


RESEARCH ARTICLE

Hunters' structured questionnaires enhance ecological knowledge and provide circumstantial survival evidence for the world's rarest turtle

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Abstract

1. *Rafetus swinhoei*, a giant softshell turtle from southern China and northern Vietnam, is the rarest turtle species on Earth, and only two individuals are known worldwide (one in the wild). There is very little ecological information for this species, and the remnant distribution remains completely unknown.
2. This article reports for the first time in the international literature the results of a structured questionnaire survey concerning the ecology and distribution of *R. swinhoei* in Vietnam. The standardized questionnaire consisted of 15 questions and was administered to 10 former *Rafetus* hunters with several years of experience in catching this species.
3. There was considerable consensus among the hunters regarding several aspects of the biology of *R. swinhoei*, with special reference to its reproductive and feeding habits. The mean weight of 58 captured individuals was 53 kg, with the majority of individuals weighing 15–40 kg (median = 40 kg) and only 17.2% of individuals weighing more than 100 kg.
4. Based on the hunters' answers, it was established that the population collapse of *R. swinhoei* in Vietnam occurred in two phases: first during the 1980s, when the population size dramatically decreased, and second, at the beginning of the 1990s, when many hunters simultaneously collected multiple individuals from populations already experiencing severe impacts. There was also a general agreement that these turtles became very rare after 1991–92.
5. In total, 90% of the hunters agreed that there should still be wild *R. swinhoei* individuals at their respective sites, and some of the hunters also reported a few recent sightings that they attributed to the target species.
6. As several sites of likely presence were identified, we suggest that extensive trapping should be planned at these sites in future.

KEYWORDS

conservation ecology, former hunters, local ecological knowledge, *Rafetus swinhoei*, Vietnam

1 | INTRODUCTION

The Swinhoe's softshell turtle (*Rafetus swinhoei*) (Figure 1a), one of the largest freshwater turtles in the world, with a maximum weight of 169 kg, is possibly the most threatened turtle species on Earth (Stanford et al., 2018). This species is known historically to inhabit exclusively the Red River in China and Vietnam and the lower Yangtze River floodplain of China, but its current ascertained population size consists of only one wild individual of unknown sex and a single captive male in Suzhou Zoo, China (after the death of the last female on 12 April 2019, mentioned by Stanford et al., 2018). Although recent intensive surveys in Yunnan, China, and Vietnam did not confirm additional wild specimens, several sightings were reported until approximately one decade ago (Stanford et al., 2018), thus providing hope

that additional individuals can still be found in Vietnam (see also http://www.asianturtleprogram.org/pages/resources/Rs_timeline_9Nov18.png). Unfortunately, field research on this species is difficult, given: (i) the wide extension of potentially suitable freshwater habitats in northern Vietnam; (ii) the elusiveness of the species; and (iii) the minimal ecological data available to date. Indeed, only Gray (1873), Heude (1880), and Pritchard (2001, 2005) addressed aspects of the natural history of the species, but no quantitative data were available (reviewed in Bettelheim, 2012).

Questionnaires and social surveys are used increasingly to collect data in ecology and conservation biology (White, Jennings, Renwick, & Barker, 2005). For instance, the likely presence, local distribution, and even apparent population trends (declining, stable, increasing) of several species of conservation concern have often been explored by face-to-face interviews with hunters, fishers, and other experienced local people (Hellier, Newton, & Gaona, 1999; Padmanaba & Sheil, 2007; Padmanaba, Sheil, & Basuki, 2013; Turvey et al., 2015). Face-to-face interview methodology with experienced local people has proved very useful in discovering previously unknown species (for examples of primates and fishes, see Lorini & Persson, 1990; Mourão & Barbosa Filho, 2018), including a presumed extinct species of large freshwater softshell turtle species in East Africa (Demaya et al., 2019; Demaya et al.,). Any type of ecological information collected via interviews with local communities is defined in the scientific literature as local ecological knowledge (LEK) and, by definition, does not have the scientific validity of data collected directly by scientists; therefore, conservation managers must accept that uncertainty is inherent in any interpretation of LEK (Turvey et al., 2015). Indeed, it may be difficult to verify the trustworthiness of answers provided by informants (Moro et al., 2013; Roberts, Elphick, & Reed, 2009) given that there is a well-known tendency for interviewees to say what they think the interviewers want to hear instead of what they really think (Gomm, 2004), as well as other confounding factors (Jenkins et al., 2011; Knapp, Rentsch, Schmitt, Lewis, & Polasky, 2010).

When using LEK in conservation biology, the application of standardized questionnaires to selected participants is preferable over 'free interviews', for several reasons (Sauro & Lewis, 2016). First, the reliability of the responses may be quantitatively estimated basically by the repeatability of the questionnaire, i.e. how consistent the responses are to the questions. Second, the sensitivity increases with the number of respondents, as even poorly worded questions can detect differences between true and untrue responses with a large sample size of respondents. Third, the objectivity is higher than that noted in informal interviews because standardized questionnaires allow external users (for instance conservation practitioners) to verify independently the measurement statements of the interviewers. Fourth, standardization also allows a finer grain of reporting and statistical analysis than non-structured interviews.

