ARTICLES

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Home Ranges and Movement Patterns of the Chinese Softshell Turtle (*Pelodiscus sinensis*) in the Yellow River, Northwestern China

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Abstract. – A detailed understanding of the spatial ecology and habitat requirements of endangered species is critical for population restoration and conservation. Home ranges and movements of the endangered Chinese softshell turtle (*Pelodiscus sinensis*) were investigated in the Yellow River, northwestern China, from October 2016 to July 2018. We monitored 9 adult turtles (5 females and 4 males) with radio transmitters. Mean linear range size was 440 ± 161 m SD, mean river channel area was 1.98 ± 0.72 ha SD, the average minimum convex polygon was 1.36 ± 0.65 ha SD, average 95% kernel density estimator measured 0.84 ± 0.51 ha SD, with a core area (50% kernel density estimator) of 0.30 ± 0.20 ha SD. Home range values were not significantly different between the sexes nor were they related to straight-line carapace length or mass. Daily movements of *P. sinensis* averaged 35 ± 18 m SD for males and 43 ± 18 m SD for females, and there was no significant difference between sexes or significant correlation between movement patterns and body size. However, during the nesting season, there was a significant difference between sexes. Turtle activity was highest in May (average daily movement 59 ± 6 m SD) and lowest in January (0.4 ± 0.6 m SD). Given that *P. sinensis* individuals have small home ranges and are capable of existing in small rivers, management efforts should protect smaller rivers that may be easily overlooked. Results from this study provide the first assessment of home range requirements for *P. sinensis*, which may be used in future population modeling efforts and are important for establishing conservation strategies for this vulnerable species.

Key Words. – daily movements; fixed kernel density estimator; minimum convex polygon; *Pelodiscus sinensis*; radio tracking; Yellow River

Chinese softshell turtles (*Pelodiscus sinensis*) have a broad geographical distribution across East Asia from China to Russia as well as some inland freshwater rivers in Japan, Korea, and southern Vietnam (Turtle Taxonomy Working Group [TTWG] 2017). Populations have been declining at rapid rates, largely due to the pet trade and because they are often used as food and traditional medicine in China (Cheung and Dudgeon 2006). As a consequence, the Chinese softshell turtle is listed on the International Union for Conservation of Nature (IUCN) Red List as Vulnerable (VU) (Zhao 1998; Bu et al. 2014). Previous research on *P. sinensis* provided descriptions of their aquaculture (Li et al. 2013), disease control (Takuma et al. 2011; Dang et al. 2015), morphological characteristics (Li et al. 2004), and sex differentiation (Du and Ji 2003). However, despite its close association with humans, very little is known about its life history and ecology in its natural habitat.

Home range analysis can be an effective tool for evaluating the area and habitat used by a focal species, which can enable targeted measures to protect these key areas (Murphy and Noon 1992; Linnell et al. 2001). Previous studies have shown that animal movement patterns are closely related to feeding and reproduction (Doody et al. 2002; Litzgus and Mousseau 2004). However, of the 356 total species of turtles and tortoises (TTWG 2017), there are detailed analyses of their home range and movement for only 64 species (18%; Slavenko et al. 2016).

The only existing information about movement patterns in *P. sinensis* comes from a summary of anecdotal accounts (Yang et al. 1999), with no quantitative data available on its home range. Proper management and conservation practices will require detailed knowledge of geospatial patterns—where animals are, where they are not, and why. In this study, we investigated the home

