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Data Paper

Species list and distribution of non-native freshwater turtles in Hong Kong

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Abstract

Freshwater turtles have been introduced to a diversity of environments worldwide, sometimes leading to devastating impacts on native biodiversity and ecosystems. Documentation of species and distribution of non-native turtles is needed to effectively manage potentially invasive turtles. Here, we compiled a species list and distribution map of non-native turtles found in Hong Kong by combining field survey data, anecdotal records made by naturalists, and citizen science data. We collected 696 records, involving 25 pure species and three putative hybrids distributed widely throughout Hong Kong. The red-eared slider (*Trachemys scripta elegans*), listed as one of the world's 100 worst invasive alien species, was the most frequently recorded species. Most, if not all, non-native turtles were probably released intentionally, as abandoned pets or in religious release. We urge for strengthening legal regulation and developing measures to stop intentional release, particularly religious release.

Key words: Chelonians, hybrids, checklist, invasive species, mercy release, wildlife trade

Introduction

Globally, non-native freshwater turtles have been introduced, accidentally or deliberately, to a diversity of habitats. The red-eared slider (*Trachemys scripta elegans*) (hereafter RES), native to the southern United States and northern Mexico, is a popular pet which can be found introduced across the globe except on the continent of Antarctica (Ramsay et al. 2007). This species is listed as one of the world's 100 most invasive alien species (Lowe et al. 2000) and the most invasive reptile species (Kraus 2009) because it may harm native biodiversity and ecosystems through competition, hybridization, and transmission of parasites/disease (Cadi and Joly 2003; Spinks et al. 2003; Polo-Cavia et al. 2010; Kraus 2015; Meyer et al. 2015; Pearson et al. 2015; Héritier et al. 2017; Ma and Shi 2017; Demkowska-Kutrzepa et al. 2018; Lambert et al. 2019). Outside of their native range, RES can impact habitats on a higher level by disrupting plant communities (Ramsay et al. 2007) and hampering ecosystem functioning (Lindsay et al. 2013).

Other freshwater turtle species are also widely introduced into the environment outside of their native ranges (Lin et al. 2015; Lee et al. 2016). Some species, such as the common snapping turtle (*Chelydra serpentina*), have high invasive potential, and may pose similar threats to ecosystems as RES do (Lee et al. 2019), but little is known about the population status and ecological impacts of these non-native species at introduction sites.

Here, a species list and a distribution map of non-native freshwater turtles in Hong Kong was compiled using data collected from field surveys, anecdotal records by naturalists, and citizen scientist data. There are two major sources of non-native turtles, abandoned pets and turtles purchased from markets for the mercy release (Kraus 2009; Liu et al. 2013; Bush et al. 2014; Maceda-Veiga et al. 2019). Hong Kong is a hotspot of non-native turtles because it is a major trade hub of turtles, with over a third of all turtle species sold in the pet and food markets (Cheung and Dudgeon 2006; Sung and Fong 2018). Documenting records of non-native turtles, including species and distribution, provides insights on their introduction pathways and potential ecological impacts on native ecosystems, which help inform policies and formulate control and management measures.

Materials and methods

We used three methods to collect records, including species and location (with geographic coordinates), of non-native turtles. First, we conducted 306 turtle surveys in 87 locations across Hong Kong between 2009 and 2020 following the methods in Sung et al. (2013). In each survey, we placed at least 10 baited hoop traps in various freshwater habitats, including streams, reservoirs, fishponds, and marshes in the afternoon. Traps were retrieved the following morning and the turtles captured were identified and measured. Second, we obtained records by consulting 40 naturalists and ecologists who have over five years of fieldwork experience in Hong Kong. We received records from 11 naturalists and ecologists, nine of which have over 10 years of experience conducting herpetological surveys. For the other two ecologists with less experience of turtle identification, they provided photos to verify the species identity. Lastly, we extracted turtle sighting data from iNaturalist (<http://www.inaturalist.org/>), an online interface collecting natural history sightings from citizens which is openly published online (Ueda 2021). To ensure the validity of records from iNaturalist, we only included records from which species identification was verified by other users. We also excluded records of cultivated or captive turtles and those with positional inaccuracy > 1 km.

