for invasive species are established through risk assessments to ensure proper treatment (Ecosystem-disturbing species, etc.; ME 2020a, b).

Despite ongoing management efforts, invasive turtle species remain a problem in South Korea. Indeed, all reptiles designated as ecosystem disruption organisms in South Korea are turtles (Park et al. 2023a). Remarkably, these turtles have been consistently observed in the South Korean wild (Koo et al. 2017; Park et al. 2022b), and all of them have been confirmed to be traded in Korean online pet shops (Koo et al. 2020a). Moreover, instances of traded species being discovered in the wild are steadily increasing, as documented by recent studies (Ham et al. 2022; Park et al. 2022b).

This steady increase in discoveries underscores the importance of distribution data and monitoring, including novel location and environment reports for existing invasive species as well as new species discoveries, in the conservation of biodiversity (Park et al. 2022a, b). In this study, we focus on a report of *S. carinatus* in Gwangju, South Korea, an area significantly distant from previous records in the species' global distribution.

Materials and methods

On August 23, 2022, the turtle was captured at Yongbong Reservoir (35.183503°N; 126.890733°E) in Gwangju City using a hoop net trap as part of a study on invasive turtle species in the region. It was tentatively identified as *S. carinatus* based on its appearance. Yongbong Reservoir is situated in the central part of the city, serving as a cultural space for residents. It is surrounded by walking paths and is a waterfront park widely used by residents (Figure 1).

To confirm the initial identification, we conducted a DNA analysis on the specimen. We excised a section of the hind limb web (approximately 0.5 cm) using sterilized scissors and placed it in a tube containing alcohol for fixation. We extracted the genomic DNA from the tissue using a Qiagen DNeasy Blood and Tissue gDNA Extraction Kit (Qiagen, Germany). After extraction, polymerase chain reaction (PCR) amplification was conducted using Solg nPfu DNA polymerase (Solgent, South Korea) and a primer pair targeting the *Cytb* (cytochrome B) gene (Table 1). We amplified samples in 20 µL reactions containing 0.5 µL of Pfu enzyme, 2 µL of 10x buffer, 0.4 µL of 10 mM DNTP, 0.8 µL each of Primer_F and Primer_R, 1 µL of genomic DNA, and 14.8 µL of sterilized distilled water. Cycling parameters included an initial 5 min denaturing period at 95 °C; 35 cycles of denaturing at 95 °C for 40 s, annealing at 53 °C for 40 s, and extension at 72 °C for 1 min; and a final 10 min extension period at 72 °C. The amplified DNA sequences were compared with the sequences uploaded to GenBank through the BlastN algorithm provided by the National Center for Biotechnology Information