To gather data on the distribution and natural history of this almost extinct species, non-standardized interviews with local people have been repeatedly used by earlier authorities. For instance, Pritchard (2001, 2005) recorded multiple anecdotal accounts describing the capture of this species by local fishers and traders, and skeletal

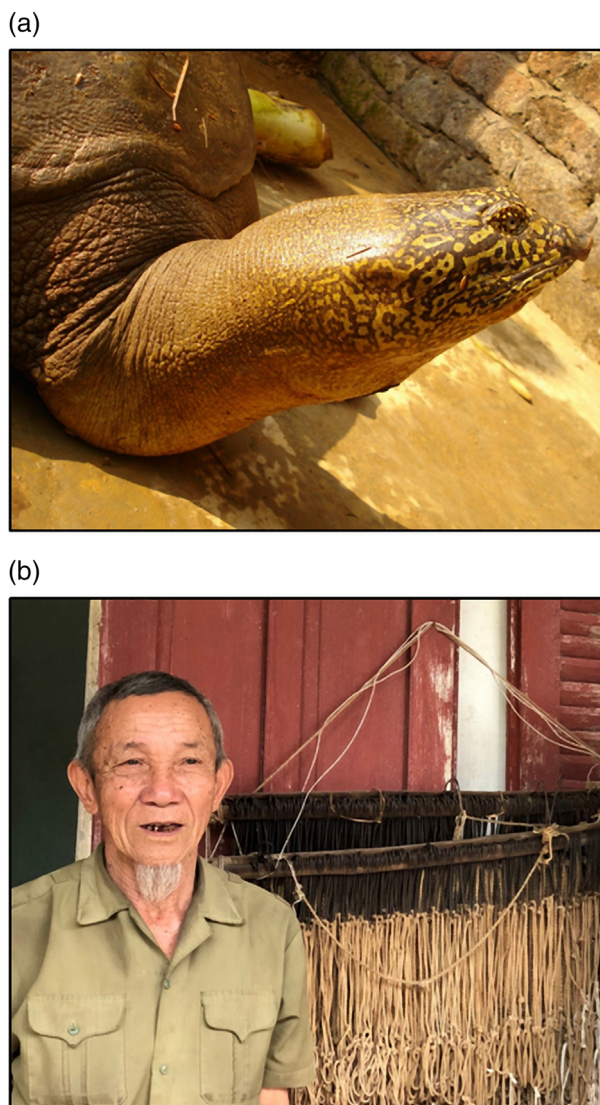


FIGURE 1 (a) *Rafetus swinhoei* rescued and released back to Dong Mo Lake in 2008. (b) A hunter with his own fishhook lines used to catch many *Rafetus* individuals in the past. Photo credits: Hoang Van Thai and Olivier Le Duc

remains kept as trophies confirmed the accounts received. Jian, Hai-Tao, Cheng, and Lian-Xian (2013) provided a description of habitat characteristics in southern China obtained from indirect LEK information, and the Asian Turtle Program has also been conducting interviews about this species in Vietnam (www.asianturtleprogram.org). Structured interviews with *Rafetus* hunters have never been analysed in peer-reviewed literature, however, and therefore their potential importance for enhancing our knowledge on the species and for determining potential sites of presence has remained largely unevaluated.

This article presents the results of structured interview surveys with several former hunters of *R. swinhoei* (Figure 1b), aimed at providing additional details on the ecology of the species, and to explore whether additional sites of remnant presence can be found for further dedicated surveys. Compared with previous studies published on this almost extinct species, this is the first formal analysis of hunters' answers to structured interviews.

2 | MATERIALS AND METHODS

2.1 | Study area

Interview surveys were performed at historical sites of presence of *R. swinhoei* in Vietnam (Figure 2). There were 10 historical sites within Vietnam where *R. swinhoei* had been captured in the past, with several specimens recorded in 1997–2000 (Le et al., 2014; Le & Pritchard, 2009; Pritchard, 2012) (see Appendix S1).

2.2 | Protocol

The interviews were conducted by one of the authors (TPV) from 21 March to 7 April 2019. The interview method followed the British Sociological Society guidelines for ensuring appropriate ethical standards in projects involving data collection from people for research purposes. All respondents were assured that their identity would remain anonymous; interviews were only conducted in Vietnamese following the verbal consent of participants. Before the present questionnaire survey, the structure of the questionnaire, the interview methodology, and associated data collection techniques were refined in a pilot study performed at the Da and Ma rivers, northern Vietnam. A standard questionnaire consisting of 15 questions (see below) was used and took approximately 30 minutes to complete.

The hunters were selected based on TPV's experience while he was working with *R. swinhoei* projects for 10 years (2009–2019). The interviews were conducted individually. All interviewees were well known locally in their communities as former *R. swinhoei* hunters. The interviewees ($n = 10$) were active as *R. swinhoei* hunters during the 1960s–2000s. Unfortunately, several additional *R. swinhoei* hunters who had died in recent years could not be interviewed. The hunters' names are not reported here for reasons of privacy.