All records were identified to species level except for genus *Cyclemys* because most records did not provide sufficient information for species identification by morphology. We followed the taxonomy in Turtle Taxonomy Working Group (2017) and the conservation status of species from Rhodin et al. (2018). As in previous studies (Parham et al. 2001;

Table 1. Number of records of non-native turtles in Hong Kong. Records are ordered based on the total number of records, with highest being first. Underlined taxa indicate putative hybrid individuals. Number in parenthesis shows the number of sites with the species present from interviews and iNaturalist. (Geographical region: AF = Africa, AS = Asia, AU = Australasia, NA = North America, and SA = South America; conservation status: DD = data deficient, LC = least concern, NT = near threatened, VU = vulnerable, EN = endangered, and CR = critically endangered).

Species	Geographical region	Conservation status	Field survey	Interview	iNaturalist	Total
<i>Trachemys scripta elegans</i>	NA	LC	199	76 (51)	226 (55)	501
<i>Mauremys sinensis</i>	AS	EN	18	37 (25)		55
<i>Mauremys mutica</i>	AS	CR		31 (13)		31
<i>Cyclemys</i> sp.	AS	DD/LC/NT/EN	7	17 (6)	2 (2)	26
<i>Palea steindachneri</i>	AS	EN	15	5 (3)		20
<i>Cuora amboinensis</i>	AS	EN	1	11 (5)		12
<i>Chelydra serpentina</i>	NA	LC	1	4 (4)	5 (4)	10
<i>Cuora flavomarginata</i>	AS	CR		5 (5)		5
<i>Indotestudo elongata</i>	AS	CR		5 (5)		5
<i>Cuora galbinifrons</i>	AS	CR		4 (3)		4
<i>Trachemys scripta scripta</i>	NA	LC	1	2 (2)		3
<i>Graptemys pseudogeographica</i>	NA	LC		3 (3)		3
<i>Sacalia quadriocellata</i>	AS	EN	2	1 (1)		3
<i>Sternotherus carinatus</i>	NA	LC		2 (1)		2
<u><i>Cyclemys</i> sp. × <i>Sacalia bealei</i></u>	AS	–	1	1 (1)		2
<i>Carettochelys insculpta</i>	AU	EN		1 (1)		1
<i>Cuora mouhotii</i>	AS	CR		1 (1)		1
<i>Cuora picturata</i>	AS	CR		1 (1)		1
<u><i>Cuora trifasciata</i> × <i>Cuora amboinensis</i></u>	AS	–		1 (1)		1
<i>Heosemys grandis</i>	AS	EN		1 (1)		1
<i>Macrolemys temminckii</i>	NA	VU		1 (1)		1
<i>Mauremys nigricans</i>	AS	CR		1 (1)		1
<u><i>Mauremys reevesii</i> × <i>Mauremys sinensis</i></u>	AS	–		1 (1)		1
<i>Melanochelys trijuga</i>	AS	NT		1 (1)		1
<i>Morenia ocellata</i>	AS	EN		1 (1)		1
<i>Pelusios castaneus</i>	AF	LC		1 (1)		1
<i>Phrynops hilarii</i>	SA	LC		1 (1)		1
<i>Pseudemys concinna</i>	NA	LC			1 (1)	1
<i>Siebenrockiella crassicollis</i>	AS	EN		1 (1)		1

Buskirk et al. 2005; Stuart and Parham 2006; Fong and Chen 2010), we identified putative hybrid turtles based on external morphology as they usually have combined or intermediate morphological characteristics from both parent species. To verify the hybrid status of turtles, it is necessary to incorporate molecular methods (such as Fong and Chen 2010). As the focus of our study is to document the phenomenon of non-native turtle release in Hong Kong, we do not verify hybrids using molecular methods, and thus our discussion regarding these individuals is tentative. As turtles are illegally hunted in Hong Kong and sold into pet and food markets, we refrain from providing detailed species record of field surveys and interviews.