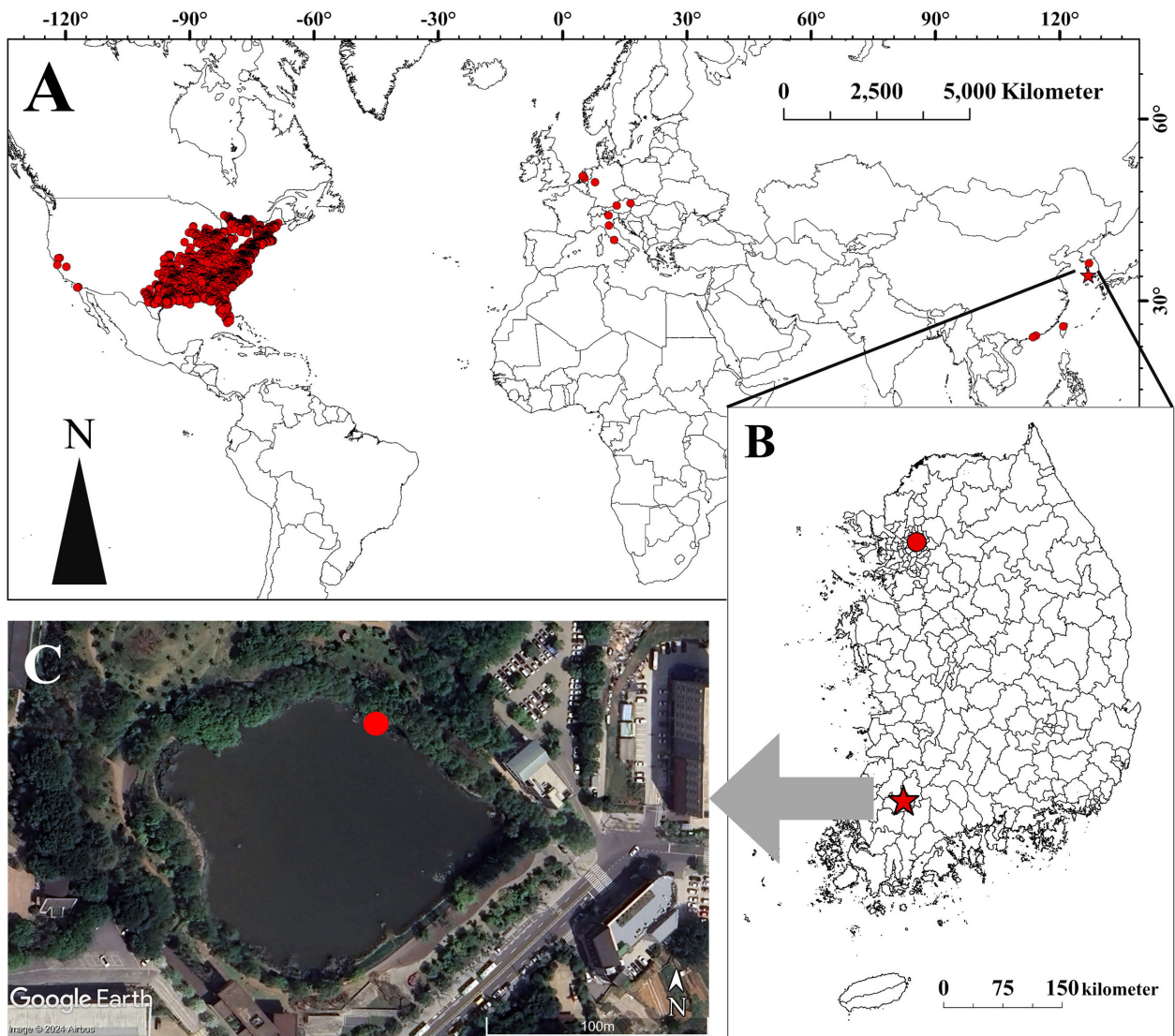


Figure 1. The global distribution of species in the genus *Sternotherus* and the locations of *Sternotherus carinatus* observations in South Korea, including the observation in our report (red star). A: All observations of species of the genus *Sternotherus* from GBIF, distributions outside of the native ranges were confirmed in the European and East Asian regions. B: The locations of the observation reported in this study (red star) and a previous observation (red dot) from GBIF in South Korea. C: An aerial image of the reservoir in which the turtle was captured with a red dot indicating the capture location.

Table 1. COI Primer sequences used for larger grain borer species identification

Maker	Primer name	Primer sequence (5'→3')
<i>Cytb</i>	Primer_F	TGACTTGAARAACCAAYCGTTG
	Primer_R	TCTTCTACTGGTTGTCCTCCGATTCA

(NCBI, USA). We then performed a phylogenetic analysis based on the maximum likelihood method using the sequence generated in the present study and representative *Cytb* sequences of *Sternotherus* species retrieved from GenBank.

Additionally, we collected data on the global distribution of the genus *Sternotherus*. The data were sourced from the GBIF, and occurrence information with “Human Observation,” “Machine Observations,” and “Occurrence” as the basis of the record were collected. Records lacking coordinates or accurate species names were excluded.