Structured interviews were conducted using the following questions:

1. How many *R. swinhoei* have you caught in your life, and what is the method that you used to hunt *R. swinhoei*? As all the hunters interviewed were perfectly able to identify *R. swinhoei* from other softshell turtles (they also described the juveniles very carefully

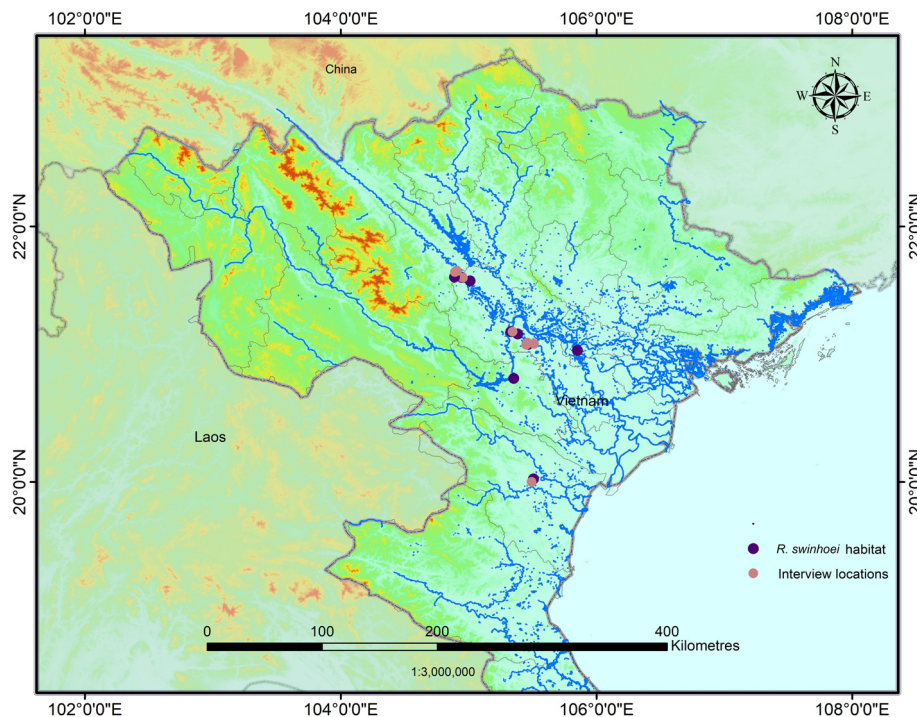


FIGURE 2 Map of northern Vietnam showing the localities of hunting activity of the various *Rafetus swinhoei* hunters interviewed during the present study, and the localities of historical presence of the species in the wild in Vietnam

and reliably), we consider the numbers of individuals that they caught as reliable records of their hunting activity.

2. What was the size (weight) of the individuals that you have caught in your life? All hunters interviewed remembered the weight of most of their captured *Rafetus* exactly, as this has been a topic of general economic interest in their communities, thus providing a first analysis of the size structure of the populations of this species in the wild.
3. Can you describe the habitat of males, females, and juveniles? All the hunters were able to distinguish between the sexes (although this is not easy based on external characteristics; see Bettelheim, 2012) because they slaughtered their prey to sell various pieces of meat to other members of their communities. Thus, it was presumed that they were also able to associate the habitat of capture with the sex of the captured individual.
4. In which months did you find most of the individuals?
5. In which months do the females lay eggs?
6. What is the nesting habitat?
7. How many eggs does each female oviposit?
8. What was the size of the eggs?
9. What food did the turtles eat? As hunters dissected the captured turtles for selling their meat, they observed their ingested food on many occasions.
10. How many *R. swinhoei* were you able to catch every year?
11. When did you catch the last individual?
12. Did you observe any decline in the number of individuals during the last years of your activity?
13. If yes, in your opinion what was the main reason for the decline?
14. Do you think that there are still *R. swinhoei* at the sites where you conducted your hunting activities?
15. Have you recently heard of any *R. swinhoei* being caught at your site?

2.3 | Statistical analysis

To correlate the number of captured turtles with time, first the period of hunting activity of the various interviewees (1960–2019) was divided into five decadal intervals, and a Spearman's rank correlation

coefficient analysis was performed between the various decades and the total number of turtles that the various hunters had captured. In the text, means are presented with ± 1 standard deviations.

3 | RESULTS

Ten former *Rafetus* hunters were independently interviewed. The oldest interviewed hunter is currently 88 years old, and the mean age of the interviewees was 64.1 ± 15.2 years (median = 60.5 years). Interviewees worked in five different provinces of northern Vietnam (Table 1), and overall their hunting activities occurred in the great majority of sites where *R. swinhoei* was recently present (Figure 2).

3.1 | How many *R. swinhoei* have you caught in your life, and what is the method that you used to hunt *R. swinhoei*?