Results

We collected 696 records of non-native turtles, involving 25 species and three putative hybrids in Hong Kong (Table 1). Non-native turtles were found throughout Hong Kong, including all major islands (Figure 1). The most frequently recorded species was RES (33% of records), followed by *Mauremys sinensis* (17%) and *M. mutica* (15%). Among the species found,

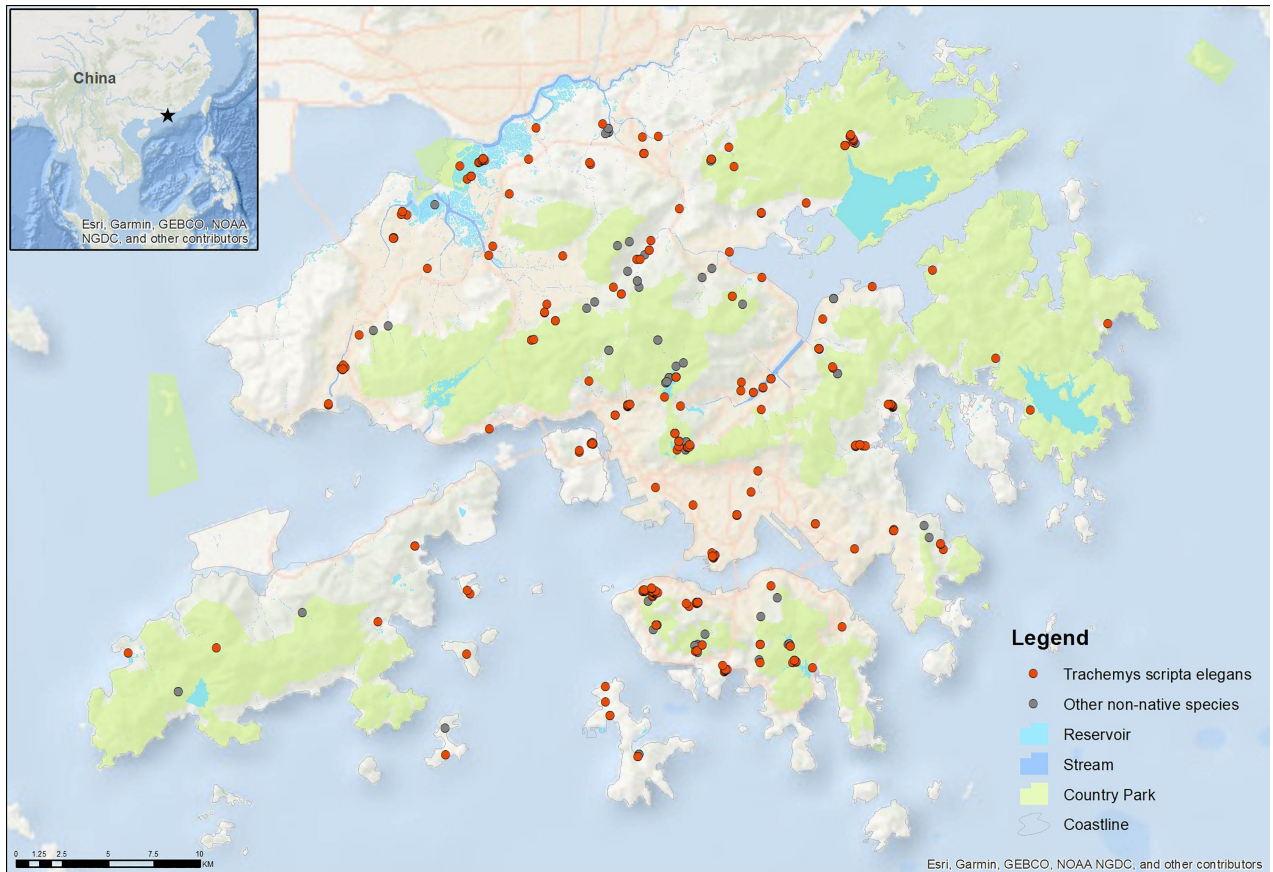


Figure 1. Geographic locations of non-native turtles found in Hong Kong. Records of the red-eared slider (*Trachemys scripta elegans*) are in red and other non-native species are in grey (for details see Supplementary material Table S1).