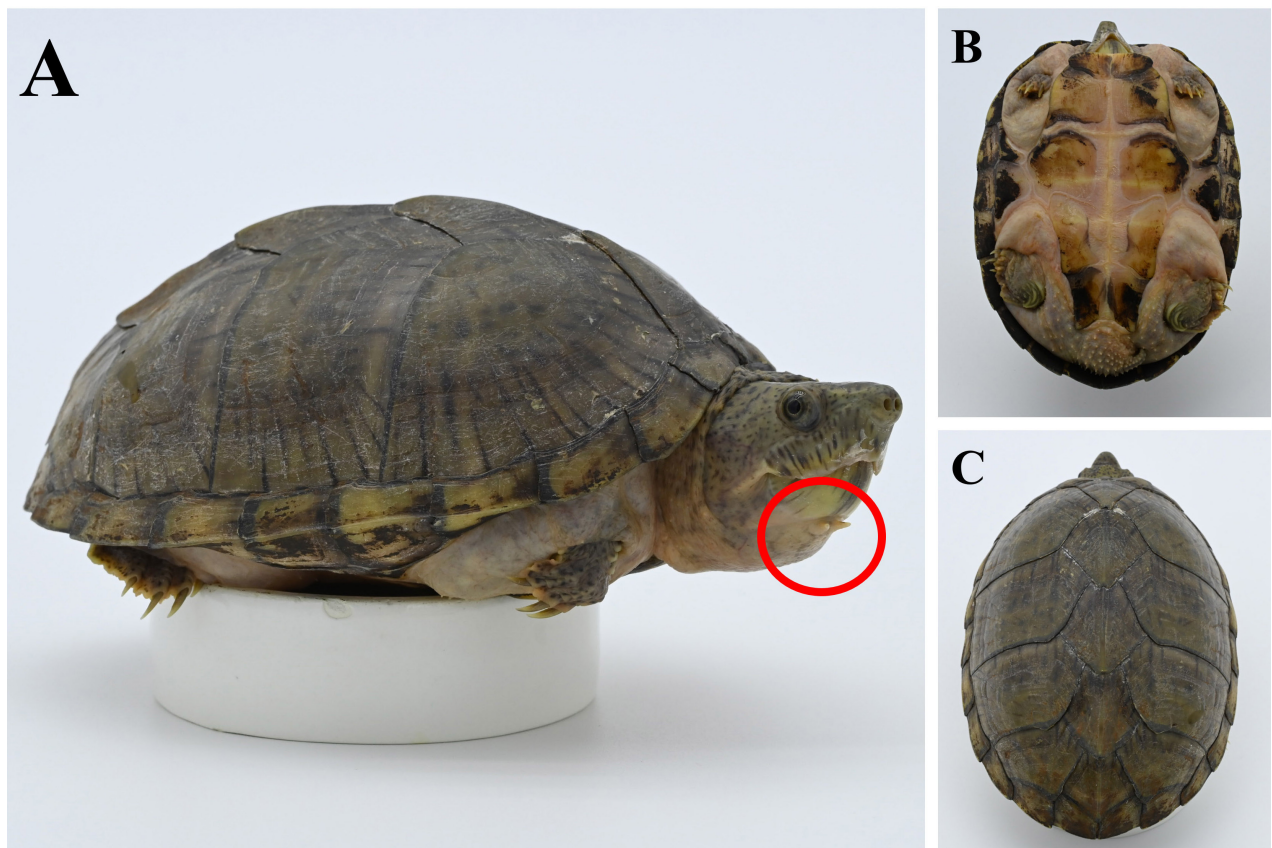


Figure 2. The external morphological features of *Sternotherus carinatus*. A: A side view of *S. carinatus* with a red circle highlighting the barbels on the chin. B: A plastron view confirming 10 scutes on the plastron. C: A carapace view showing the overall yellow-brown coloration. Photographs by SMP

Table 2. COI BlastN search results for the Cytb gene sequence isolated from the turtle found in this study. Included are the most similar sequences of the four closest *Sternotherus* species.