All hunters claimed to remember exactly the number of adult *R. swinhoei* that they were able to catch during their hunting activities; however, they did not catch juveniles, so their numbers were not remembered exactly. Nonetheless, juveniles were regularly observed between 1970 and 2000 by various hunters interviewed and in various localities.

Overall, the 10 hunters reported catching 151 adult *R. swinhoei* in the period 1970–2010, with the highest number reported from a single respondent being 25 individuals across his hunting life. Thirteen additional individuals were reported to have been captured by other hunters (friends of the interviewees); however, as this is indirect information, it was excluded from any analysis. The last individual reportedly captured was in the year 2004 at Lien Hiep village in the Minh Quan commune, where a 29-kg individual was captured and killed by one of the interviewed hunters. After dividing the period of hunting activity of the various interviewees into 10-year intervals, there was a significantly negative correlation between the time elapsed (over a timespan of 50 years) and the number of *R. swinhoei* captured in each decade ($r_s = -0.90$, $n = 5$, $P < 0.05$; Figure 3), with the highest peak noted in the period 1970–80. Using shorter time intervals (3 years),

TABLE 1 Synopsis of the attributes of the *Rafetus* hunters that were interviewed during the present study. The hunters' names are not reported for privacy reasons

Interview no.	Age	Period of <i>Rafetus</i> hunting activity	Area of hunting activity	Province of hunting activity
1	88	1969–86	Suoi Hai Lake, Dam Long Lake, Tho Xuyen Lake	Hanoi & Vinh Phuc
2	56	1991–92	Dong Mo Lake	Hanoi
3	51	1991–92	Dong Mo Lake	Hanoi
4	62	1986–92	Dong Mo Lake	Hanoi
5	47	1990–92	Dong Mo Lake	Hanoi
6	59	1991–92	Dong Mo Lake	Hanoi
7	62	1979–82	Minh Quan Lake	Yen Bai
8	79	1980–2010	Minh Quan Lake, Van Hoi Lake	Yen Bai
9	87	1978–99	Dong Ben Lake	Phu Tho
10	50	1989–92	De Lake	Thanh Hoa

however, the highest capture rate was 15 individuals between 1990 and 1992.

Six of the 10 hunters used long fishhook lines to hunt *R. swinhoei*, three hunters used a set of harpoons (one pointed at one end and one curved at one end), and one hunter caught the turtles using fishing nets. The long fishhook lines were of simple design, with a string holding hundreds of strong hooks made from bicycle spokes. The fishhook lines were put in the water across the place where hunters believe that the turtle normally stays. When a turtle was caught, the hooks entered the shell or the legs, so that the turtle could not escape. This method normally killed or seriously injured the turtles.

3.2 | What was the size (weight) of the individuals that you have caught in your life?

Overall, the hunters remembered the weight of 58 out of 151 individuals caught (38.4%). They were unable to remember the sex of each individual for which they remembered the weight, but all of them agreed that the males were far larger than the females. In fact, whereas males were greater than 100 kg in some cases (the record size was 124 kg in their sample, but weights of up to 169 kg have been reported in other sites), the females never exceeded 50 kg. The size structure of the *R. swinhoei* population as determined by the weight of the individuals reportedly captured by the interviewees is provided in Figure 4 (mean = 53 ± 34.2 kg; median = 40 kg). The majority of the individuals were 15–40 kg, but 17.2% of the individuals were greater than 100 kg in weight.

3.3 | Can you describe the habitat of males, females, and juveniles?

Nine of the 10 respondents could not differentiate the habitat types of males, females, and juveniles, and only one interviewee claimed

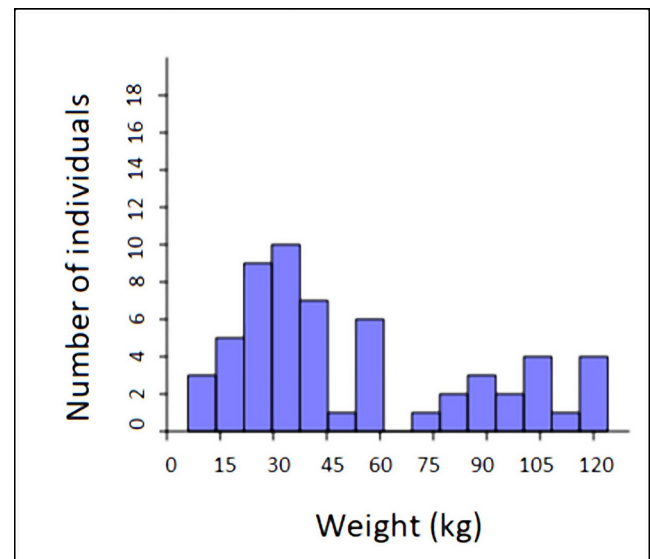


FIGURE 4 Size structure of the *Rafetus swinhoei* population, as determined by the weight of the individuals reportedly captured by the interviewees. These data are from turtles that were caught at 11 independent sites

that the males moved between deep water and floating plant-covered shallow waters, whereas the females and the juveniles inhabited shallow waters (Figure 5).