nearly two thirds (64%, 16 species) were listed in threatened categories, including eight (32% of total species) endangered and seven (28%) critically endangered (Rhodin et al. 2018). All three putative hybrid species involved both native (i.e. *Cuora trifasciata*, *M. reevesii* and *Sacalia bealei*) and non-native species (i.e. *Cu. amboinensis*, *Cyclemys* sp., and *M. sinensis*) (Figure 2).

Discussion

In this study, we recorded 25 species of non-native freshwater turtles in Hong Kong. Given the small size of Hong Kong (1106 km² land area), such non-native diversity is exceptionally high compared to studies in other countries [e.g., including nine species in Korea (Lee et al. 2016; Koo and Sung 2020); four in China (Lin et al. 2015); and four in Portugal (Anastacio et al. 2019)]. We believe that most of the non-native turtles were intentionally released as abandoned pets or in religious releases (Yeung 2018). Accidental release/escape of turtles is probably rare in Hong Kong because outdoor turtle farms are rare in Hong Kong. We suggest that the high diversity of introduced turtles can be, at least partly, attributed to the high volume and diversity of turtles available in the local pet markets, as all species recorded in this study can be found in the local pet market (Sung and Fong 2018).

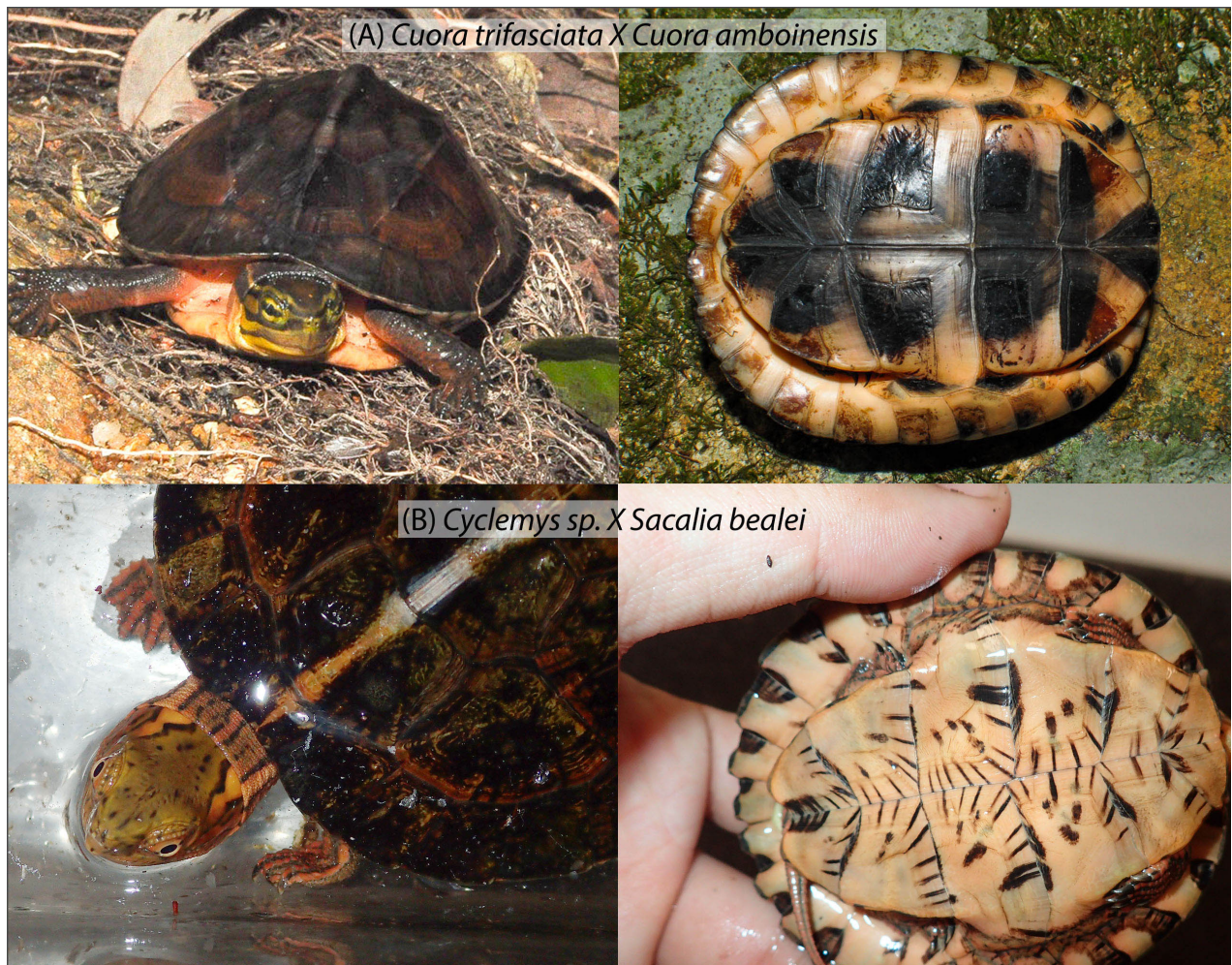


Figure 2. Two putative hybrid individuals found in Hong Kong. Potential parental species were inferred based on morphological features of the hybrid individual: (A) *Cuora trifasciata* × *Cuora amboinensis*, with limb color and carapace and limb color resembling *Cu. trifasciata* and head pattern resembling *Cu. amboinensis*; and (B) *Cycllemys* sp. × *Sacalia bealei*, with carapace and plastron shape resembling *Cycllemys* sp. and spots on back of head (false eye) resembling *S. bealei*. Photographs by Anthony Lau and Yik-Hei Sung.

The wide distribution of non-native turtles indicates that the intentional release of turtles is widespread and common in Hong Kong. Religious release is of particular concern because large number of individuals (up to dozens at a time) of turtles are released at a single location, increasing the chance of establishment (Lockwood et al. 2009). Additionally, welfare of the animals may also be a concern as release of RES, a freshwater species, have been observed occasionally in marine environments (personal observations). From our observations, lower-priced, heavily farmed turtles (e.g. RES and *M. sinensis*) are often involved in religious release. There are currently no laws regulating religious release in Hong Kong. Although cruelty towards animals (e.g. releasing turtles in non-hospitable environments) is punishable to a fine up to US\$25,000 and to imprisonment up to 3 years (Cap. 169. Prevention of Cruelty to Animals Ordinance), this has not been enforced against religious release. We encourage studies to uncover the scale (frequency, location, and species involved) of religious release (Magellan 2020), providing the basis for enacting legislation and formulating management measures prohibiting release (Wasserman et al. 2019).

Additionally, regulation of trade should also be considered in order to reduce market availability of highly invasive species (Liu et al. 2013; Koo and Sung 2020).