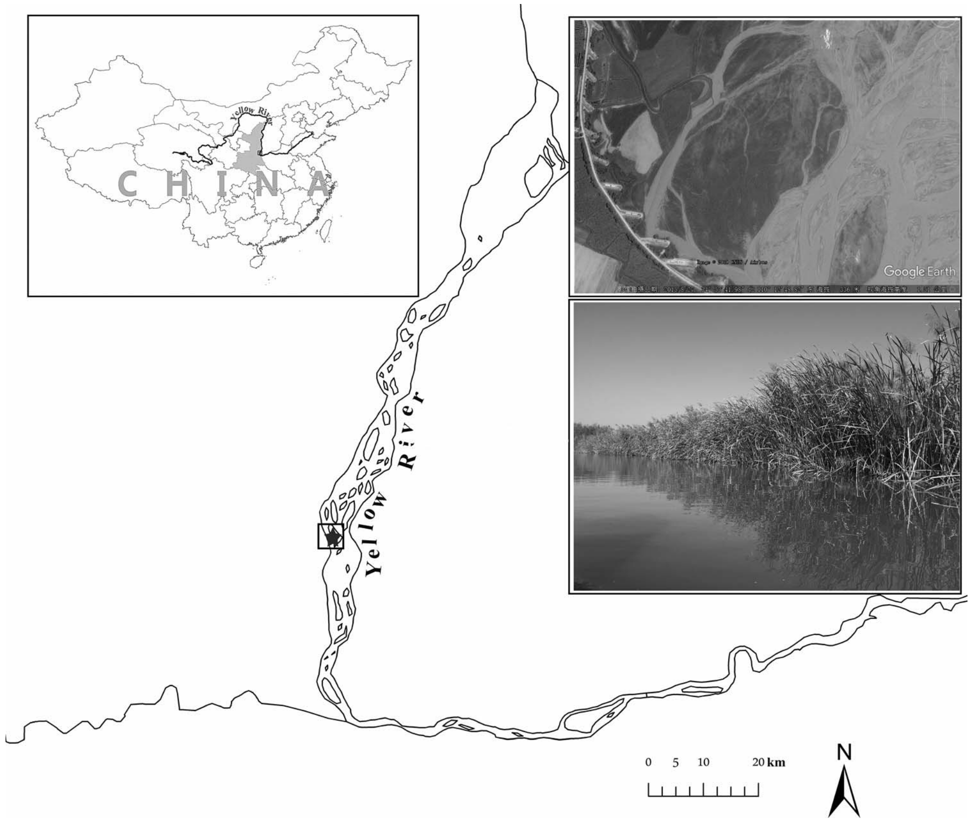

Figure 1. Habitat of *Pelodiscus sinensis* in the Yellow River, with the study area indicated with a star.

range size and movement patterns of *P. sinensis* in the Yellow River, northwestern China.

METHODS

Study Site. — The research site is a 2-km section of the Yellow River (34°53′33″–34°59′13″N to 110°10′23″–110°13′06″E) in northwestern China (Fig. 1). This section includes more than 120 ha of wetlands, associated tributaries, and channels which feed into the main streams. Tributaries range from 21 to 71 m in width; while all the water bodies are 0.5–3.2-m deep with sand and soil substrata. Dense patches of *Phragmites australis*, which reach 2.5 m in height, cover tributaries, while *Acorus calamus* and *Carex dispalata* cover the surrounding area (Fig. 1). Much of the shoreline of the Yellow River is unvegetated and thus is available for basking or nesting. Vertebrate species (fish, frogs, etc.) and invertebrates (insects, mollusks, shrimp, etc.) are found in the area and, along with some plants, serve as potential prey for *P. sinensis*. A large number of soft-shelled turtles in this area are caught on baited hooks or entangle themselves in fishing nets of fisherman every year, and these captured individuals are sold for human consumption (Kong 2020).

Radiotelemetry and Data Collection. — All turtles were trapped using cylindrical, dual-funnel nylon hoop net traps with 3-cm square mesh (60 cm in diameter × 10 cm high; funnel opening 25 cm in diameter). Captured turtles were equipped with very high frequency (VHF) transmitters (164 MHz; AL-2F, Holohil Systems Ltd, Caro Ontario, Canada) with the transmitter and recorder being tested and calibrated before attachment. The transmitters were fixed to an aluminum plate before being secured at the rear edge of the carapace with nylon wire through 2 holes (0.5 mm in diameter) (Fig. 2). The total weight of the transmitter was 25 g, which amounted to 1.2–4.2% of the turtle's body weight (Table 1). All the turtles were released at their capture sites within 48 hrs.