3.4 | In which months did you find most of the individuals?

Only five respondents answered this question. Four of them agreed that the majority of *R. swinhoei* individuals were observed between May and June/July (spring), whereas one respondent said April and August–September (hot, dry summer). Interestingly, all of them agreed

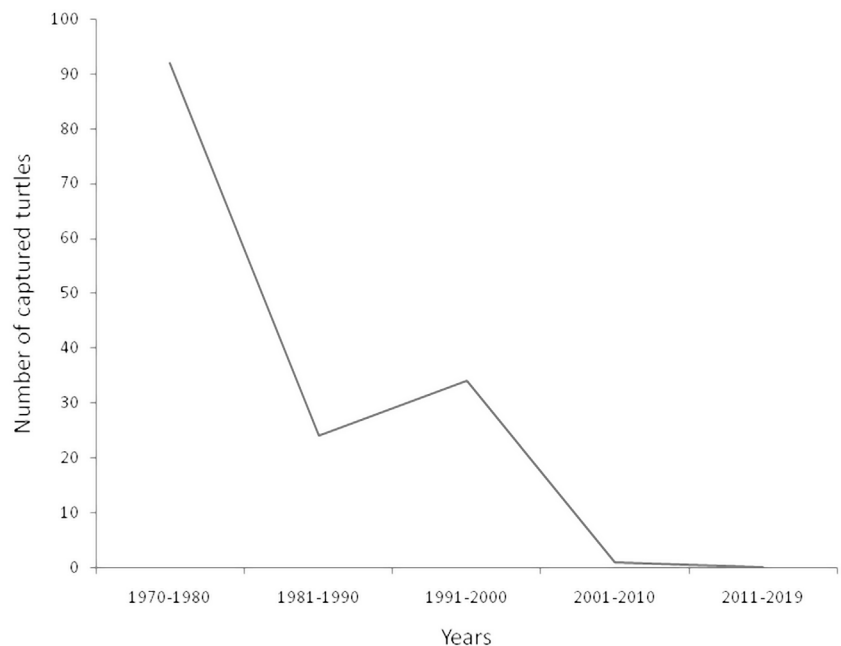


FIGURE 3 Variation in the total number of *Rafetus swinhoei* captured in each decade by the 10 hunters interviewed. It should be noticed that for the period 1970–80, the turtles were not from one sampling site but from eight independent sites. For statistical details, see the text



FIGURE 5 Current habitat at historical sites of *Rafetus swinhoei* in northern Vietnam: (a) Minh Quan Lake; (b) Suoi Hai Lake; (c) Dong Mo Lake; (d) De Lake. Photo credit: Pham Van Thong

that it was more difficult to find active individuals between October and March.

3.5 | In which months do the females lay eggs?

Six of the 10 interviewees said that they had no idea of the nesting period for this species. Two respondents claimed that the females laid eggs in August–September, and two other respondents said that the nesting season occurred between March and May.

3.6 | What is the nesting habitat?

Six of the 10 interviewees had no precise idea of the nesting habitat selected by the female turtles; however, two interviewees stated that most females selected the soft soil of cassava plantations surrounding the water basin and returned to the same spot in different years to deposit their eggs. Another hunter claimed that the species selected sandy banks to oviposit eggs or sites with grassy vegetation near to water bodies. Hunters claimed that they did not target gravid/nesting females specifically and also caught adult males.

3.7 | How many eggs does each female oviposit?

Four hunters agreed that female *R. swinhoei* dig multiple holes in the nesting site but oviposited in only one of these holes. The various

holes were approximately 2–3 m apart in the same sandy area. Approximately 60–70 eggs were placed in a single hole according to one hunter, 54–57 eggs according to another hunter, and up to 100 eggs according to another three hunters.

3.8 | What was the size of the eggs?

There was considerable agreement among hunters that the eggs were the same size as a table-tennis ball. One respondent claimed that the eggs were even larger, and another claimed that the eggs were the size of chicken eggs. According to all hunters, the eggs were white and very round.

3.9 | What food did the turtles eat?

Four of the 10 hunters responded to this question: two of them claimed that these turtles were omnivorous because they found fish, crabs, snails, birds (*Amaurornis* spp. and *Ardeola* spp.), rats, and various types of aquatic vegetation, such as lotus roots, grasses, and water hyacinth, inside the turtles' stomachs. One hunter found only grass roots and water lily roots, whereas another hunter exclusively found fish. Thus, an omnivorous diet seems to be certain in this giant soft-shell turtle species.

3.10 | How many *Rafetus swinhoei* were you able to catch every year?

Half of the interviewees were not able to answer this question. The remaining interviewees agreed that they were able to catch up to five individuals per year during the most successful years.

3.11 | When did you catch the last individual?

Nine of the 10 interviewees remembered precisely when they caught their last *R. swinhoei* individual: in 1982 (one hunter), 1986 (one hunter), 1991 (one hunter), 1992 (four hunters), 1999 (one hunter), and 2004 (one hunter). The last individual was caught at Lien Hiep village, Minh Quan commune, Tran Yen district, Yen Bai province.