Description	Identity (%)	Accession
<i>Sternotherus carinatus</i> isolate cytochrome b gene. Partial cds mitochondrial	99.89%	MG460029.1
<i>Sternotherus depressus</i> voucher PAS_Sd10 cytochrome b (cytb) gene partial cds mitochondrial	95.38%	KT865020.1
<i>Sternotherus odoratus</i> isolate UAHC16530 cytochrome b gene partial cds mitochondrial	94.62%	MG460016.1
<i>Sternotherus minor minor</i> isolate Sm14066 cytochrome b gene partial cds mitochondrial	93.76%	MG460071.1

Results and discussion

The captured individual's carapace length measured 12.2 cm and plastron length measured 9.8 cm. Based on these measures and external morphological characteristics (overall yellow-brown color, distinct keel, marginal serrations, 10 scutes on the plastron, barbels under the chin; Figure 2), we classified this turtle as *Sternotherus carinatus* (Lindeman 2008). The genetic analysis revealed a high degree of similarity (99.89%) between the captured turtle's Cytb gene sequence and that of *S. carinatus* MG460029.1 (Table 2). In the phylogenetic analysis, our specimen was clearly distinguishable from *S. depressus* and *S. minor* sequences and grouped closely with *S. carinatus* sequences (Figure 3). Thus, based on both external morphological features and the genetic analysis, the captured individual was definitively identified as *S. carinatus* (razor-backed musk turtle).

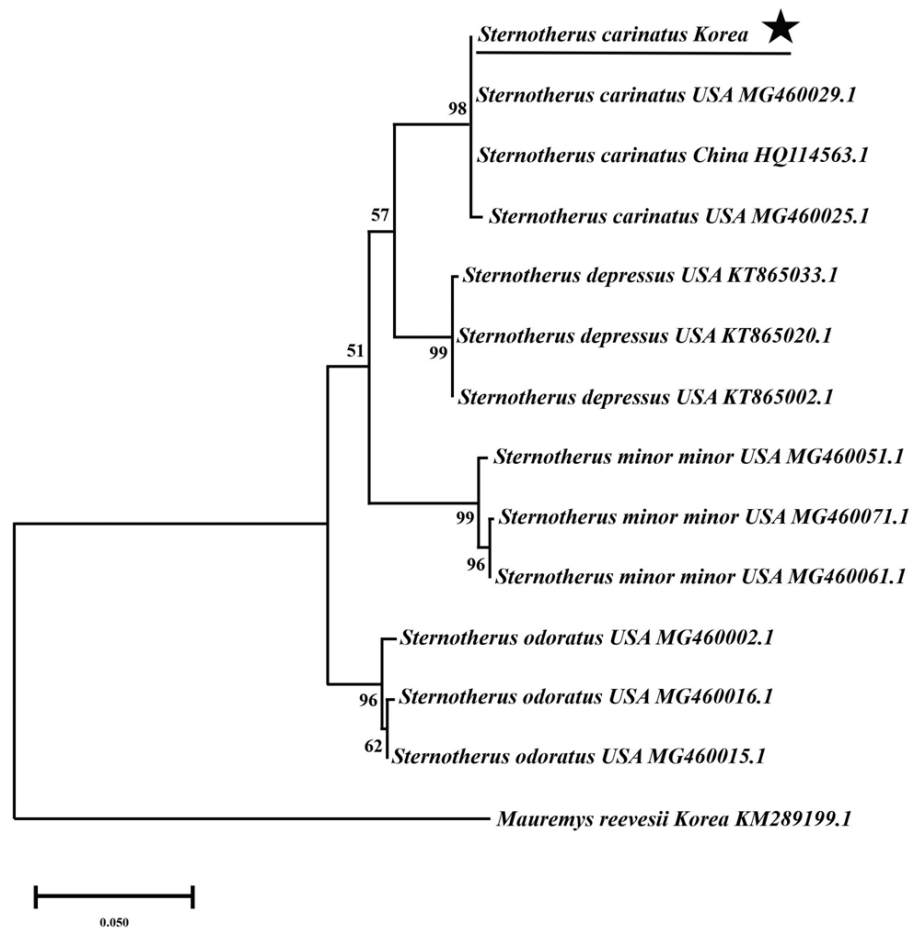


Figure 3. Maximum likelihood (ML) tree of *Sternotherus* based on Cytb gene sequences. The sequence marked with a star represents the focal turtle in the present study