We tracked turtles from October 2016 to July 2018, during 1 wk per month in the overwintering period (November to March) and during 3 d per week in the active season (April to October). The breeding season is from April to August, and the turtles nest from May to August (Yang et al. 1999). We used a TRX-1000S receiver (Carbondale, IL) and a three-element antenna to track the radio-tagged turtles. A Garmin 60 CSX global positioning system (GPS) was used to record positions, and GPS Track Maker was used to plot positions on maps to calculate daily movement distances. The GPS accurately recorded the daily position changes of each turtle, and the data were accurate to within 1 m based on signal strength.

Data Analysis. — We used ArcGis 9.3 (Environmental Systems Research Institute [ESRI]) to measure linear ranges (LRs) by calculating the linear distance between the most-separated positions of each turtle (Sexton 1959; Pluto and Beilis 1988; Lue and Chen 1999). Because this turtle species is highly aquatic, the LRs did not include possible

Figure 2. *Pelodiscus sinensis* with a very high frequency radio transmitter attached to its posterior carapace.

terrestrial movements, but rather indicated the shortest aquatic distance between the most-separated positions. The analysis of turtle movements was based on the river channel area (RCA) estimator, and 3 different home range estimators: 1) the minimum convex polygon (100% MCP); 2) the 50% kernel density estimator (KDE); and 3) the 95% KDEs. RCA data were calculated by multiplying the average river width by the aquatic LR length of the turtles (Kay 2004; Souza et al. 2008). Row and Blouin-Demers (2006) suggested using MCPs as a consistent means for calculating home ranges that avoid subjective choices of smoothing factors and the type of kernel used. However, it tends to include large areas never used by the animal (Powell 2000). MCPs are easy to compare among studies and are the most frequently used measure and, therefore, were included in the present analysis (Harris et al. 1990; White and Garrott 1990). KDEs are obtained using a special nonparametric probability density function that is used to describe the nonlinear contour of the range of animal activities (Worton 1989). Because turtles are aquatic organisms, the final KDE data excluded all land data. MCPs, 95% KDEs, and 50% KDEs were calculated using Home Range Tools for ArcGIS version 2.0.

Table 1. Summary of morphometric and telemetry data of the *Pelodiscus sinensis* studied for home range and movement analyses. F = female; M = male; BM = body mass; SCL = straight-line carapace length; Fixes = the numbers of relocations; * = excluded from analyses.

Turtle ID	BM (g)	SCL (mm)	Fixes	No. of days	Tracking periods
Males					
M1-009	1300	22.0	47	189	10/16–05/17
M3-209*	1000	20.0	0	8	10/16–11/16
M4-028	591	17.5	41	112	03/17–08/17
M5-209	627	17.5	60	172	04/17–11/17
M6-050	897	20.0	36	76	04/17–08/17
Females					
F2-028	650	17.5	47	189	10/16–05/17
F7-240*	1425	23.0	0	2	08/17–08/17
F8-058*	1050	21.0	0	5	08/17–08/17
F9-240	1425	23.0	30	52	08/17–10/17
F10-058	1050	21.0	30	52	08/17–10/17
F11-028*	1069	21.0	0	6	05/18–06/18
F12-101	1250	22.0	26	47	05/18–07/18
F13-107	2100	20.3	26	47	05/18–07/18

SPSS 19.0 (SPSS, Chicago, Illinois) was used to test for differences in turtle movement and home range data. We tested data for normality and uniformity of variance before the analyses (Sokal and Rohlf 1969). Differences in radio-tracking data between sexes were tested using Mann-Whitney U-tests ($p < 0.05$). The relationship between movements and body size was tested with linear regression.

RESULTS

From October 2016 to July 2018, we radio-tracked 13 adult turtles (5 males and 8 females) with mean mass of 1110 g (range, 591–2100 g); mean straight-line carapace length (SCL) was 20.3 cm (range, 17.5–23.4 cm). Because of transmitter failure in one case, and because 3 other turtles were never located, data were analyzed only for the remaining 9 turtles (4 males and 5 females). Mean tracking time was 17 ± 9 wks SD (range, 8–28 wks). Most