3.12 | Did you observe any decline in the number of individuals during the last years of your activity?

Eight of the hunters interviewed had a clear opinion that the species has declined substantially in their locations, with four respondents stating that the most substantial decline occurred between 1991 and 1992. Although agreeing that the turtle population has greatly declined, three respondents could not provide any precise date for the observed decline. In addition, although agreeing that the species has declined, another hunter claimed that *R. swinhoei* are still present in Dong Mo Lake (see below for further details).

3.13 | If yes, what in your opinion was the main reason for the decline?

Here, all of the hunters indicated that the species underwent a substantial decline as a result of overhunting, and two of them also mentioned habitat loss (with the clearing of floating vegetation in shallow waters and the creation of dams at some sites). The hunters also reported that these turtles were caught because of the considerable damage that they caused to fishing activities locally by 'stealing' fishes and by breaking fishermen's nets. One hunter also reported that people were afraid of the turtle and that there was even a fatal case with a human victim of a turtle bite. A local woman collecting shrimps and small fishes for her family in Dam Long swamp complex received a deep bite from a large *R. swinhoei* that removed part of her calf; she died in hospital as a result of haemorrhage. The woman was from Thai Bat village, Tong Bat commune, Ba Vi district, Hanoi.

3.14 | Do you think that there are still *R. swinhoei* at the sites where you conducted your hunting activities?

Nine of the 10 hunters indicated that there are still a few *R. swinhoei* individuals in the wild at their place of activity. Their answers are presented in detail as these responses are important for conservation to direct further management efforts.

One hunter was certain that several individuals remained in Suoi Hai Lake after he stopped hunting in 1986, including a very large

turtle that was caught by his fishhook line but bent the fish hook three or four times to escape as well as a juvenile that he observed repeatedly. As no one hunted these turtles after he left and the habitat has not changed much, this hunter was almost sure that the species is still present in Suoi Hai Lake. He also hunted for turtles at Dam Long Lake, and he believes that no *Rafetus* remained at the end of his activity because the marshland was drained by a channel. Thus, the lake was very shallow, and the floating plants were removed to create a rice field. Another hunter from Long Ho village, Yen Bai commune, Ba Vi district, Hanoi, Vietnam, confirmed that there are still *Rafetus* individuals where he hunted and that he saw a large adult until the summer of 2018. Two hunters from Ngai Son village, Kim Son commune, Son Tay district agreed that there are still at least three individuals of different sizes (approximately 20, 80, and >100 kg) at their location because they have repeatedly observed these turtles during recent years. A hunter from Dong Mo Lake claimed that he still regularly sees five or six individuals at lake site B (Mr Thinh's site), whereas he does not know whether any turtles remain at lake site A (Mr Tų's site). Another hunter from Dong Mo Lake confirmed that there are still at least three individuals in the lake: two of them are approximately 20 kg and another is approximately 80 kg (the latter is the individual that has been regularly monitored by Asian Turtle Program staff since 2006). According to another hunter, one or two individuals should be present in Minh Quan Lake, but he did not claim to have observed any in recent years. Another hunter reported that several people recently saw a large adult (estimated as >100 kg) at Mong Hoi Lake, but he could not confirm this record by direct personal sighting. At De Lake, Tho Xuan, and Yen Dinh district, Thanh Hoa province, one hunter firmly believes that there are at least two remaining turtles. One turtle (approximately 50–60 kg), with a completely black carapace, was seen in 2006 in Mr Hòa Lake, and one (approximately 30 kg) with a yellowish carapace was seen in 2003 in Mr Manh Lake. On one fishing day in 2019, he observed a carp being severely bitten by what appeared to him as a large turtle. Only one hunter claimed that the species was extirpated from his fishing area.

3.15 | Have you recently heard of any *R. swinhoei* being caught at your site?

All of the interviewees stated that they are unaware of any recently captured *Rafetus* individuals at their sites of former hunting activity. As any capture would attract considerable attention locally, it is unlikely that any captures have occurred during the last 10 years.

4 | DISCUSSION

The present study provided noteworthy insights into: (i) knowledge of the population size, structure, and ecology of *R. swinhoei*; (ii) the quantification of its decline during the last 50 years; and (iii) the possible remnant distribution of this almost extinct species. As these insights came from LEK, they lack the scientific validity of directly collected data (Turvey et al., 2015); however, we believe that the information

collected by this study is reliable given the considerable experience of the various hunters with the study species (some of them were even used by the Vietnamese authorities to free the waters from turtles when they represented a serious threat to fishing activities), the relatively robust sample size ($n = 10$ independent hunters), and the fact that this species is very charismatic for the local culture (Bettelheim, 2012; Vietnamtravel, 2016).

