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RESEARCH ARTICLE

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Fishers, dams, and the potential survival of the world's rarest turtle, *Rafetus swinhoei*, in two river basins in northern Vietnam

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Abstract

1. Next to cetaceans and megafishes, freshwater turtles are the most iconic endangered freshwater species.
2. A detailed questionnaire survey conducted with more than 100 individuals from fishing communities in northern Vietnam was used to investigate the current status of Southeast Asian turtles and provides new hope concerning the survival of *Rafetus swinhoei*, for which recent official records in the wild are limited to a single individual in Vietnam.
3. The survey included the entire Vietnamese portion of the Da River in Hoa Binh and Son La provinces, as well as the Chu and Ma river system in Thanh Hoa Province, as they are the last sites where the world's rarest and largest Asian softshell turtle has been seen. The questionnaire, conducted in Vietnamese, focused on demographic details, fishing intensity and gear, the status of fishing grounds, and the frequency of interaction with turtles.
4. The great majority of fishers could recognize different turtle species from photographs and describe their preferential breeding habitats; not all knew that they are protected. A few confirmed that more than once each year they still encounter freshwater turtles during their fishing activities.
5. This survey provides detailed information on sites where freshwater turtles are still seen in northern Vietnam and broadens our hope that wild individuals of the extremely rare *R. swinhoei* may still be present in the remaining riparian wetlands of these biodiverse, dammed, and controlled river basins in North Vietnam.

KEYWORDS

conservation ecology, fishers, local ecological knowledge, *Rafetus swinhoei*, sustainability, Vietnam

1 | INTRODUCTION

Several studies from separate regions of the world have shown that fishing activities represent a threat to freshwater turtles, including North America (Midwood, Cairns, Stoot, Cooke, & Blouin-Demers, 2015), Central America (Moll, 1986), South America (Alho, Reis, & Aquino, 2015), Africa (Demaya et al., 2019), and Asia (Sk, 2000). Fishing activities are a primary cause of the depletion of freshwater turtle populations, and in some cases to their almost complete extinction. This has been the case for large-sized softshell turtle species (Trionychidae), including the African *Cyclanorbis elegans* (Demaya et al., 2019) and the Asiatic *Rafetus swinhoei* (Bettelheim, 2012;

Pritchard, 2012). Swinhoe's softshell turtle (*R. swinhoei*) is one of the largest freshwater turtles in the world, with a maximum recorded body mass of 169 kg, and is currently considered as the most threatened turtle species on Earth (Pritchard, 2001; Stanford et al., 2018). Swinhoe's softshell turtle is known only from the Red River basin in China and Vietnam, and from China's lower Yangtze River floodplain (Jian, Hai-Tao, Cheng, & Lian-Xian, 2013; Pritchard, 2012). It has been pushed to the brink of extinction by overfishing, habitat loss, and pollution (Stanford et al., 2018). Documented observations confirm the present-day survival of only one individual of unknown sex in the wild and of a single captive male in Suzhou Zoo, China. Recent intensive surveys in Yunnan (China) and in northern Vietnam have not disclosed additional wild specimens, despite a few sightings being reported until about a decade ago (Stanford et al., 2018; Van et al., 2020).

In the face of the catastrophic decline suffered by *R. swinhoei* (Stanford et al., 2018), it is imperative to find additional wild individuals; however, the large number of rivers and lakes in the historical distribution area of this species, the heavy economic constraints on local research, the suboptimal skills of the authorities involved, and the very scarce ecological information available on the study species (Van et al., 2020) have made it very difficult to uncover new potential areas of occurrence for this species. Thus, the use of local ecological knowledge, through interviews with fishers and/or experienced persons, represents an important tool to indirectly uncover new sites of presence for *R. swinhoei*. Two independent river systems in northern Vietnam were surveyed and more than 100 fisher families were interviewed in early 2019, using standardized questionnaires, with the aims to: (i) uncover new potential areas of presence of *R. swinhoei*; (ii) highlight local threats; and (iii) provide recommendations for conservation actions. The results presented here identify specific sites where Swinhoe's softshell turtle has been sighted recently and provide crucial information on the presence of additional wild individuals of the world's rarest turtle species, which will be vital for designing adequate conservation and management measures.

2 | MATERIALS AND METHODS

2.1 | Study areas

The field study was carried out in two separate river basins in northern Vietnam: the Da River in Hoa Binh and Son La provinces and the Chu and Ma rivers in Thanh Hoa Province (Figure 1). The Da River (a major tributary of the Red River) and the shorter Chu and Ma rivers are among the 10 largest river systems of Vietnam (Dao, 2010). The Da River (21°13′N, 105°20′E) flows 910 km from its source in Yunnan Province, China. It flows through Vietnam for over 500 km, crossing five provinces, including Dien Bien, Lai Chau, Son La, Hoa Binh, and Phu Tho, before joining the Red River in Ba Vi District, Hanoi (Cavendish, 2007; Dao, 2010; Vinh, Ouillon, Thanh, & Chu, 2014). The Chu and Ma (19°52′N, 105°45′E) rivers run through Thanh Hoa Province for 325 and 528 km respectively. The Chu River comes from Laos; it flows through Nghe An Province, on to Thanh Hoa Province to meet the Ma River in Thieu Hoa District. The Ma River has its origin in the Tuan Giao District, Dien Bien Province. It goes through Laos and it returns through Thanh Hoa Province (see http://thanhhoa.gov.vn/portal/pages/dieu-kien-tu-nhien.aspx).

2.2 | Protocol

The interview survey was structured on the basis of historical records of the presence of *R. swinhoei* within the study region (Le et al., 2014; Pritchard, 2012). In the Da River basins, the survey was conducted by visiting fishing families while we descended the river in a boat. The survey extended from Hoa Binh dam, in Hoa Binh Province, to Son La dam in Muong La District, Son La Province. In the Chu and Ma river basins, a similar survey was conducted travelling by motorbike from Thieu Hoa District, Thanh Hoa Province, to Que Phong District, Nghe An Province for the Chu River, and from the western Thieu Hoa District to Quan Hoa District, within the same Thanh Hoa Province.

Surveys were conducted by a single interviewer (TPV) from 6 to 18 April 2019 along the Da River, and from 24 April to 6 May 2019 in the Chu and Ma river basin provinces. Our interviews followed the British Sociological Society's guidelines for ensuring appropriate ethical standards in projects involving data collection for research purposes. The identities of respondents were kept anonymous; interviews were only conducted in Vietnamese following the oral verbal consent of the participants. The questionnaire structure, interview methodology, and associated data collection techniques were refined in a preliminary *ad hoc* pilot study carried out on the Da River from the 31 March to 2 April 2019. A standard set of 31 questions (see below) was used, which took about 30 min to complete.

Respondents were selected at random among fishers met while surveying 200 km of the Da River and about 1250 km of Thanh Hoa Province visited by motorbike. During the survey period, all respondents (n = 123 in the Da River and n = 67 in Thanh Hoa Province) were active fishers. Each interview started by recording the location, date, geographical coordinates, name, gender, age class, and mobile phone contact (if available) of the interviewee (Appendix S1).