As in many other places across the world, RES is prevalent in Hong Kong, inhabiting a wide range of habitats, including urban parks, rivers, streams, reservoirs, agricultural fields, fishponds, and lowland wetlands. The impact this species has on native species can vary between locations. Studies in mainland China indicated that RES compete with native species for food and habitat (Ma and Shi 2017), whereas in Taiwan such competition may be limited (Chen 2006). In Hong Kong, among the five native turtle species, *M. reevesii* and *P. sinensis* occupy similar lentic habitats (e.g. reservoirs, agriculture fields, fishponds, and lowland wetlands) as RES and are thus more likely to compete directly against each other. From our field surveys, RES (> 200 captures) were considerably more abundant than *M. reevesii* and *Pe. sinensis* (< 10 captures for each species), indicating RES may greatly outnumber native species in the wild (YH Sung unpublished data). Given the negative impacts posed to native turtles elsewhere (Ma and Shi 2017; Taniguchi et al. 2017; Lambert et al. 2019) and the similar resources that these turtles exploit (RES and *M. reevesii* are both generalist omnivores, while *Pe. sinensis* is predominantly carnivores), RES may contribute to the rarity of these two native species through competitive exclusion. It should be noted that it is difficult to empirically prove that RES is the cause of the rarity of the two native species because both native species have long been depleted by illegal hunting throughout Hong Kong (Lau et al. 2000; Sung et al. 2013). On the other hand, the presence of large number of non-native RES may make it even more difficult for the depleted native turtle populations to recover.

We recorded three putative hybrid individuals. Although we did not verify the hybrids using molecular methods, we raise potential issues with this phenomenon. The introduction of non-native species may lead to genetic pollution to remnant native populations, exacerbating population decline caused by over-exploitation (Fujii et al. 2014). It is of conservation concern that all putative hybrids found in this study involve a native and non-native species to Hong Kong. Notably, all three individuals were found within the distribution of the putative native parent species (*Cu. trifasciata*, *M. reevesii*, and *S. bealei*). These three native species are heavily hunted and thus listed as endangered or critically endangered (Turtle Taxonomy Working Group 2017; Rhodin et al. 2018). If these individuals are hybrids, the hybridization could have been produced in the wild (i.e. offspring from released non-native and wild native turtles) or in captivity (i.e. human-produced hybrid that was then released). Regardless of how a hybrid is produced, immediate action, such as timely removal of non-native and hybrid individuals from the wild, needs to be considered and taken by respective authorities.

Fifteen of the recorded species are endangered or critically endangered, with populations plummeting in their native range (Rhodin et al. 2018). Conservationists have suggested that, in some cases, non-native populations are useful for the conservation of native populations, for example acting as sources for augmentation and reintroduction (Gibson and Yong 2017). In Hong Kong, *Palea steindachneri* might be a potential candidate for such a purpose because populations are rare in its native range (Wan et al. 2015), and we have observed hatchlings of *Pa. steindachneri*, indicating successful breeding of the introduced populations. Before we use the Hong Kong populations for conservation purposes, we must take the opportunity to study the ecology and natural history of this species because such studies may not be possible in their native ranges because of their rarity. Given many turtle species are on the brink of extinction, the potential conservation value of non-native populations needs to be considered when formulating plans to manage non-native turtles.

In summary, we documented the diversity and distribution of non-native turtles in Hong Kong, highlighting the severity of intentional release of turtles, and we encourage similar studies in other parts of the world so we can understand the global scale of turtle release and their impacts on native turtles. To limit the impact of invasive alien species on local biodiversity and natural habitats, we strongly urge against intentional release of turtles and other wildlife and resources to implement and enforce such legislations and management measures.

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Authors' contribution

Research conceptualization: YHS. Sample design and methodology: YHS. Investigation and data collection: YHS, WHL, MWL, AL, CD and HYY. Data analysis and interpretation: YHS, PPYW and JJF. Ethics approval: YHS. Funding provision: YHS, CD, and JJF. Writing original draft: YHS and JJF. Writing – review and editing: YHS, WHL, MWL, AL, PPYW, CD, HYY, and JJF.

Ethics and permits

We obtained a permit to conduct turtle surveys from the Agriculture, Fisheries and Conservation Department, Hong Kong Government (AF GR CON 09/51 Pt.6).

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Supplementary material

The following supplementary material is available for this article:

Table S1. Geo-referenced records of non-native freshwater turtles in Hong Kong.