4.1 | Population size structure and ecology

Assuming that the data provided by the various hunters are reliable, the present study provides the first quantitative data on the size structure of *R. swinhoei* in the wild. Although the sizes obtained from the hunters' data do not include juveniles (which were never collected by them, although seen frequently) these values clearly indicate that the majority of the adult individuals were 15–45 kg. All individuals exceeding 60 kg were males (note that previous publications have suggested that males are larger than females; Bettelheim, 2012). Unfortunately, data are not available for any of the other giant softshell turtle species for comparison with those provided here for *Rafetus* (size structure data are available for smaller species; Plummer, 1977; Plummer & Mills, 2008). In future investigations on the potential occurrence of remnant *Rafetus* populations, it would be better to ask interviewees about the presence of mid-sized turtles (15–45 kg) instead of very large individuals that are no longer likely to exist. Indeed, it may be that *R. swinhoei* is not as rare as currently thought because local people may not be aware that mid-sized softshells are *Rafetus*, perhaps believing these turtles to be *Pelodiscus sinensis*, a smaller sympatric softshell turtle species. For scientific studies on this species using LEK, focusing on turtles of average size (15–45 kg) is useful because local fishermen and hunters are usually able to distinguish *R. swinhoei* from other sympatric softshell species based on their external appearance. It should be noted, however, that Jian et al. (2013) reported that these species are frequently confused in southern China. Indeed, *R. swinhoei* is locally named 'Con Chạnh', 'Con Giãi', or 'Con Giãi Mép Vàng', which means 'large softshell turtle with yellow mouth corner'. On the other hand, the sympatric *P. sinensis* is called 'Ba Ba Trơn', which means 'smooth softshell turtle', and *Palea steindachneri* is called 'Ba Ba Gai', which means 'thorny softshell turtle'. *Pelodiscus sinensis* is small in size (with a carapace of up to 25 cm (Ernst & Barbour, 1989) and a maximum weight of 2 kg (Pham Van et al., unpubl. data)) and a habitat generalist (Ernst & Barbour, 1989; Haramura, Yamane, & Mori, 2008), whereas *Palea steindachneri* has an easily recognizable thorny carapace (Jian et al., 2013) and is mid-sized (with a carapace of up to 47 cm (Ernst & Barbour, 1989) and a maximum weight of 30 kg (Pham Van et al., unpubl. data)), and lives only in upstream areas and in faster currents instead of lakes, slow rivers, and swamps, as *Rafetus* does (Bonin, 2006; Radford, 2011). Thus, although very large *Palea* can be as large as small *Rafetus* (and so possibly confused by fishermen), the only sympatric turtle that can weigh up to 100 kg and reach the same size as large *R. swinhoei* is *Pelochelys cantorii* (Ernst & Barbour, 1989), which may also inhabit large rivers. However, the species is easily distinguished from *R. swinhoei* by its external appearance and by its

defensive behaviour: it is called 'Đấm Đấm' by local fishermen (meaning 'punch softshell turtle', as it defends itself by punching the heads of those who capture it). In addition, it has a round and thinner shell than *R. swinhoei*, and local fishermen can even differentiate *Rafetus* from 'Đấm Đấm' based on the small eyes of *P. cantorii* (TPV, unpubl. data).

Finding the nests of *R. swinhoei* was clearly a difficult task, as few hunters knew of them. Thus, these results possibly show that meat consumption by local communities is more common than egg consumption. On the other hand, egg consumption is a serious threat for other remnant populations of large Trionychidae elsewhere (e.g. *Cyclanorbis elegans* in South Sudan; Demaya, Benansio, et al., in press).

Face-to-face interviews performed during the present study suggested that *R. swinhoei* shows a yearly activity cycle similar to that of temperate-zone reptiles, with a prolonged period of inactivity during the winter months and with summertime nesting. At Dong Mo Lake, however, one of the authors (TPV) observed *R. swinhoei* in winter and early spring, when it appeared very slow moving or basking during sunny days, especially after prolonged cold days. These sightings suggest partial hibernation during the winter months. The hunters suggested that females use the same 'beaches' to oviposit their eggs every year. This is the same behaviour that is likely to have caused the population collapse and the near total extinction of a giant softshell turtle in tropical Africa (Demaya, Benansio, et al., in press). Thus, as a future conservation priority, the nesting areas used by *R. swinhoei* females should be identified and carefully protected, as these are probably used for egg-laying each year.

Males of *R. swinhoei* appeared significantly larger than females. This is quite unusual in species of Trionychidae, where females are usually the larger sex (Ceballos, Adams, Iverson, & Valenzuela, 2013). According to sexual selection theory, males are larger than females when large male size evolves as an adaptation to increase success in male combat or to enable the forcible insemination of females (Berry & Shine, 1980). Thus, we predict that male–male combat should be strong in *R. swinhoei* during the mating season, and that this intense male–male competition together with the extremely large size of this species may account for the observed low density of individuals. In addition, as clutch size generally correlates positively with female size in chelonians (Dodd, 1997; Elgar & Heap, 1989), it can be hypothesized that smaller females compared with males could perhaps give rise to lower reproductive output and consequently be related to a naturally lower abundance in the wild.