We considered each reported *R. swinhoei* sighting as reliable when the interviewee was able to: (i) correctly identify the species in a photo among a series of other photos representing different species of native and alien turtles; (ii) correctly describe its gigantic size by giving an approximate body mass/carapace length that unequivocally identify the species; (iii) give the exact local name for the species; and (ive) describe the colouration characteristics that are typical for the species. We also asked several questions concerning the respondent's marital status, education level, etc., in order to verify whether the demographic profiles of the two groups of respondents in the two areas were similar and, therefore, directly comparable. Otherwise there is the risk of getting biased answers because of marked differences in the demographics and cultural background among the interviewed samples (Corrao, 2005). In addition, we asked whether or not the fish and invertebrate resources were depleted in order to

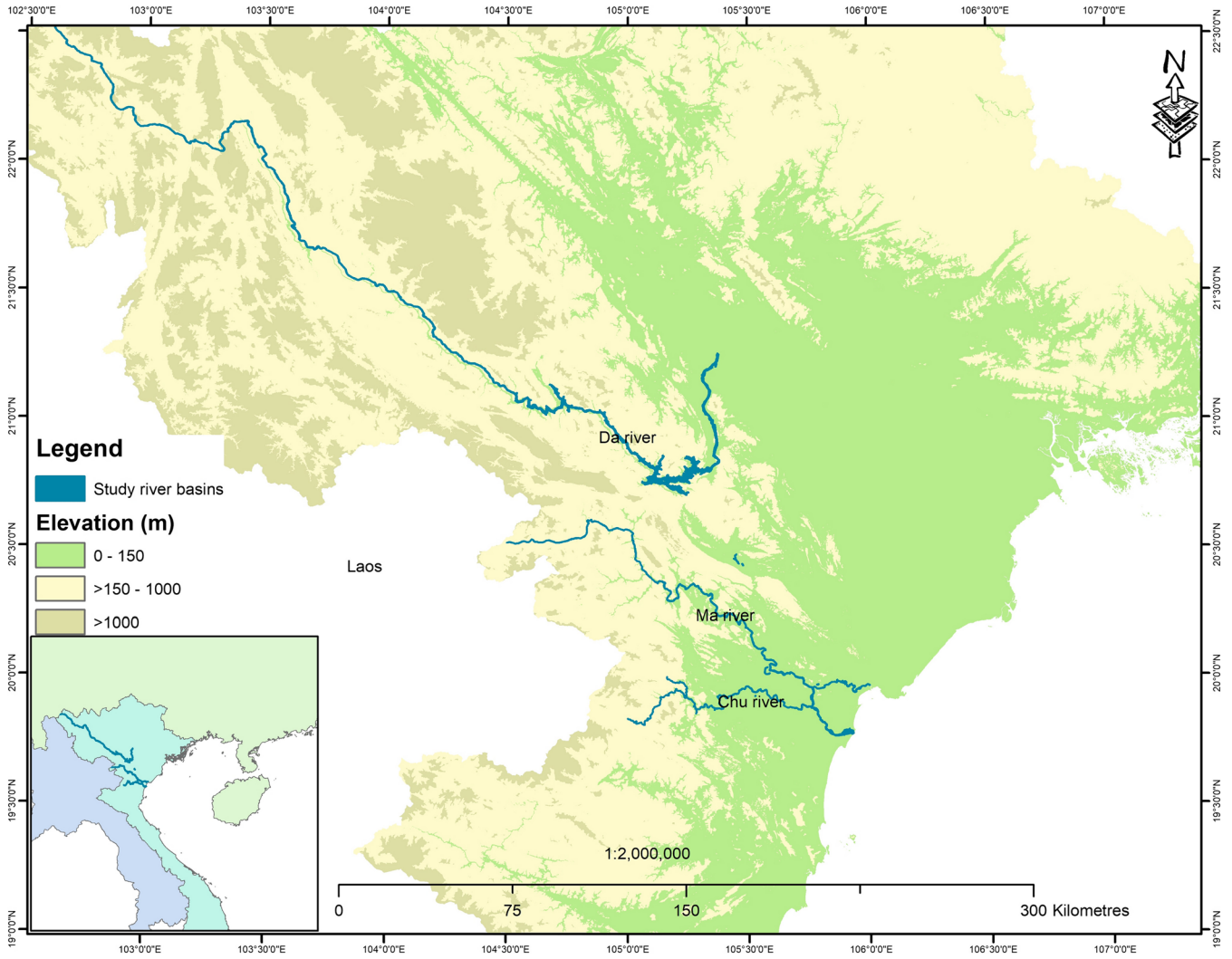

FIGURE 1 Map of northern Vietnam showing the two riverine areas surveyed during the present study: Da River and the Chu and Ma river system in Thanh Hoa Province

understand whether overfishing has been a serious issue for decades at the local scale, and thus eventually affecting the turtle populations.

In addition to the structured questionnaire, we also asked the interviewees whether they had any individual turtles (alive to be sold or even the shells), and, where available, these specimens were examined and identified for species and sex and the carapace length was measured.

2.3 | Statistical analysis

In order to uncover differences in the characteristics of the fishing activities among the study areas, and their effect on turtles, we evaluated the statistical differences in the gender, marital status, and level of education of respondents in the Da River basin and the Chu and Ma river basins using χ^2 tests. Similarly, χ^2 tests were used to explore the inter-site frequency variation of the answers given to the questions. All tests were performed with PAST 3.0 (Hammer, 2012).

3 | RESULTS

3.1 | Fisher demographic profile

The demographic profiles of the fishers were similar across the study areas (in all comparisons, $P > 0.05$): male respondents accounted for 87.8% in the Da River and 88.1% in Thanh Hoa; the ages ranged from 25 to 84 years and from 29 to 94 years, respectively (Appendix S1); and nearly all were married (98.4 cf. 97.0%). In both study areas many of the interviewees had attended secondary school (66.7 cf. 38.8%), but in Thanh Hoa there were significantly ($P < 0.01$) more interviewees with no school education (29.9%) than in the Da River basin (3.3%).

3.2 | Socio-economic profile

Despite the similarity in age distribution of the fishers (Appendix S1), there were significant differences in the time that they spent

fishing within their respective fishing grounds (χ^2 = 38.6, *df* = 4, *P* < 0.0001). In total, 64.2% of interviewees in Thanh Hoa had fished for more than 30 years, compared with 25.2% in the Da River basin. In both areas, most fishers (93.5 and 95.5%, respectively) fished only within their own site, were first trained by family members, and fishing was the only way of subsistence (73.8% of respondents in the Da River basin and 37.2% in Thanh Hoa). The two study areas differed significantly (χ^2 test, *P* < 0.05) in that only 37.4% of the interviewees were full-time fishers in the Da River basin, compared with 62.7% in Thanh Hoa. In both areas, the majority of interviewees (61.8% in Da River versus 53.7% in Thanh Hoa) did not want their children to continue their fishing activity.

3.3 | Habitat protection and conservation

In both the Da River basin and in Thanh Hoa, the great majority of the respondents (82.1% in each area) considered the local fishery stock to be severely depleted, whereas only 12.2% of respondents in Da River and 7.5% in Thanh Hoa considered it to be unexploited. Overall, there was no significant difference between the two sites in the frequency distribution of the answers given by interviewees describing the condition of the local fish stock (χ^2 = 4.91, *df* = 4, *P* = 0.297).

According to several fishers interviewed, the main species to have become depleted in the Da River were: the fishes *Chanos chanos*, *Cranoglamis sinensis*, *Culter* spp., *Cutler alburnus*, *Hemibagrus* spp., *Hemiculter* ssp., *Oxyeleotris marmorata*, Pellonulinae spp., Pollulinae spp., *Protosalanx chinensis*, Siluridae ssp., Sisorinae ssp., and *Squaliobarbus curriculus*; the shrimps *Caridina flavilineata* and *Macrobrachium nipponensis*; and the turtle *Pelodiscus sinensis*.