After vetting the GBIF data, a total of 6,366 observations were collected (GBIF 2024). The identified species observations included 5,195 *S. odoratus*, 574 *S. carinatus*, 279 *S. minor*, 315 *S. peltifer*, and 3 *S. depressus*. Out of the total observations, 6,354 were exclusively from their native ranges in North America, while 8 were found in Europe and 4 in East Asia. The species identified in the European region were *S. odoratus*, *S. carinatus*, and *S. minor*, with only *S. carinatus* observed in both Europe and East Asia (Figure 1A). The genus *Sternotherus* is currently classified into six species, all of which are native to the North American continent (Scott et al. 2018). Scott et al. (2018) introduced *S. intermedius* as a new species based on phylogenetic and morphological characteristics and its habitat. The GBIF records we collected only confirmed five species, excluding *S. intermedius*. Consequently, there is no indication of the new species' range. *Sternotherus carinatus* is distinguished from the other five species by its high carapace, a pair of barbels on the chin, the absence of stripes on the head and limbs, distinctive black dots, and 10 scutes on the plastron (Lindeman 2008).

Sternotherus carinatus is considered an invasive species in South Korea. Moreover, its trade in online pet shops has been confirmed (Koo et al. 2020a), and it is possible that someone who had been keeping the individual in this

study as a pet released it into the wild for some reason. According to the GBIF distribution data, *S. carinatus* is observed in Hong Kong (HK), Macau (MO), Taiwan (TW), South Korea (KR), and Italy (IT), and our report only reaffirms this. Previous research indicates the popularity of *S. carinatus* juveniles, in particular, as pets in East Asian pet shops (van Dijk 2011). This may explain why this species appears to be uniquely found as an invasive species in East Asia. Notably, this is the second reported case in Korea, highlighting the need for continuous monitoring to understand the distribution of the species.

Sternotherus carinatus, like other species confirmed to be sold in pet shops (Koo et al. 2020a), is increasingly being discovered in the wild. Reasons for such observations include escape from captivity and abandonment (Oh and Hong 2007), a trend described in recent findings as well (Ham et al. 2022; Park et al. 2022b). The turtle species reported in this study is among the commonly traded species (Koo et al. 2020a), and the majority of recently discovered alien species in the wild are also turtles (Koo et al. 2020b, 2021; Park et al. 2022b, 2023b). In fact, recent reports even indicate instances of wild reproduction by alien species (Koo et al. 2023; Cheon et al. 2023), raising concerns about their establishment (Kopecký et al. 2013). Reflecting this serious situation, the Ministry of Environment in Korea categorizes introduced alien species as “Ecosystem disruption organisms,” “species with potential risks to the ecosystem,” and “species of concern for domestic inflow” (Ministry of Environment 2020a, b). Nevertheless, along with the species reported in this study, *Pseudemys penisularis* (Cheon et al. 2023) and *Chrysemy* spp. (Park et al. 2023b), are not included in the legally managed species. Still, these species are traded in the pet industry and are increasingly being found in the wild. These issues emphasize the need for a registration system governing the importation of exotic creatures and pets.

In conclusion, this study reports a new record and highlights previous records of the invasive species *Sternotherus carinatus*, a species that is traded as a pet and has an identified global distribution. Therefore, continuous monitoring is essential to verify and track its distribution, and effective management strategies for this invasive species are warranted.

Authors' contribution

JHC and HWN contributed to the investigation and individual capture. SJC contributed all DNA analysis. SMP and MMR identified the specimen and wrote all draft of the manuscript. HCS contributed all processes and supervised. All authors read and approved the final version of the manuscript.

Acknowledgments

We are grateful to anonymous reviewers and editors for their valuable comments on our manuscript.

Funding declaration

This work was supported by Korea Environment Industry & Technology Institute (KEITI) through Exotic Invasive Species Management Program, funded by Korea Ministry of Environment (MOE)(RS-2018-KE000335).

Ethics and permits

This study was conducted with permission from the Animal Experiment Ethics Committee of Chonnam National University (CNU IACUC-YB-2024-7).

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