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Habitat Preference and Management of a Chinese Pond Turtle Population Protected by the Demilitarized Kinmen Islands

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ABSTRACT.—**Demilitarized zones may aid in the protection of endangered wildlife. We compared relative abundance of the endangered Chinese Pond Turtle (*Mauremys reevesii*) among water bodies on the Kinmen Islands, a recently demilitarized zone between Taiwan and China. Vegetation and wildlife on the two islands, located 2 km from the Chinese coastline, were degraded by bombardment and military occupation between 1958 and early 2000s. However, natural habitats gradually recovered after military forces withdrew. More than 100 ponds, mostly produced during the occupation to provide freshwater for the soldiers, are now abandoned and provide habitat for aquatic turtles. We sampled 41 ponds and found that presence of *M. reevesii* was tightly associated with vegetation coverage around the pond, whereas its relative abundance was associated with aquatic vegetation and distance from roads. Comprehensive protection and management of this species should consider both vegetation coverage and road effects in certain vulnerable areas where establishment of a natural reserve might be considered.**

The function of demilitarized zones (DMZs) as wildlife refugia is a peculiar issue in conservation biology. Such locations usually are established to separate different nationalistic, political, or ideological groups and to stop international military conflicts. DMZs previously suffered intense military action, which might result in the local extinction of flora and fauna. However, wildlife populations may recolonize and recover after the establishment of corridors (Kim, 1997; Draulans and Krunkelsven, 2002; McNeely, 2003). The most famous example is the DMZ between North and South Korea (Kim, 1997; McNeely, 2003), which provides a sanctuary for many rare wild animals and plants (Higuchi et al., 1996; Kim, 1997). Similar cases have been described in Vietnam (Dillon and Wikramanyake, 1997), Guinea (Fairhead and Leach, 1995), and several eastern European countries (McNeely, 2003). These examples indicate that neglected landscapes created by human warfare may provide suitable habitats for wildlife by limiting human population densities (Dudley et al., 2002; McNeely, 2003).

The Kinmen Islands might be one of the recent cases of DMZs protecting wildlife populations (You et al., 2013). The two islands, including Kinmen (134.3 km^2) and Lesser Kinmen (14.9 km^2), located 2 km from the southeastern coastline of mainland China, are among the few islands that are close to the mainland but remained under Taiwanese military control after the post–World War II separation from China. In August 1958, the fierce "Bombardment of Kinmen" started in this region and destroyed almost all of the buildings and vegetation on the two islands. To defend against the Chinese army, approximately 100,000 Taiwanese soldiers were stationed on Kinmen. The resulting high human population density further degraded native ecosystems and wildlife populations.

However, relaxation of political tensions between Taiwan and China has resulted in the gradual withdrawal of most of Taiwan's military force from the islands. Since 2001, the Chinese and Taiwanese governments agreed to use this region as a trade and transportation center. Fewer than 5,000 Taiwanese soldiers remain, and the military has abandoned large areas outside the main cities and harbors. Recent studies have shown the population recovery of several endangered species from near extinction or from local extinction, including the Eurasian Otter *Lutra lutra* (Hung et al., 2004) and the Horseshoe Crab *Tachypleus tridentatus* (Chen et al., 2004). A large lagoon in Kinmen is now sustaining one of the largest wintering populations of cormorants (*Phalacrocorax carbo*) in East Asia (Chang et al., 2008), whereas Blue-Tailed Bee-Eaters (*Merops philippinus*) take advantage by nesting in artificial sand banks abandoned by the military (Yuan et al., 2006; Wang et al., 2009). A stable population of Burmese Pythons (*Python molurus*) was found after they were thought to be extinct for nearly 40 years, using abandoned military underground tunnels as wintering shelters (You et al., 2013). All of this evidence shows the process of wildlife recovery after natural habitats are released from human disturbance.

The Chinese Pond Turtle, *Mauremys reevesii*, is endangered (IUCN, 2013); wild populations have declined (Lovich et al., 2011) because of intense harvesting for food or for traditional Chinese medicines (Chen et al., 2000; Cheung and Dudgeon, 2006; Shi et al., 2008; Zhou and Jiang, 2008). This species still exists in large numbers but mainly on commercial turtle farms in China, and natural populations rarely are found. However, the unique military situation and the creation of numerous freshwater habitats on Kinmen helped preserve a natural population of *M. reevesii*. We investigated its status and habitat preferences; the information will aid in developing conservation and management guidelines.