In Thanh Hoa, the species reported as being most depleted were: the fishes *Bagarius rutilus*, *Bangana lemassoni*, *Cirrhinus* spp., *Cranoglanis sinensis*, *Cyprinus carpio*, *Hemibagrus* spp., *Hemiculter leucisculus*, *Lateolabrax* spp., *Macrognathus* spp., Pleuronectiformes, *Spinibarbus maensis*, *Squaliobarbus curriculus*, and *Wallago attu*; polychaete worms of the genus *Eunereis*; the shrimps *Caridina flavilineata* and *Macrobrachium nipponensis*; and the turtle *P. sinensis*.

The use of illegal gear and the increase in the number of fishers were considered to be very important reasons for the decline of fishery stocks at both study sites (Figure 2). Many fishers (46.7% in the Da River basin and 67.2% in Thanh Hoa) reported that they fish every day (the frequency of answers by fishers showed no difference between the two areas).

3.4 | Turtle distribution within the two study areas

In addition to interviewing fishers about turtles, during the surveys 101 individual turtles (including both living individuals and shells) were

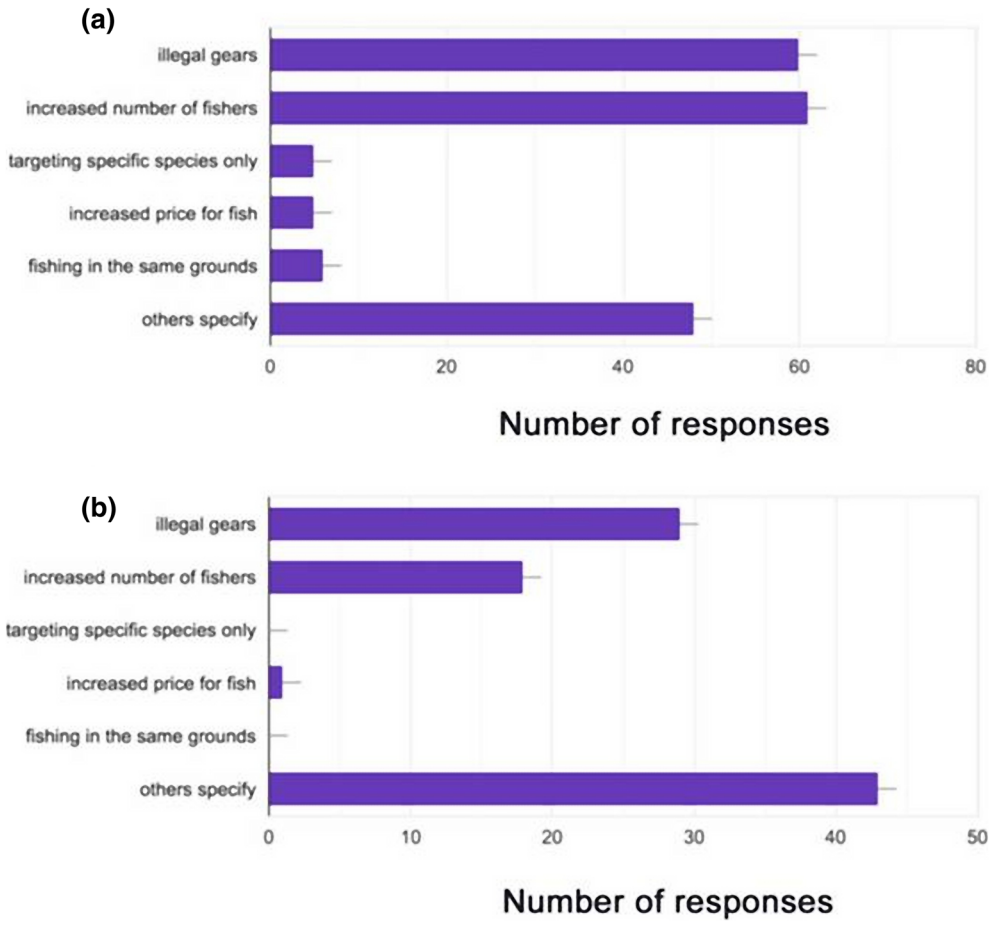

FIGURE 2 Synopsis of the respondents' answers to the question: 'By what means did fishing deplete fish stocks?': (a) Da River; (b) Thanh Hoa Province

observed, with 27 belonging to four species in the Da River and 74 belonging to eight species in Thanh Hoa Province (Table 1). Most of the records in Da River were *P. sinensis*, whereas in Thanh Hoa Province the majority were *Mauremys sinensis*. A juvenile individual of a non-native species (the North American *Trachemys scripta elegans*) was also observed in a local house, reportedly having been caught in the Da River. It is possible that the turtle had been released for religious reasons as there was a Buddhist temple nearby (Everard, Pinder, Raghavan, & Kataria, 2019).

In the list of observed turtles (Table 1), the specimen of *R. swinhoei* kept in Hoa Binh Museum was not included as it has already been documented (Le et al., 2014). In Thanh Hoa Province, a *R. swinhoei* skull found by TPV in December 2018 was recorded, as this has not been reported previously. This skull was from a turtle of about 50 kg that had been captured by Mr Thai, who has fished for *R. swinhoei* for the past 40 years in De Lake, Tho Xuan District, Thanh Hoa Province. The animal had been eaten and the skull preserved.

3.5 | Fishers and turtles

Fishers were well aware of the presence of different species of turtles in their local area and were able to describe them. They identified turtle species using species-specific local names and could indicate the habitat types preferred by each taxon (Table 2). Very large turtles (of the size of *R. swinhoei*) were known to 52% of the local fishers from the Da River and to 64.2% from Thanh Hoa ($P < 0.05$, χ^2 test with $df = 1$).

Turtles were caught primarily using hooks and long lines at both study areas (53.3% of respondents from the Da River compared with 50.7% from Thanh Hoa, with no differences between sites). Cast nets

TABLE 1 Synopsis of the number of turtle individuals directly observed, by species and by study site, in the two areas of northern Vietnam