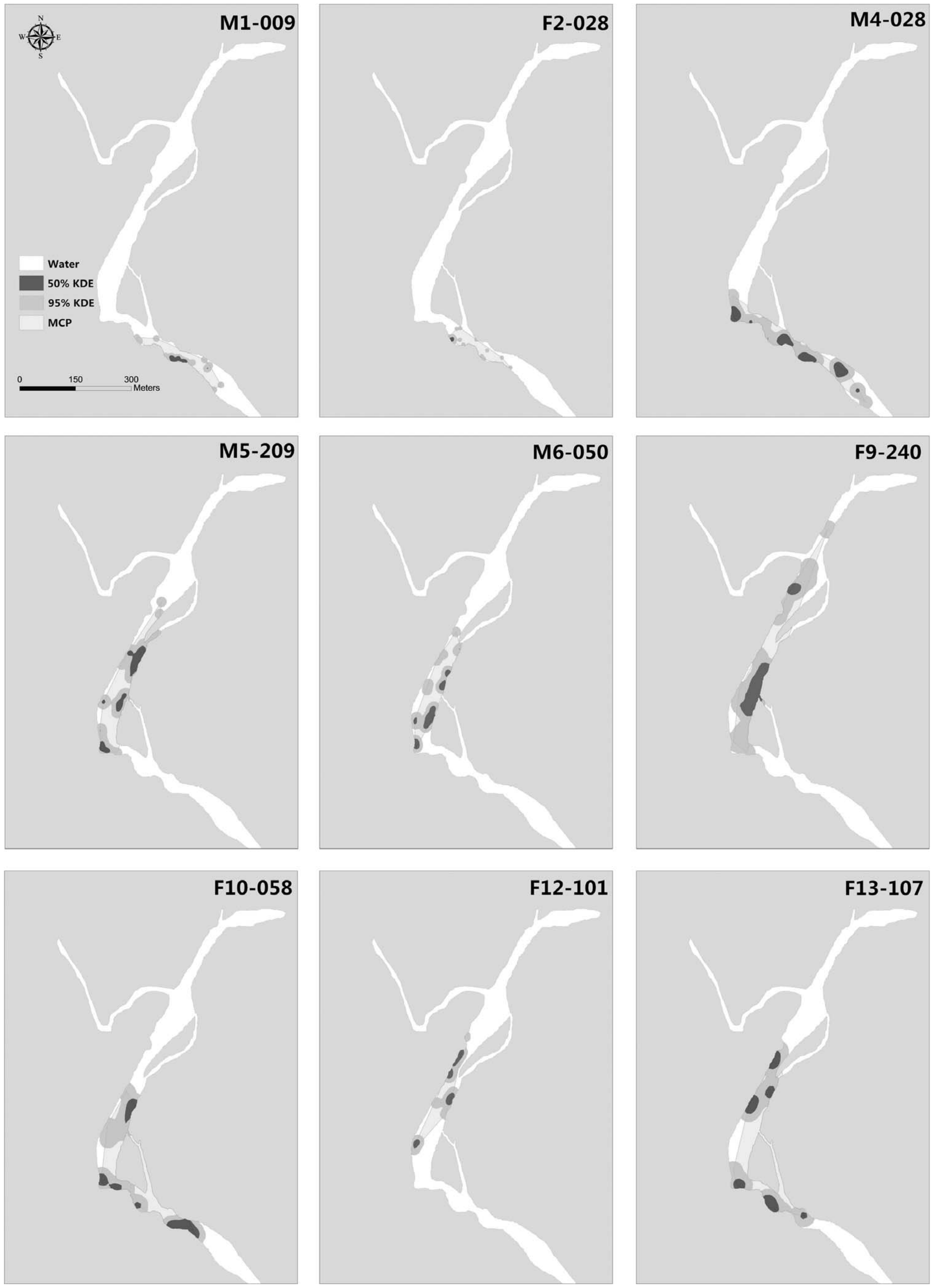

Figure 3. Map of the study area showing 9 *Pelodiscus sinensis* MCPs, 9% KDE, and 50% KDE home ranges (map designed using ArcGis 9.3, ESRI Inc).

relocations were confined to aquatic areas and basking sites along the river (n = 343 total number of fixes; Table 1).