MATERIALS AND METHODS

Study Area.—The Kinmen Islands (24°27′N, 118°24–28′E), which comprise Kinmen (134.3 km^2) and Lesser Kinmen (14.9 km^2), are located roughly 2 km from the southeastern coastline of mainland China (Fig. 1). They have a subtropical monsoon climate with 21°C mean annual temperature (winter mean temperature = 14°C; summer mean temperature = 29°C) and uneven precipitation (mean annual precipitation = 1,047 mm; winter is the dry season). To sustain the water use of the 100,000 soldiers, villagers were encouraged to dig water pools to preserve valuable freshwater resources during the war. Thus, numerous ponds and lakes (> 100 ponds within a 150-km2 area) were built and maintained on the islands. Six turtle species have been recorded on Kinmen, including the most abundant native *M. reevesii*, the comparatively rarer *Pelodiscus sinensis*, and the

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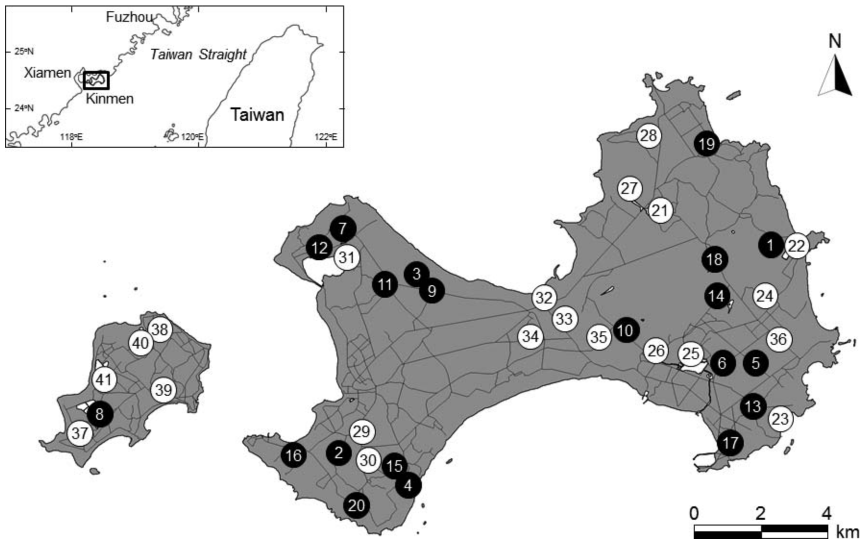

FIG. 1. Sample sites and main roads on Kinmen and Lesser Kinmen Islands. Filled and open circles denote ponds with or without *Mauremys reevesii*, respectively. Further information, including parameters, sympatric species, abundance index, and sex ratio of each pond is available in Appendix 1.

recently introduced species *Mauremys sinensis*, *Mauremys mutica*, *Cuora flavomarginata*, and *Trachemys scripta* in small numbers.

Trapping Procedure and Habitat Delineation.—We conducted captures in 41 ponds, lakes, and marshes. Six sites were on Lesser Kinmen Island, and 35 sites were on Kinmen Island (Fig. 1). We trapped between June and September in 2011 using floating hoop net traps baited with canned fish. Depending on the size of the water body, 2–5 traps with 50-m spacing were deployed for 4 days, and baits were replenished daily. Each captured turtle was weighed, measured (carapace and plastron length), and sexed. Individuals were marked uniquely by notching the marginal scutes (Cagel, 1939) and then released.

We measured or estimated 7 habitat variables at the start of the capture event in each water body (Table 1). Two of these factors, shortest distance to main roads (DM) and shortest distance to secondary roads (DS), were continuous variables. Other categorical data included level of vegetation coverage on the land (VL), level of vegetation coverage in the water (VW), substrate type around the pond (PS), area of the pond (PA), and depth of the pond (PD) (definitions in Table 1). These categorical factors were transformed into dummy variables to convert categorical data into 0 and 1 for regression analysis and then combined with continuous factors as explanatory variables in the subsequent statistical analyses.