Species	IUCN red list*	No. of individuals	Locality	Condition	Age
Thanh Hoa Province					
Cuora mouhotii	EN[1]	1	Nga Ba Xua village, Xuat Hoa, Lac Son, Hoa Binh Province	Alive	Subadult
Cuora mouhotii	EN	1	5th region, Quan Hoa town, Quan Hoa District, Thanh Hoa Province	Alive	Subadult
Pelodiscus sinensis	VU[2]	2	Nga Ba Xua village, Xuat Hoa, Lac Son, Hoa Binh Province	Alive	Adult
Cuora mouhotii	EN	1	Thach Thanh District, Thanh Hoa Province	Alive	Subadult
Mauremys sinensis	EN	60	Quang Phu commune, Tho Xuan, Thanh Hoa Province	Alive	Subadult
Rafetus swinhoei	CR[3]	1	Quang Phu commune, Tho Xuan, Thanh Hoa Province	Skull	Adult
Indotestudo elongata	EN	1	Quang Phu commune, Tho Xuan, Thanh Hoa Province	Alive	Subadult
Pelodiscus sinensis	VU	2	Quang Phu commune, Tho Xuan, Thanh Hoa Province	Alive	Juvenile
Manouria impressa	VU	2	Quan Yen, Đinh Cong, Yen Dinh, Thanh Hoa Province	Shell	Adult
Platysternon megacephalum	EN	1	Xuan Lien NR, Dong Phong village, Que Phong, Nghe An Province	Carapace	Adult
Cyclemys oldhamii	NE[4]	1	Pang village, Dong Van, Que Phong, Nghe An	Shell	Adult
Cuora mouhotii	EN	1	Kho village, Tan My, Lac Son, Hoa Binh	Alive	Subadult
Da River					
Pelodiscus sinensis	VU	2	Nua, Vay Nua, Da Bac, Hoa Binh	Alive	Subadult
Cuora mouhotii	EN	2	Xom Liem, Ngoi Hoa, Tan Lac, Hoa Binh	Alive	Subadult
Cuora mouhotii	EN	1	Xom Mu, Ngoi Hoa, Tan Lac, Hoa Binh	Carapace	Adult
Pelodiscus sinensis	VU	11	Tan Dan, Mai Chau, Hoa Binh	Alive	Adult
Trachemys scripta elegans		1	Tan Dan, Mai Chau, Hoa Binh	Alive	Hatchling
Pelodiscus sinensis	VU	1	Ban, Tan Dan, Mai Chau, Hoa Binh	Dead	Subadult
Pelodiscus sinensis	VU	3	Bo Sen, Suoi Nanh, Da Bac, Hoa Binh	Alive	Juvenile
Pelodiscus sinensis	VU	1	Da Phu, Bac Phong, Phu Yen, Son la	Alive	Juvenile
Pelodiscus sinensis	VU	1	Suoi Xoay, Tan Hop, Phu Yen, Son La	Photo	Adult
Pelodiscus sinensis	VU	1	Hang Mieng, Quang Minh, Moc Chau, Son La	Photo	Adult
Cyclemys oldhamii	NE	1	Ban Nhan Noc, Ta Khoa	Alive	Juvenile
Pelodiscus sinensis	VU	2	Hoa Binh dam board park, Hoa Binh city	Alive	Adult

*CR, Critically Endangered; EN, Endangered; NE, Not Evaluated; VU, Vulnerable.

TABLE 2 Local names given to freshwater turtles found within the two study basins

Species	Kinh ethnic group	Mng ethnic group	Thanh Hoa Province	Habitat types
Rafetus swinhoei	Con Gii	Con Tp/Con Tái	Con Chnh	Small rivers, not too deep, and swamps
Palea steindachneri	Ba Ba Gai	Con Tp/Con Ti	Ba Ba Gai	Streams from forests, rarely enter river
Pelodiscus sinensis	Ba Ba Trn	Ba Ba Trn	Ba Ba Trn	Rivers
Pelochelys cantorii	m m/Rành Rnh	m m/Rành Rnh		Deep sections of large rivers

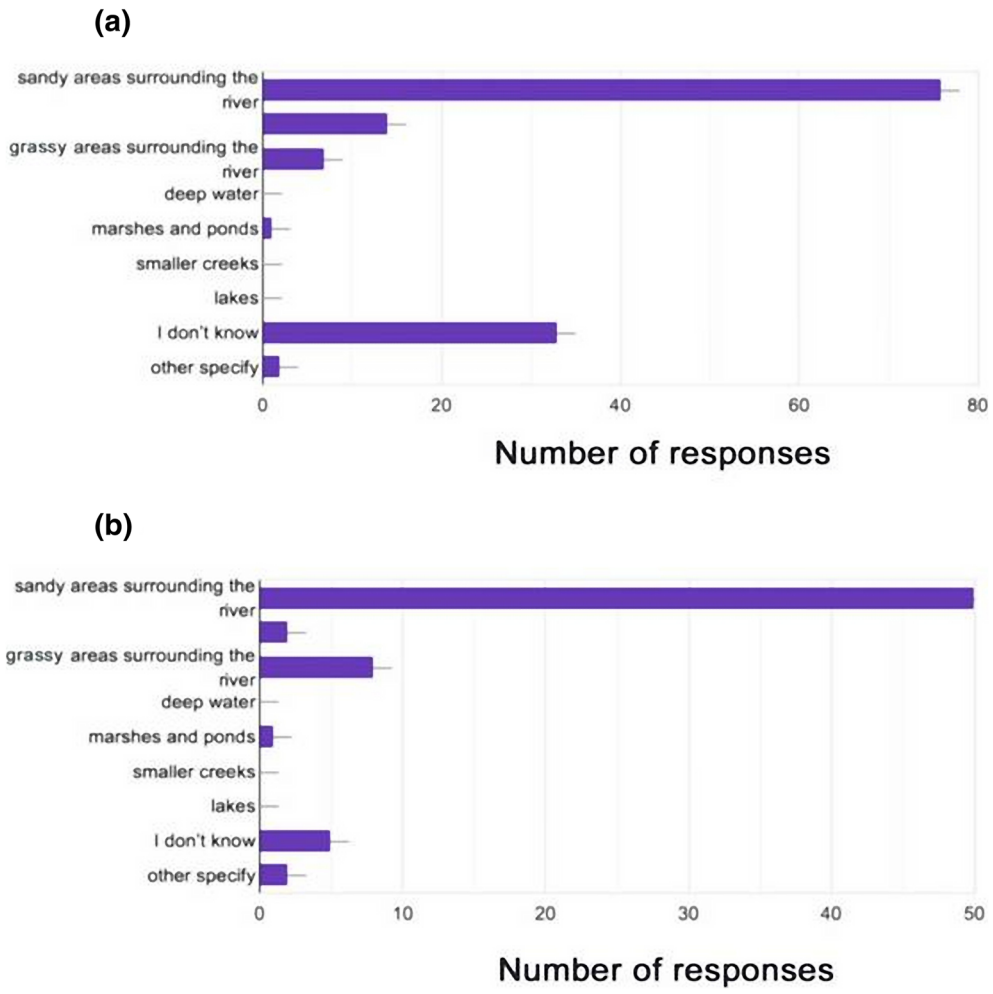

FIGURE 3 Synopsis of the respondents' answers to the question: 'What are the preferred turtle breeding habitats within this area?': (a) Da River; (b) Thanh Hoa Province

(5.7%) and stationary gill nets (9%) were used regularly, especially by fishers from the Da River. Other turtle fishing methods were also commonly used, including maze funnel traps, diving and catching by hand, electrofishing, and the use of harpoons (54.1% in Da River and 70.1% in Thanh Hoa).

In the Da River, 22.8% of fishers had not caught turtles for the last 10 years; 41.5% said that they capture fewer than one turtle per month, 22.8% at least one turtle, 6.5% at least two turtles, 4.1% at least three turtles, and 2.4% catch more than five turtles per month. In Thanh Hoa, 62.1% of the interviewees had not captured any turtle in the last 10 years, 16.7% answered that they capture at least one turtle per month, 13.6% at least two turtles, 3% at least three turtles, and 4.5% catch more than five turtles per month. In both areas the great majority of fishers agreed that they could catch very few turtles per month; overall, the frequency of the answers differed significantly between the study areas ($\chi^2 = 73.1$, $df = 5$, $P < 0.0001$).