Home Range Size. — Mean LR of radio-tracked *P. sinensis* was 400 ± 109 m SD (279–496 m, n = 4) in males and 473 ± 200 m SD (188–694 m, n = 5) in females. Mean LR size was 440 ± 161 m SD (188–694 m, n = 9) for all turtles. Mean RCA was 1.98 ± 0.72 ha SD (0.85–3.12 ha, n = 9) for all turtles, with a mean in males of 1.80 ± 0.49 ha SD (1.26–2.23 ha, n = 4) and in females of 2.13 ± 0.90 ha SD (0.85–3.12 ha, n = 5; Table 1). The LR/RCA ratio showed no significant difference between sexes (U = 14, p = 0.413, n = 9) and no significant relationship with SCL (linear regression: r = 0.287, p = 0.454, n = 9).

The size of the MCPs varied greatly among individuals (0.44–2.19 ha), with a mean size of 1.36 ± 0.65 ha SD. The mean total KDE size was 0.84 ± 0.51 ha SD, whereas individual 95% KDEs ranged from 0.11 to 1.70 ha. The mean core area was 0.30 ± 0.20 ha SD and ranged from 0.01 to 0.56 ha (Fig. 3). Home range size did not differ between the sexes (U = 13, p = 0.556, n = 9), and there was no significant relationship with body size (MCP and SCL: r = 0.202, p = 0.603,

Table 2. The home range by minimum convex polygon (100% MCP), 95% and 50% kernel density estimator (KDE) core areas, linear range (LR), and river channel area (RCA) for the 9 radio-tracked *Pelodiscus sinensis* individuals.

	Home range sizes				
Sex and ID	MCP (ha)	95% KDE (ha)	50% KDE (ha)	LR (m)	RCA (ha)
Males					
M1-009	0.69	0.26	0.05	279	1.26
M4-028	1.36	1.09	0.41	496	2.23
M5-209	1.65	0.87	0.31	488	2.20
M6-050	1.18	0.68	0.21	336	1.51
Females					
F2-028	0.44	0.11	0.01	188	0.85
F9-240	2.19	1.70	0.56	694	3.12
F10-058	1.98	1.24	0.47	551	2.48
F12-101	0.71	0.48	0.16	356	1.60
F13-107	2.06	1.14	0.48	576	2.59

$n = 9$; 95% KDE and SCL: $r = 0.265$, $p = 0.491$, $n = 9$; 50% KDE and SCL: $r = 0.192$, $p = 0.621$, $n = 9$; Table 2).

Home Range Overlap. — Each turtle's MCP overlapped with the MCPs of 3–8 other turtles (mean = 0.53 ± 0.50 ha SD, $n = 9$). Mean MCP overlap areas varied from 0.09 ± 0.17 to 1.13 ± 0.33 ha SD. The total 95% KDEs overlapped with 4–8 other turtles (mean $t = 0.33 \pm 0.32$ ha SD, $n = 9$), with mean areas of overlap ranging from 0.04 ± 0.05 to 0.76 ± 0.35 ha SD. The 50% KDEs overlapped with 2–7 core areas of other turtles (mean = 0.03 ± 0.04 ha SD, $n = 9$), with mean areas of overlap ranging from 0.003 ± 0.005 to 0.08 ± 0.03 ha SD.

Movements. — Average daily movement of turtles was 40 ± 17 m SD, with distances traveled in a day ranging from 0 to 384 m. Males moved an average of 35 ± 18 m/d SD and females moved 43 ± 18 m/d SD. The daily movement distances of radio-tagged turtles spanned 0–77.42% of their LR (Table 3). Male and female movements did not differ (U = 15, $p = 0.286$, $n = 9$), and there was no significant correlation between movements and body size (movements and SCL: $r = 0.659$, $p = 0.053$, $n = 9$).

Daily movements were greatest in May (average 59 ± 6 m/d SD) and lowest in January (average 0.4 ± 0.6 m/d SD). The most active months for males were April to May (54 ± 19, 56 ± 6 m/d SD) and for females were May to August (63 ± 5, 57 ± 3, 49 ± 5, 57 ± 0 m/d SD; Fig. 4).