Model Building and Evaluation.—We used the 7 habitat variables to build regression models of the presence and abundance of *M. reevesii*. First, we checked the correlation among habitat characteristics to prevent multicollinearity. If the coefficient of the pairwise Spearman correlation ($|r_s|$) between two variables was > 0.7, we retained the biologically meaningful variable or the variable that better explained the deviance and variation of the response variable. After excluding multicollinearity, we chose a useful subset of predictors by variable selection to explain the variation of the response variable from numerous predictor variables through forward selection procedures (enter and leave probabilities were equal to 0.10). Interaction terms among explanatory variables were checked after variable selection according to the approach proposed by Hosmer and Lemeshow (2000). We completed multiple logistic regression analysis to predict the presence of *M. reevesii* by using binominal presence–absence data as the response variable. We used summarized area under the curve (AUC; > 0.7 indicated the model to be discriminative) to evaluate the discrimination of final logistic regression model. In addition, we conducted a multiple regression analysis using habitat variables to predict the relative abundance of *M. reevesii*. Because residuals of the regression model were not normally distributed, captures per trap day were log-transformed (ln + 1) and used as a response variable; goodness-of-fit was evaluated by its coefficient of determination (R^2). Both likelihood ratio test and partial F-test were used to choose the best model from candidate models, which have different terms of selected variables, and to check the significance

TABLE 1. Variables of habitat characteristics and the results of forward selection procedures with enter and leave probabilities of 0.1.

Abbreviation	Description	Data type	Selected for logistic regression	Selected for linear regression
DM	Shortest distance to a main road	Continuous	No	Yes
DS	Shortest distance to a secondary road	Continuous	No	No
VL	Vegetation coverage on land[a]	Ordinal	Yes	No
VW	Vegetation coverage in water[b]	Ordinal	Yes	Yes
PS	Substrate type around the pond[c]	Ordinal	No	No
PA	Area of the ponds[d]	Ordinal	No	No
PD	Depth of the ponds[e]	Ordinal	No	No

[a]Defined by the height of vegetation within 10 m around the shore. Low: vegetation height under 50 cm; high: vegetation height above 50 cm.
[b]Defined by the ratio of vegetation coverage with respect to the pond area. Low: <10%; medium: 10%–50%; High: >50%.
[c]Defined by the level of artificial modification: natural substrate, artificial substrate, and partially modified substrate.
[d]Small: <1,000 m^2; medium: 1,500–10,000 m^2; large: >10,000 m^2.
[e]Shallow: <0.6 m; medium: 0.6–1.5 m; deep: >1.5 m.

TABLE 2. Parameter estimates of final regression models for predicting the presence and abundance of *Mauremys reevesii* on Kinmen Islands.

Variable	Coefficient	SE	χ^2/F-ratio	P-value
Final logistic regression model of presence				
Constant	−0.7538	0.4287		
VL	1.8524	0.7191	6.63	0.0100
Final linear regression model of abundance				
Constant	0.0218	0.0447		
DM	0.0004	0.0002	5.51	0.0247
VW(medium)	0.1047	0.0698	2.25	0.1425
VW(high)	0.2735	0.0818	11.18	0.0020
DM × VW(medium)	−0.0008	0.0004	4.05	0.0519
DM × VW(high)	0.0022	0.0006	15.79	0.0003

DM = Shortest distance to a main road; VL = vegetation coverage on land; VW = vegetation coverage in water.

of a single coefficient in the model for predicting presence and abundance, respectively. We used Brown–Forsythe and Shapiro–Wilk tests to check constancy of variance and normality of residuals in the final models, respectively. All statistical analyses were conducted with JMP 7 (SAS Institute Inc., Cary, North Carolina, USA). Alpha (α) = 0.05 for all statistical tests.

RESULTS

Mauremys reevesii was present in 20 of 41 sites (48.8%) during our experimental period (19 in Greater Kinmen, 1 in Lesser Kinmen). We captured and marked 135 individuals, including 74 males, 58 females, and 3 juveniles in 683 trap nights. The number of captured individuals ranged from 1–41 captured individuals, and the capture efficiency yielded 0.07–1.95 captured individuals per trap per day among the different water bodies. *Mauremys sinensis*, *M. mutica*, and *T. scripta* were captured from several localities (Appendix 1). Three turtles showed intermediate patterns of neck stripes, carapace keels, and plastron blotches characteristic of *M. reevesii* and *M. sinensis*. They were putatively identified as hybrids (Fong and Chen, 2010; Xia et al., 2011) and were not included in the subsequent analyses.