In both areas the majority of the interviewees (65% in Da River and 55.2% in Thanh Hoa) stated that they normally sell the captured turtles to traders, although they may also use them for domestic consumption or even keep them as pets. The average price of turtle meat was reported to range from 70,000 VND/kg ($2.9/kg) to 500,000 VND/kg ($21.2/kg), but most often ranging between 200,000 VND/kg ($8.5/kg) and 400,000 VND/kg ($17.0/kg) in the Da River, and from 100,000 VND/kg ($4.2/kg) to 1,000,000 VND/kg ($42.5/kg), but most often ranging between 200,000 VND/kg ($8.5/kg) and 500,000 VND/kg ($21.2/kg) in Thanh Hoa. In both areas, large turtles (>1 kg) were reported to be more expensive than smaller ones, with the price of *Palea steindachneri* being much greater than that of

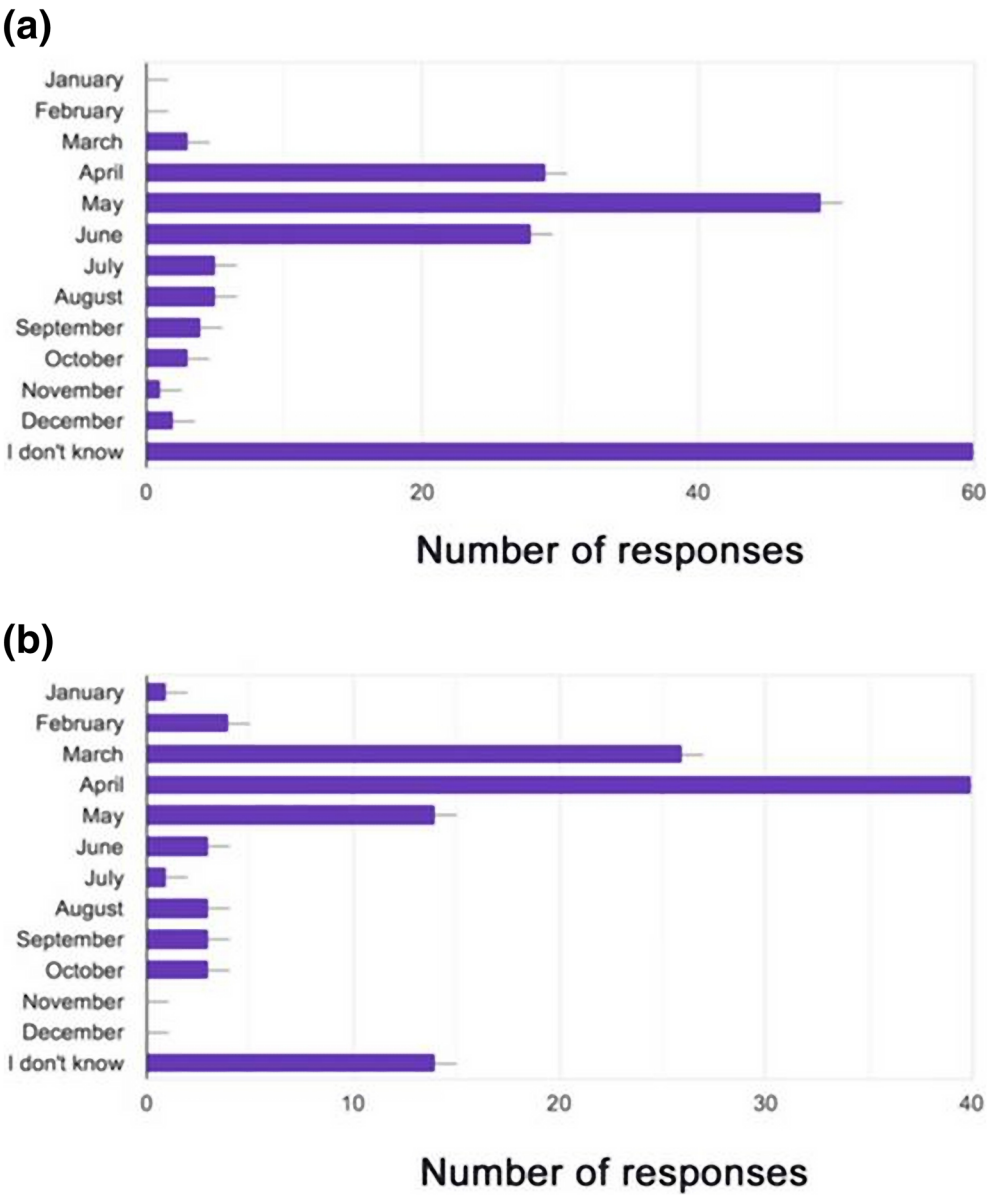

FIGURE 4 Synopsis of the respondents' answers to the question: 'What is the main turtle reproductive season in this area?': (a) Da River; (b) Thanh Hoa Province

Pelodiscus sinensis, with average prices of 500,000 VND/kg ($21.2/kg) and 300,000 VND/kg ($12.7/kg), respectively.

Most respondents from both study areas observed that the most important habitat for turtle nesting was sandy riparian beaches along the rivers and, to a lesser extent, riparian grasslands adjacent to the rivers (Figure 3), with no significant differences between study areas ($P > 0.05$, χ^2 test). Fishers from the two study areas were also relatively consistent in their opinion concerning the reproductive phenology of the turtles in their respective areas: shelled eggs in butchered turtles and nesting emergence, which are evidence of nesting, are concentrated between April and June in the Da River and between March and May in Thanh Hoa (Figure 4).

Several fishers from both study areas were able to describe *R. swinhoei* in great detail and to recognize its photograph among the pictures of the other turtle species shown to them. Records from the Da River (Figure 5) were greater than in Thanh Hoa (Figure 6). The geographical coordinates of the sightings of *R. swinhoei* within the two study basins and the year of sighting are given in Table 3. For the Da River, 16 reliable *R. swinhoei* sightings were recorded for the period 2000–2019, with seven independent records for the period 2015–2019. In addition, 32 independent *R. swinhoei* sightings were recorded during the years before Hoa Binh dam was built (1979), thus suggesting a population collapse coincident with damming (Table 4). For Thanh Hoa Province, five recent *R. swinhoei* sightings were recorded (2004–2017), whereas 18 sightings were recorded from distinct sites within the area before the year 2000 (Table 3), suggesting a similar population collapse in this area. In all cases, however, no information is available on the observation effort in each of the periods being compared, and thus the temporal change in populations cannot be accurately evaluated with the present data.