There was a consensus among hunters that plant materials, and especially the roots of floating species, represent the main dietary items, together with small mammals, birds, fishes, and aquatic invertebrates. One of the hunters even claimed to have seen turtles actively feeding on floating plants. Thus, it seems evident that *R. swinhoei* is an omnivorous species in contrast to most of the other softshell species that are almost invariably carnivorous (Akani, Capizzi, & Luiselli, 2001; Cochran & McConville, 1983; Williams & Christiansen, 1981). It remains to be determined, however, whether *R. swinhoei* individuals are benthic feeders and scavengers, or if they feed more in the water column (Luiselli, Akani, Politano, Odegbune, & Bello, 2004). In addition, the foraging niche relationships of *R. swinhoei* with other

sympatric softshell turtle species have yet to be clarified (Luiselli, 2008; Pritchard, 2001).

4.2 | Quantification of population decline

Taking into account the comments from the hunters who started collecting this species decades ago, the numbers of animals that they captured is quite small. For example, the highest single respondent captured only 25 individuals throughout his hunting life of a few decades. In contrast, for other species of large freshwater turtles, such as *Podocnemis expansa* in the Amazon, there are reports of hundreds or thousands of animals being captured by hunters (Arraes, Regina, Cunha, Ferreira, & Tavares-Dias, 2016; Conway-Gómez, 2008; Smith, 1979). As larger turtle species tend to be captured or targeted by hunters instead of smaller sympatric species (Demaya, Benansio, et al., in press; Smith, 1979), the small number of *R. swinhoei* captured is still quite surprising. For instance, between 1970 and 1980 the turtles reported were not obtained from one sampling site but from eight distinct sites, still representing a very low number of individuals per site.

Assuming that there is a correlation between the observed variation in the total number of individuals captured in each decade and the overall population collapse, the present data suggest that the population collapse of *R. swinhoei* in Vietnam occurred in two phases: first during the 1980s, when the population size decreased dramatically, and second at the beginning of the 1990s, when many hunters simultaneously collected multiple individuals from populations already severely affected. Indeed, there was general agreement that these turtles became very rare after 1991–92. The data for 2011–19 cannot be compared with those from previous decades with any certainty because the hunters interviewed generally did not hunt during this period, not only because *R. swinhoei* had become very rare in the wild but also because the species is now strictly protected in Vietnam. This species is fully protected by national law, by decree 160/2013/NĐ-CP, together with four other turtle species (*Cuora galbinifrons*, *Cuora trifasciata*, *Mauremys annamensis*, and *Pelochelys cantorii*) and five marine turtle species, and is also listed in Appendix 1B of the new law decree 06/2019/NĐ-CP. According to the 2015 National Penal Code, any violation (such as hunting, trading, or consuming) related to the species listed in decree 160/2013/NĐ-CP and in Appendix 1B of decree 06/2019/NĐ-CP will be considered a criminal offence, resulting in up to 15 years in prison and up to 15 billion VND in fines (~\$653 000), depending on the level of violation; however, although the species is strictly protected, its habitat is not.

Overhunting and habitat modifications have certainly affected the population abundance of these turtles (Jian et al., 2013). In particular, dams represent a major threat as they reduce water flow while dividing the species' population into smaller segments (Jian et al., 2013). In Vietnam, during the period 1950–80, several dams were built to convert small swamps and streams (the original habitat types for *R. swinhoei*) to provide water for agriculture (Appendix S2). After the dams were built, mud, floating grasses, and aquatic trees were systematically removed, and the sandy beaches used by the species to oviposit were inundated.

4.3 | Possible remnant distribution

Although there is no doubt that *R. swinhoei* has undergone a catastrophic decline during the last 25 years (currently considered as the rarest turtle in the world; Stanford et al., 2018), almost all of the hunters interviewed were very confident that the species still exists at their respective sites in small remnant population sizes. Some of their comments are very interesting with regards to individuals that were recently observed. In particular, reliable recent sightings occurred at Dong Mo Lake, De Lake, Suoi Hai Lake, Mong Hoi Lake, and Van Hoi Lake.

Owing to practical and economic constraints, field monitoring has only been performed at a very local scale (for instance by ATP in just part of Dong Mo Lake and at Xuan Khanh Lake; see more at: http://www.asianturtleprogram.org/project_page/rafetus_project.html). We would urge the competent authorities to support extensive trapping surveys in at least the following areas: Thinh's site at Dong Mo Lake, De Lake, Suoi Hai Lake, Van Hoi Lake, and Mong Hoi Lake. The food preferences indicated by the hunters may be used as baits in the traps, thus maximizing the chance of capturing these large turtles.

In conclusion, the data presented in this paper suggest that the remnant distribution of *R. swinhoei* may be wider than currently reported, and that there are several sites of likely presence for the species. We suggest that a combination of techniques could be used to detect more individuals, such as visual surveys, extensive trapping, and the use of environmental DNA (eDNA). At least 24 DNA samples have been collected to date from Vietnam and China for analysis, aimed at confirming the presence of *R. swinhoei* (Le et al., 2014). These techniques should be used to identify new individuals and to evaluate the true distribution and rarity of this species in Vietnam.

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