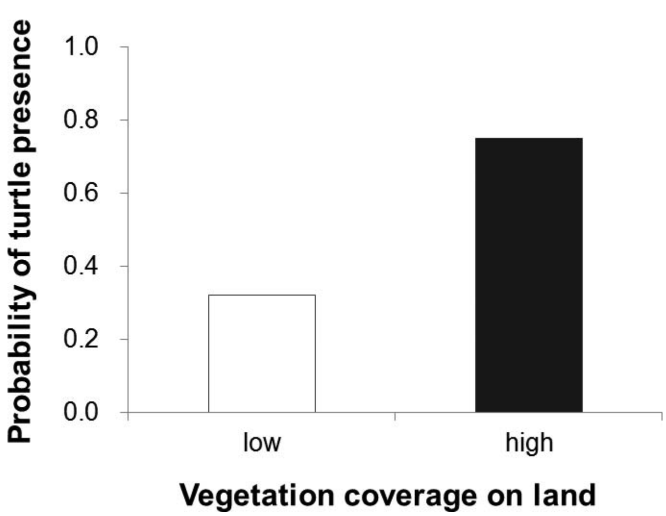

FIG. 2. Probability of the presence of *Mauremys reevesii* predicted by the final logistic regression model.

TABLE 3. Results of likelihood ratio tests of three candidate models for the presence of *Mauremys reevesii* on Kinmen Islands. A P-value < 0.05 denotes that the full model is significantly better than the reduced model.

Full model	Reduced model	df	χ^2	P-value
VL + VW	VL	2	5.15	0.0762
VL + VW	VW	1	4.51	0.0337

VL = vegetation coverage on land; VW = vegetation coverage in water.

Sample bias caused by attraction of males to mature females is a potential problem in turtle research using hoop net traps for sampling during breeding season (Cagle and Chaney, 1950; Vogt, 1979; Frazer et al., 1990; Mali et al., 2013). Analysis of the sex ratio at each pond (Appendix 1) revealed no association between the presence of both sexes (Fisher exact test: $P = 0.53$). Furthermore, residuals of the number of males versus the total number of individuals did not significantly correlate with the number of females ($F_{1,19} = 9.27$, $P = 0.08$). These results imply that such type of sample bias is not prominent in our study.

Four pairs of habitat variables were correlated (VL–VW, VL–PS, VW–PD, and PA–PD), but none of the correlation coefficients exceeded the threshold of 0.7, and all variables were used in the regression analyses. The final multiple logistic regression for predicting the presence of *M. reevesii* showed preference for ponds with high terrestrial vegetation coverage (Table 2, Fig. 2). Variable selection chose vegetation coverage on land and water (VL, VW) with no interaction. Thus, we compared three candidate models of presence with VL and VW singly and together. Likelihood ratio tests selected a model with VL only (Table 3), and the summarized AUC for this model was 0.7048, showing good discrimination ability. Occurrence of *M. reevesii* in a pond with high vegetation coverage around the water has more than twice the probability compared to a pond with low vegetation coverage (Fig. 2).

For modeling relative abundance, VW, DM, and their interaction were selected through forward variable selection (Table 1). The full model with both variables and the interaction was significantly better than the reduced alternative models (Table 4). The final linear regression model of relative abundance consisted of six terms: VW (medium or high), DM, interactions, and intercept ($R^2 = 0.75$, $F_{5,35} = 20.47$, $P < 0.0001$; Table 2). This model did not violate statistical assumptions of linear regression (Brown-Forsythe test: $t = 0.38$, df = 39, $P = 0.71$; Shapiro-Wilk test: $W = 0.96$, $P = 0.16$). There was a positive relationship between the relative abundance of *M. reevesii* and the distance to a main road (Table 2). The increase in relative abundance with increasing distance from roads was greater in ponds with high VW than in ponds with low and medium VW (Table 2; Fig. 3). Mean abundance in ponds with high vegetation

TABLE 4. Partial F-test results of the four candidate models for abundance of *Mauremys reevesii* on Kinmen Islands. A P-value < 0.05 denotes that the full model is significantly better than the reduced model. The second degree of freedom in the full model = 35.

Full model	Reduced model	df	F^*	P-value
VW + DM + interaction	VW+DM	2	34.29	<0.0001
VW + DM + interaction	VW	3	44.22	<0.0001
VW + DM + interaction	DM	4	112.90	<0.0001

Abbreviations: DM, shortest distance to a main road; VW, vegetation coverage in water.