A stuffed *R. swinhoei* individual from the Da River drainage, deposited in the Hoa Binh Museum, was examined (Figure 5). Its carapace width was 80 cm and it had a body mass of 121 kg when alive

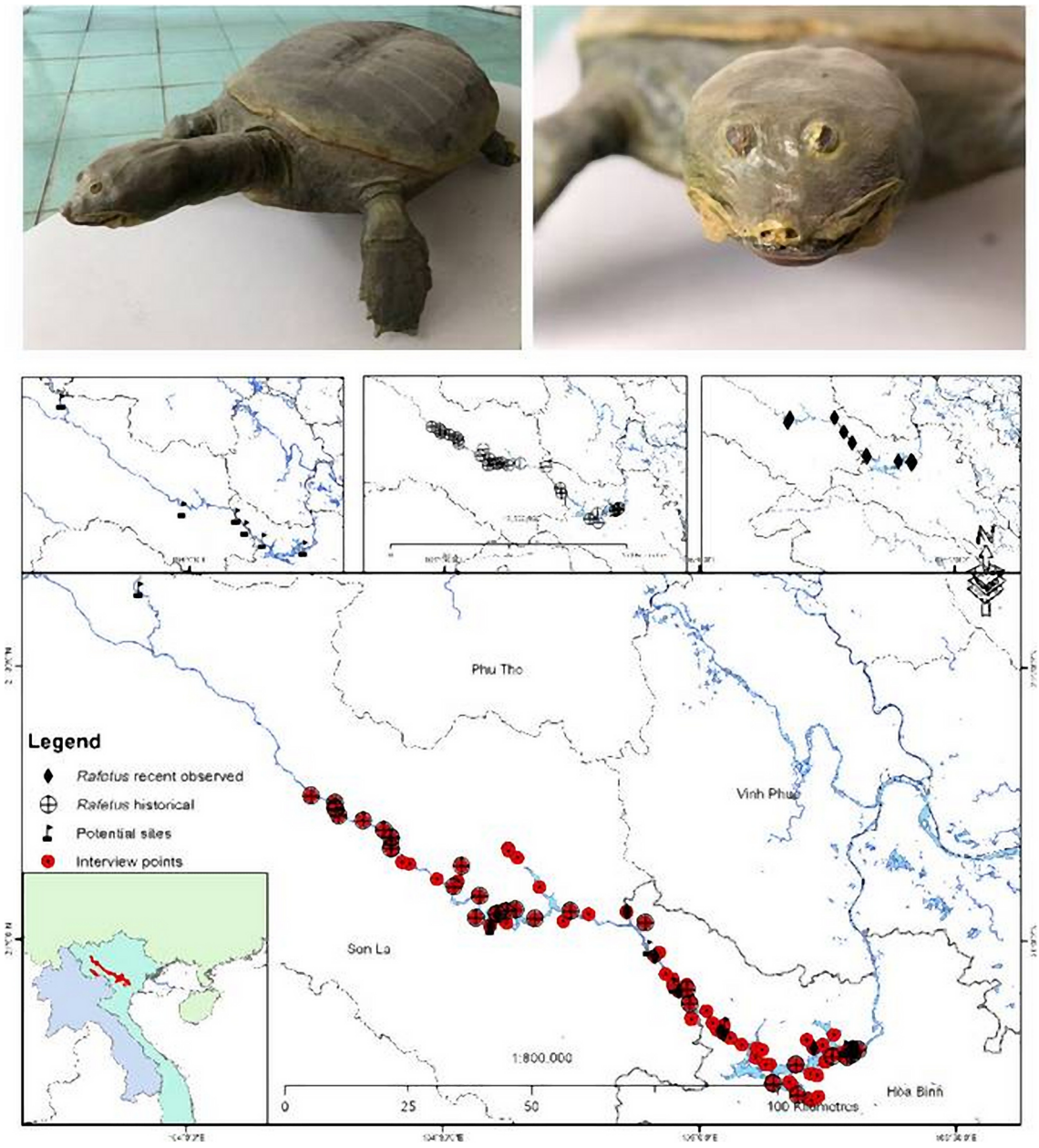

FIGURE 5 *Rafetus swinhoei* adult from the Da River basin (Quynh Lam lake) and map of the Da River showing the interview sites in which the fishers reported recent and reliable *R. swinhoei* sightings. Photos by Olivier Le Duc

(Pham, 2016). This turtle was caught in Quynh Lam Lake in Hoa Binh city in 1993. Before the building of the dam in 1979, Quynh Lam Lake was a large, natural, shallow (1–2 m in depth) wetland (of a few hundred hectares in size) with extensive mudflats and floating grasses (Pham, 2016). The lake was originally connected to the Da River but after the dam was built it became partially drained, reduced in area, and fragmented. This turtle was captured in one of the small remaining ponds. Today, the drained lake bottom has been entirely converted to agriculture and urban areas, and *R. swinhoei* has certainly disappeared from the site. Fishers along Chu and Ma Rivers, however, also confirmed the presence of large softshell turtles in small tributaries of the Chu and Ma, such as the Buoi, Am, Dat, and Cau Chay rivers. Based on our records, *R. swinhoei* were caught more often in smaller rivers and swamps rather than in the large river systems (Table 4). In the Buoi River, fishers claimed that they were able to capture more than 100 *R. swinhoei* individuals during the period 1960–1990.

3.6 | Fishers and turtle conservation perspectives

Fishers from the two study areas diverged considerably in their cultural attitude towards turtles. In Da River 63.9% of the respondents did not eat turtle eggs, whereas in Thanh Hoa Province 62.7% of the respondents routinely ate turtle eggs (inter-site differences statistically significant at $P < 0.01$, χ^2 test), and almost all of them (>95%) from both areas declared no interest in the protection of turtle eggs.