The difference in daily movement estimates for males and females was not significant during the overwintering period (November to March of the following year; U = 10, $p = 0.429$, $n = 11$), the active season (April to October; U = 154, $p = 0.173$, $n = 31$), the breeding season (April to August; U = 98, $p = 0.073$, $n = 24$) or the mating season (April to May; U = 12, $p = 0.83$, $n = 10$). There was a significant difference in movements between sexes during the nesting season, with females moving more than males (May to August; U = 68, $p = 0.012$, $n = 18$), but there was no significant relationship between movements and body size at this time (movements and SCL: $r = 0.613$, $p = 0.143$, $n = 7$).

DISCUSSION

Home Range Size. — Previous studies and estimates of the home range sizes of trionychid turtles include *Apalone spinifera* (Galois et al. 2002), *Rafetus euphraticus* (Ghaffari et al. 2014), and *Apalone mutica* (Jason 2016). Our results show that home range sizes (including MCP, 95% KDE, 50% KDE) of *P. sinensis* were smaller than those of other trionychid turtles. Differences in home range size between different trionychid turtles are likely to be explained by the type of habitat and the size of the river in which they occur (Ghaffari et al. 2014). Compared with previous studies of trionychid home ranges (*A. spinifera*, 2424 ha, Galois et al. 2002; *R. euphraticus*, 266.42 ha, Ghaffari et al. 2014; and *A. mutica* 15 km, Jason 2016), our study area was relatively small, covering only 2 km of tributaries through wetlands (120 ha) that fed into the

Table 3. Daily movement distances of *Pelodiscus sinensis*.

	Daily movement distance (m)		% of linear range	
Sex and ID	Mean ± SD	Range	Mean ± SD	Range
Males				
M1-009	9.2	0–62	3.3	0–22.22
M4-028	45.9	0–384	9.25	0–77.42
M5-209	40.7	2–207	8.34	0.41–42.42
M6-050	46.1	7–178	13.72	2.08–52.98
All males	35.48 ± 17.69	0–384	8.65 ± 4.27	0–77.42
Females				
F2-028	11.9	0–102	6.33	0–54.26
F9-240	46	7–144	6.63	1.01–20.75
F10-058	46	6–144	8.35	1.09–26.13
F12-101	55.8	5–148	15.67	1.40–41.57
F13-107	54.4	3–132	9.44	0.52–22.92
All females	42.82 ± 17.88	0–148	9.28 ± 3.79	0–54.26
All turtles	39.56 ± 17.10	0–384	9.00 ± 3.76	0–77.42

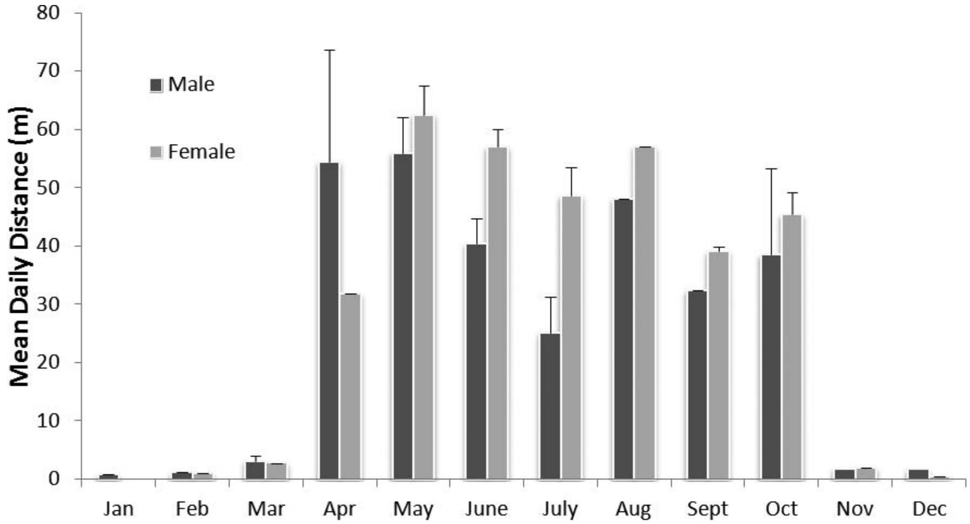

Figure 4. Monthly average movements (± SD) of *Pelodiscus sinensis* in the Yellow River from 2016 to 2018 (n = 343).