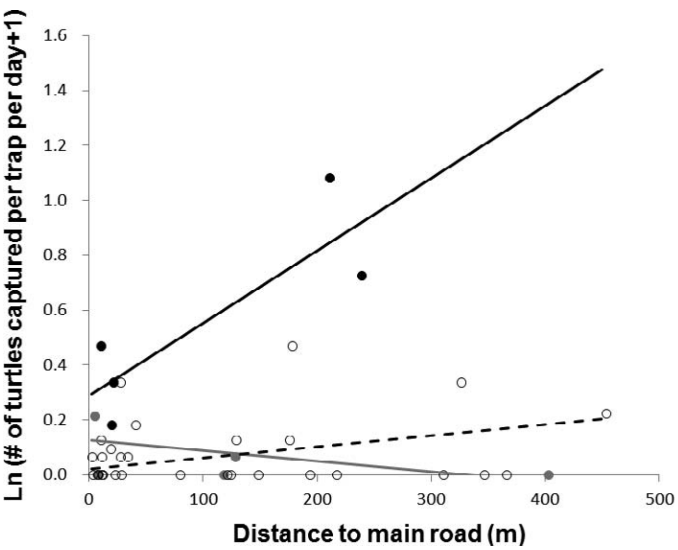

FIG. 3. Abundance of *Mauremys reevesii* with respect to distance to a main road in ponds with high, medium, and low amounts of aquatic vegetation. Black, gray, and white circles denote ponds with high, medium, and low vegetation coverage in the water, respectively. Lines indicate the abundance estimated from the final regression model.

coverage in water was about 10 times that of ponds with medium and low coverage (mean captured individuals per trap per day in high-VW pond: 0.8438, SE = 0.1178; in medium-VW pond: 0.0928, SE = 0.1075; in low-VW pond: 0.0789, SE = 0.0481).

DISCUSSION

Key Factors Affecting the Population of M. reevesii.—The presence and abundance of *M. reevesii* were associated with vegetation coverage on land, vegetation coverage in water, and the distance to a main road. Aquatic vegetation plays a crucial role in providing resources, shelters, and nesting sites in the freshwater ecosystems (Engel, 1990; Janzen and Morjan, 2001; Radomski and Goeman, 2001; Carrière and Blouin-Demers, 2010). Similar results have been documented in other studies of freshwater turtles (e.g., Carrière and Blouin-Demers, 2010; Forero-Medina et al., 2012). Our results indicate that maintaining terrestrial vegetation is critical in protecting the turtles (Spencer and Thompson, 2003; Carrière and Blouin-Demers, 2010; Cosentino et al., 2010; Rosenberg and Swift, 2013).

Our results also demonstrate a road effect. Roads may reduce the abundance of slow-moving animals directly through mortality (Steen et al., 2006; Beaudry et al., 2008; Fahrig and Rytwinski, 2009) and indirectly through habitat degradation (Forman and Alexander, 1998; Trombulak and Frissell, 2000). Researchers who stayed on Kinmen Islands from 2010 to 2013 recorded frequent roadkills throughout the period. Most of the roadkills occurred in spring and summer (18 of total 21 roadkills), coinciding with the breeding season of *M. reevesii* (Lovich et al., 2011).

Contrary to expectations, the substrate around the pond, one of the major indicators of human disturbance around the water, was not significantly associated with the presence or abundance of *M. reevesii*. In usual cases, artificial alteration of riparian zones is considered a threat to wild populations of freshwater turtles (Bodie, 2001; Saunders et al., 2002; Spinks et al., 2003). For instance, evidence of population decline of wild *M. reevesii* attributable to artificial alteration of shores has been documented in Japan (Usuda et al., 2012). Failure to detect the effects of human disturbance may be a statistical artifact caused by collinearity between terrestrial vegetation and substrate, which may lead to the abandonment of the less important factor (i.e., PS) in the variable selection procedure. In this study, the probability of turtle occurrence found through simple regression analysis was significantly higher in a pond with natural substrate than that in a pond with artificially modified substrate (LRT: $\chi^2 = 7.10$, $P = 0.0287$). An increasing number of ponds with seminatural or artificial bank types are being constructed on Kinmen, and the negative effects on turtle conservation should be monitored.

Further Threats to the Species.—As trade and tourism between Kinmen and coastal cities of China increase, wildlife in Kinmen is now facing increasing pressure from habitat destruction and degradation. Recent construction of shopping malls and trading centers to attract trade and tourists from China destroyed some natural habitats. Populations of turtles in nearby ponds may be degraded by construction, human disturbance, alteration of bank substrates, and clearing of vegetation around the ponds. Increased development may lead to increased road mortality.