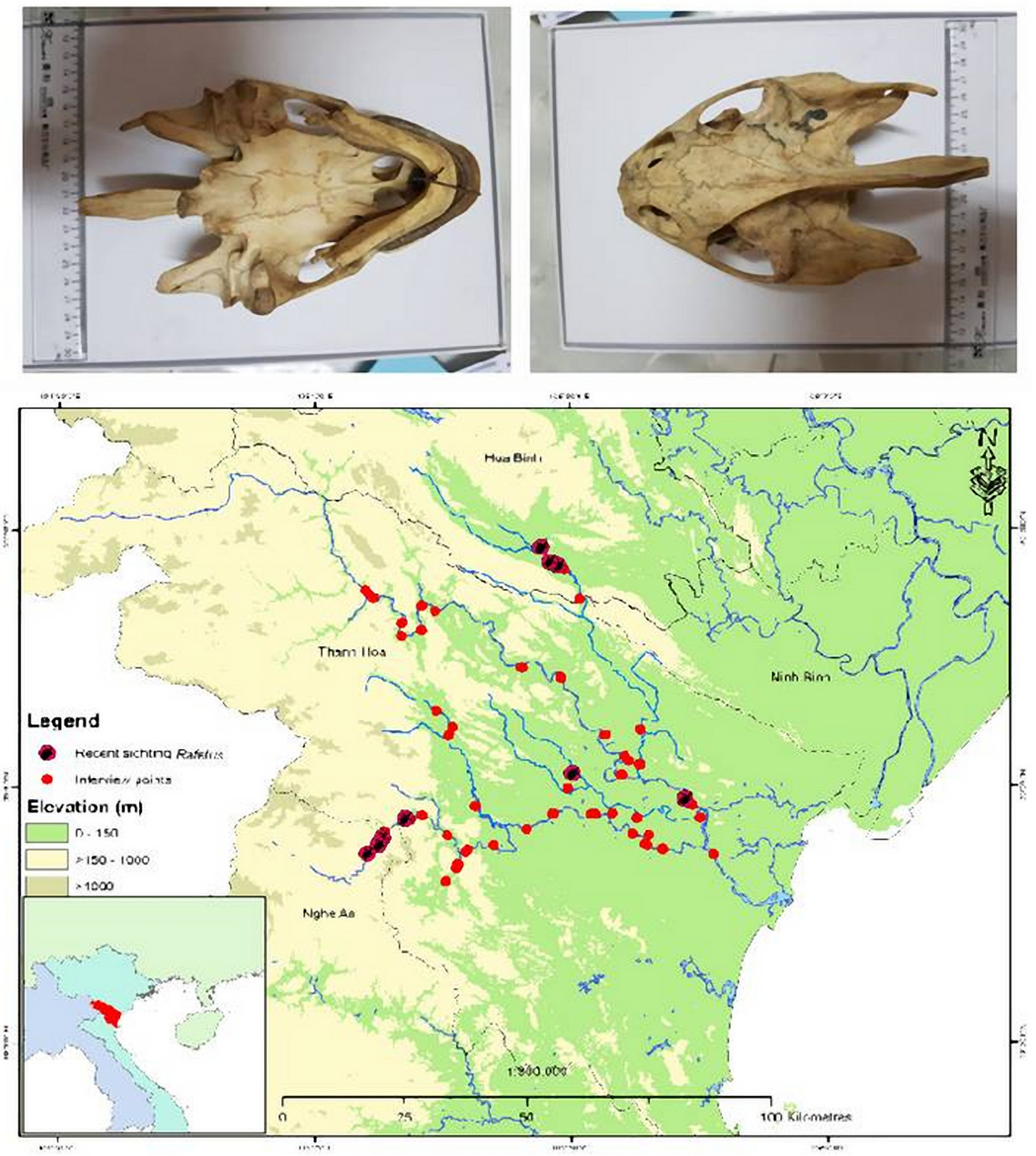

FIGURE 6 Skull of a *Rafetus swinhoei* adult from Thanh Hoa and map of Thanh Hoa Province showing the interview sites in which fishers reported recent and reliable *R. swinhoei* sightings. Photos by Thong Pham Van

Despite this, turtle eggs are not sold in markets (as confirmed by all the interviewees in both study areas), whereas adult turtles are hunted because there is considerable market demand in Da River (according to 62.7% of the interviewees) but not in Thanh Hoa Province, where only 41.8% of the interviewees considered turtles to be of relevant economic value (inter-site differences statistically significant at $P < 0.01$, χ^2 test).

4 | DISCUSSION

Face-to-face interviews with local inhabitants, especially using structured or semi-structured questionnaires, have been found to be useful for exploring the likely presence, local distribution, and apparent population trends (declining, stable, or increasing) of several species of conservation concern (Hellier, Newton, & Gaona, 1999; Padmanaba, Sheil, & Basuki, 2013; Turvey et al., 2015), and have also been validated in some instances against reliable field data. For charismatic animals such as venomous snakes, for example, interannual long-term declines derived from capture–mark–recapture studies matched closely with the results obtained from interviews (Akani, Ebere, Franco, & Luiselli, 2013). The use of traditional knowledge in conservation biology may be affected, however, by the difficulty of verifying the trustworthiness of the answers given by informants (Moro et al., 2013). Indeed, here best

TABLE 3 Synopsis of records of *Rafetus swinhoei* from interviews in the two study basins

Local name	Site name	Locations	Year	Size estimate
Gii	Da River	Voi village, Thai Thinh, Hoa Binh city, Hoa Binh Province	Aug 2017	Head size is ~15 cm in diameter
Ba ba	Da River	Voi village, Thai Thinh, Hoa Binh city, Hoa Binh Province	2006–2007	100 kg
	Da River	Voi village, Thai Thinh, Hoa Binh city, Hoa Binh Province	1989	70–80 kg
	Da River	Vay Nua village, Vay Nua commune, Da Bac District, Hoa Binh Province	Apr–May 2013	Carapace is same as buffalo size (>100 cm)
Con Ti	Da River	Xom Bich village, Thai Thinh, Hoa Binh Province	2000s	Carapace is ~200 cm
	Da River	Suoi Mu stream, Xom Bich, Thai Thinh, Hoa Binh city, Hoa Binh Province	2014–2015	100 kg
	Da River	Xom Bich village, Thai Thinh Hoa Binh city, Hoa Binh Province	2016	10 kg
	Da River	Xom Bich village, Thai Thinh Hoa Binh city, Hoa Binh Province	2009	100 kg
Con Ti	Da River	Suoi Tan, Suoi Cong Long, Hang Mieng temple, Tan Dan commune, Hoa Binh Province	2009	Carapace size is ~40–50 cm
	Da River	Yen Phong village, Yen Hoa commune, Da Bac, Hoa Binh Province	Jul–Aug 2018	10 kg (head and carapce are 10 and 40 cm, respectively)
Ba ba	Da River	Nhap stream, Nhap village, Dong Ruong commune, Da Bac District, Hoa Binh Province	2014	30 kg (head and carapace are 30 and 120 cm in diameter, respectively)
Ba ba	Da River	Thong Bai, Muong Tuong, Da Bac, Hoa Binh Province	2009	100 kg
	Da River	Ban Bin village, Nam Phong commune, Cao Phong, Hoa Binh Province	2005–2006	30 kg (carapace 50 cm in diameter)
	Da River	Bac Ban, Bac Phong, Phu Yen, Son La Province	2014–2015	Carapace size >100 cm, head size is ~20 cm
Ti	Da River	Suoi Bung stream, Bac Phong, Phu Yen, Son La Province	Feb–Mar 2019	14–15 kg
	Da River	Suoi Bung stream, Bac Phong, Phu Yen, Son La Province	Nov–Dec 2018	Carapace is ~40–50 cm
Gii, Tái, Tp	Da River	Pia stream, Muong La, Son La	1998	40–50 kg
Chnh	De swamp	Yen Dinh town, Yen Dinh District, Thanh Hoa Province	1998	30–50 kg
Ba ba to	Chu River	Dat hydro electric dam, Xuan Lien, Thuong Xuan, Thanh Hoa Province	2013–2017	Carapace is ~200 cm
Gii	Ma River	Dinh Cong, Yen Dinh, Thanh Hoa Province	1999–2004	15–20 kg
Gii	Ma River	Dinh Cong, Yen Dinh, Thanh Hoa Province	2016	17–18 kg
Chnh (Gii)	Chu River	Dong Van, Que Phong, Nghe An Province	2005–2007	40–50 kg
Chnh	Chu River	Dong Van, Que Phong, Nghe An Province	2008–2009	40–50 kg
Gii	Buoi River	Xom Kho, Tan My, Lac Son, Hoa Binh	2011–2012	30–40 kg
Gii	Buoi River	Dap Nai, Lac Son, Hoa Binh Province	2014–2015	Carapace is ~100 cm
Gii	Buoi River	Dap Nai, Lac Son, Hoa Binh Province	2017	Carapace is ~100 cm

practices that are known to minimize the untrustworthiness of informants were used (i.e. large sample sizes, independence of interviews, selection of only people with direct experience of the subject investigated, and the use of rigidly structured questionnaires; Padmanaba et al., 2013; Turvey et al., 2015), and the methodology was applied to a highly charismatic species (*R. swinhoei* is an important animal in local tradition; Van et al., 2019). We consider, therefore, that the results presented herein are likely to be reliable and can be helpful in directing future conservation works in the region surveyed.

TABLE 4 Estimate of the number of captured *Rafetus swinhoei* in Thanh Hoa Province and in the Da River basin

Local name	Site name	Year	Estimated number of *R. swinhoei* caught
Chnh (Gii)	Chu river	1968–1986	20
Chnh	De swamp	1970–1983	23
Gii	Buoi river	1960–1990	107
Gii (Chnh)	Dat river	1975–1990	3
Gii	Ma river	1970–1980	3
Chnh	Cau Chay river	1970–1980	6
Gii, Tái, Tp	Da river	1920–1998	39
		Total	201

Like other Asian river basins referred to by Dudgeon (2011), the Da River and the rivers in Thanh Hoa Province are highly biodiverse (Chung et al., 2017; Ngo et al., 2014); however, they have been severely affected by overfishing, damming, and catchment degradation. These activities have led to adverse impacts on subsistence use by local communities, with 70% of full-time inland fishers (almost exclusively men, helped during the flood season by children and women) being below the poverty line.