Yellow River. Moreover, the size and weight of *P. sinensis* captured in this study were smaller than those of the trionychid species investigated by previous studies. Generally speaking, large animals need more energy to maintain their activities, so they require larger foraging areas to obtain enough food (McNab 1963). In addition, previous work showed that *P. sinensis* was omnivorous (Yang et al. 1999), which differs from the more common carnivorous diet of the trionychid species previously studied. Generally, carnivores have larger home ranges than herbivores or omnivores of similar sizes (Peppy and Garland, 2002).

Movements. — In the Yellow River, movements of *P. sinensis* were extremely variable. The average daily movement data show pronounced individual variation (9–56 m/d). Turtles moved as little as 0 m and as far as 384 m in 1 d. We observed 1 individual basking for a few days along a shallow-water shoreline without any vegetation. The long-distance movements made by *P. sinensis* were probably to explore available habitat and resources (Hall and Steidl 2007; Ailed et al. 2017). Both *A. mutica* and *A. spinifera* have been observed making exploratory movements in other studies (Plummer and Shirer 1975; Plummer et al. 1997).

The study site area was in a temperate region, with an average annual temperature of 13.4°C (data from the meteorological bureau of WeiNan, http://sn.cma.gov.cn/dsqx/wnqx/). Turtles in temperate regions tend to have temporal patterns of movement (Ernst and Lovich 2009), often with a seasonally bimodal activity pattern (e.g., *Glyptemys muhlenbergii*; Nemuras 1967; Ernst and Barbour 1989). Chinese softshell turtles in our study exhibited a pattern of seasonally bimodal activity, with our data showing that activities increased significantly in spring (April–May) and autumn (September–October), just after and before hibernation. Increased feeding to restore depleted energy reserves after overwintering, seeking mates, and nesting are probable causes of the longer movements earlier in the season (Lovich 1988). In contrast, in the heat of summer (July–August), turtles were often observed aestivating in the water, presumably to escape the hot conditions, which resulted in reduced activity levels (Sun 2009).

In aquatic turtles, movements can vary greatly according to sex (MacCullogh and Secoy 1983; Doody et al. 2002). The "reproductive strategies hypothesis" proposes that males tend to be more active and travel greater distances than do females during the breeding season and that their range of activity is significantly increased in order to improve mating success (Morreale et al. 1984; Gibbons et al. 1990). Our data showed no significant difference in movements between sexes during the breeding season (April–August). The need to travel long distances in search of a mate may be reduced by the high overlap of home ranges between individual turtles documented in this study. For example, we observed 2 individuals of the opposite sex basking in the same field less than 5 m apart. In contrast, there was a significant difference between sexes in movements during the nesting season (May–August), which is consistent with the reproductive strategies hypothesis wherein activity distances of gravid females are increased as they seek suitable nesting areas.

Conservation and Management. — The Yellow River is the second-longest river in China. In the past, sandy soil riversides were frequently destroyed by the rushing waters. Local governments constructed stone and concrete riversides to protect the lives and property of the people. Although the hardened riversides have prevented the Yellow River from flooding, *P. sinensis* is directly affected by this habitat modification, especially as it affects nesting sites. Turtles might be forced to move farther or climb over the wall to lay their eggs, and overland movements may increase energy consumption and predation risks. Therefore, we suggest that conservation efforts should focus on maintaining aquatic connectivity and protecting the natural geomorphologic state of rivers as much as possible in flood regulation projects. Further, Cai et al. (2002) reported that the Yellow River population of Chinese softshell turtle exhibited better economic traits and genetic traits compared with other populations in China. With the development of turtle captive breeding, wild individuals were captured in large numbers for stock from the Yellow River over past years (Zhang 2011). To successfully sustain viable populations, China created the Chinese softshell turtle National Aquatic Germplasm Reserve of Yellow River Beach in 2012, but the phenomenon of overfishing and overharvesting frequently was noted during our investigations. For this species to be best protected, hunting, fishing, commerce, and consumption need to be prohibited while patrolling for enforcement needs to be initiated.

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