Fishing communities tend to be arranged in small groups operating at a very local scale, often using traditional fishing gear, with few connections to the commercial fishing industry (Ha & van Dijk, 2013; Long, 2002). Despite fishers operating with inefficient gear, it is likely that turtle populations have reached their current threatened state at least partly because of small-scale fishers who, for decades, took every turtle and every turtle egg that they found. Fishers agreed with a remarkably high consensus that fish and turtle stocks have become depleted over the years, suggesting that, under the current fragile climatic, environmental, and socio-economic scenario (i.e. with the overexploitation of resources, high atmospheric and water pollution, and widespread poverty of the local communities), even a relatively low density of badly equipped fishers could deplete existing resources.

Throughout Southeast Asia, recent large reservoir building operations and river control structures have affected fishing grounds, reduced overall fish abundance, and affected the composition of the fish catch by depleting iconic large-bodied species (Dudgeon, 2011), in a pattern that could be analogous to the fishing-down syndrome observed in West African rivers (Allan et al., 2005). The same depletion pattern must have also affected turtle populations (Moll & Moll, 2004). The Da River is controlled by about 13 dams, seven of which are in Vietnam, making it the primary hydroelectric resource in the country and one of the most important in the whole of Southeast Asia. The largest Vietnamese hydropower plant, Son La ($3.2 billion), was completed on the Da River in 2013, following the involuntary resettlement of nearly 100 000 poor local people to distant (50–100 km) and less fertile areas (Dao, 2010). Impacts on the local community, including social recession and increased poverty, have been much debated (Dao, 2010). The remaining population had to face the consequence of reduced natural resources per capita and the cumulative effects of the dam. Flow changes have affected most of the traditional economy, which is focused on wet rice cultivation, river fisheries, and aquaculture. Greater congestion and competition over reduced resources developed the risk of falling into an environmental degradation spiral, amplified by increasingly intense human use (Boonstra, Björkvik, Haider, & Masterson, 2016), to which local communities responded by migrating towards urban centres and coastal areas (Hahn & Boonstra, 2018).

Dams and river control structures have profoundly affected turtle populations (Moll & Moll, 2004), especially because the physical barrier to upstream or downstream movement created by a dam isolates turtle populations (Moll & Moll, 2004). In addition, detailed analysis of turtle food webs has shown that river damming induces turtles to reduce significantly the variety of their food (Tucker, Guarino, & Priest, 2012). Changes to resource availability force taxa that specialize in riverine biotopes to switch towards resources that are traditionally exploited by species adapted to lentic biotopes; in theory this effect would sharply increase interspecific competition and reduce species diversity (Morin, 2011). Research conducted in the Amazon (Salisbury, 2016) showed that the disruption of river hydrology and of the annual flood cycle reduces the extent of the remaining floodplain, destroying nesting beaches and significantly shrinking river turtle habitat. Reservoir sedimentation drastically reduces the volume of sand that can be transported downstream, causing the progressive disappearance of river beaches and sandy islands. In the lower catchment, local stream erosion is not compensated by new sediment deposition and critical turtle nesting sites tend to disappear (Moll & Moll, 2004).

The present study delivers worrying messages from the perspective of turtle conservation. At present, turtles are only found by some fishers. For instance, in the Da River and in Thanh Hoa, respectively, 22.8 and 62.0% of fishers interviewed had not caught turtles for the last 10 years; however, several turtle species can still be found within the two study basins, including species of high conservation concern according to the International Union for Conservation of Nature (IUCN) (Table 1). We also recorded the presence of an introduced individual of *Trachemys scripta elegans*, invasive in many regions of the world (e.g. Cadi et al., 2004; Cadi & Joly, 2004; Pupins, 2007), which could possibly compete with native species if viable populations are established (Cadi & Joly, 2004; Díaz-Paniagua, Pérez-Santigosa, Hidalgo-Vila, & Florencio, 2011; Rödder, Schmidtlein, Veith, & Lötters, 2009). The individual observed was a hatchling, indicating that this species may be able to reproduce in the wild in Vietnam (assuming that it was not a released captive). This species recently became abundant in the Vietnam pet trade (Hendrie & Trang, 2000; Van et al., 2019) and has been recorded in the wild since the early 2000s.

The most intriguing evidence collected concerns the world's rarest turtle, *R. swinhoei*. We recorded a skull belonging to this species from one of the study areas, providing indirect evidence that this species could still survive at a few sites within the two study areas (see also Van et al., 2020). Responses from several

fishers include occasional sightings of this huge species, especially along the Da River. A few of these sightings were made recently (2017–2018) by several people, suggesting that these observations were reliable, although no respondent has ever suggested that female *R. swinhoei* continue to oviposit in either study area.

4.1 | Implications for the conservation of *Rafetus swinhoei* in the study region

The present study produced some clear results that suggest further urgent actions are needed for turtle conservation. Indeed, although there is verbal evidence that a few *R. swinhoei* individuals still inhabit the two basins surveyed (possibly at several sites), there is no evidence that this species is still breeding in the wild. We urge the relevant authorities to conduct careful trapping expeditions at sites where *R. swinhoei* have been observed recently (see Table 3), and at historical sites where former turtle hunters continue to report a presence (Van et al., 2020), in order to evaluate whether this species remains in the region and, if so, its population status. Standard trapping methods (Vogt, 1980) can be applied systematically at all potential sites, thus greatly enhancing the chances of capturing live *R. swinhoei*. Other methods, such as sampling using environmental DNA (eDNA), may provide helpful advice for uncovering evidence of the presence of *R. swinhoei* in more sites than those currently known (Stanford et al., 2018; Van et al., 2020), as has already been achieved for other species (Davy, Kidd, & Wilson, 2015; Kundu & Kumar, 2018). However, Raemy and Ursenbacher (2018) have demonstrated that this method of population monitoring should be applied to aquatic reptiles with caution because the eDNA concentration detected is not correlated with the number of turtle individuals or with their biomass. We also suggest that the availability of potential nesting sites (sandy beaches along the river banks) should be rigorously evaluated in order to assess indirectly the future perspectives of wild reproduction if a few animals still survive locally. This information can guide decisions on whether to remove the wild individuals and relocate them with conspecifics in more adequate areas (perhaps in captivity, if nesting beaches are not available), or to artificially create suitable sites for turtle nesting *in loco*.

Community-based conservation is unlikely to work appropriately in the study areas because fishing represents the most important economic source of income for the local communities, and these giant turtles are well known to cause serious damage to fishing gear and in general to the local activities of the fishers (Van et al., 2020); however, a more stringent awareness campaign towards fishers should also be put in place to modify, if only partially, the negative view that many fishers have concerning *R. swinhoei*. In this regard, the Asian Turtle Program (http://www.asianturtleprogram.org) has already been working actively at enhancing awareness towards turtles in Vietnam, and this approach should be continued and strengthened with the help of local authorities, even reaching the most remote fisher communities. If further screening of the potential nesting beaches fails to discover new sites of reproduction of *R. swinhoei*, we believe that the only practicable solution will be to capture the few remaining wild individuals and attempt to breed them in captivity before any further release to the wild.

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CONFLICT OF INTEREST

None.

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