Another threat might be the potential risk of hybridization between native *M. reevesii* and an introduced species, *M. sinensis*, the most abundant freshwater turtle in Taiwan with a large captive breeding population. The latter species was believed to be released on the islands within the last 20 years. These turtles have bred with the native *M. reevesii* and were able to produce fertile hybrid offspring. To protect *M. reevesii*, this invasive species must be removed from ponds as soon as possible, and ponds with potential risks need to be continuously monitored to prevent genetic introgression.

Because trapping was limited to seasons when adult turtles were actively using the water bodies, the "the missing years" of juveniles (Carr, 1952), the preferred nesting sites of females, and the wintering microhabitats could not be assessed in this study. Our incomplete understanding of the ecology of *M. reevesii* means that the area needed to maintain the long-term prosperity of the turtle population might be much larger than the water body per se. Even if the abundance of a pond is relatively large, if the population declines because of factors such as habitat fragmentation or high adult mortality, the site may not benefit conservation efforts but instead may be an ecological trap. Our study has indicated several hotspots of *M. reevesii* where refugia should be established, and the Kinmen County government has responded by placing billboards near these hotspots where roadkills frequently occur. However, fences and underground tunnels might be better by stopping breeding turtles from crossing the road. Protection and management of this species should comprehensively consider both vegetation coverage and road effects in critical locations where establishment of natural reserves might be most beneficial.

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Appendix 1: The seven habitat parameters, sympatric species, abundance index, and sex ratio of the 41 ponds investigated in the study.

Pond ID	DM main roads (m)	DS	VL	VW	PS	PA	PD	Sympatric species*	AI	Sex ratio
1	210.9	52.3	high	high	natural	medium	shallow	*Ms*, *Ts*	1.95	1.86
2	239.2	74.4	low	high	natural	medium	medium		1.07	0.78
3	10.9	24.2	high	high	natural	medium	shallow	*Ts*	0.60	1.00
4	454.1	10.6	high	low	natural	large	shallow		0.60	0.29
5	326.8	8.6	low	low	natural	medium	medium		0.40	6.00
6	22.0	4.4	high	high	natural	small	shallow	*Ms*	0.40	3.00
7	178.2	4.6	high	low	natural	large	medium	*Ms*, *Ts*	0.40	1.00
8	3.9	2.7	high	medium	natural	large	deep	*Ps*	0.25	0.00
9	5.2	3.9	low	medium	artificial	medium	shallow	*Ms*, *Mm*, *Ts*	0.24	1.00
10	20.3	10.1	high	high	natural	medium	shallow		0.20	3.00
11	28.0	59.5	low	low	partial	medium	shallow		0.20	0.00 (no males)
12	175.9	5.4	high	low	natural	medium	shallow		0.13	∞ (no females)
13	129.7	17.5	low	low	partial	large	deep		0.13	∞ (no females)
14	41.6	6.5	low	low	partial	large	deep		0.13	2.00
15	10.6	16.3	high	low	natural	medium	medium		0.10	0.00 (no males)
16	3.4	13.2	low	low	artificial	medium	shallow		0.07	∞ (no females)
17	34.3	13.6	high	low	natural	large	medium		0.07	∞ (no females)
18	128.3	10.4	high	medium	natural	large	medium		0.07	1.00
19	19.2	11.3	high	low	natural	large	deep		0.07	0.00 (no males)
20	11.6	6.1	low	low	natural	large	deep		0.07	0.00 (no males)
21	28.0	12.1	low	low	natural	large	deep	*Ps*	0.00	N/A
22	12.6	9.4	low	low	artificial	large	deep		0.00	N/A
23	366.1	71.3	low	low	artificial	large	deep		0.00	N/A
24	124.6	37.6	low	low	partial	medium	shallow		0.00	N/A
25	23.2	24.2	low	low	natural	large	deep		0.00	N/A
26	28. 6	10.7	low	low	partial	medium	medium		0.00	N/A
27	8.9	3.0	high	medium	artificial	large	medium		0.00	N/A
28	11.4	7.5	low	low	natural	medium	deep		0.00	N/A
29	4.1	38.0	low	low	artificial	small	medium		0.00	N/A
30	7.7	17.1	low	low	artificial	small	medium		0.00	N/A
31	346.9	8.3	low	low	artificial	medium	shallow		0.00	N/A
32	118.1	15. 5	low	medium	natural	small	shallow		0.00	N/A
33	8.5	3.8	low	low	artificial	large	shallow		0.00	N/A
34	121.8	16. 5	low	low	artificial	large	shallow	*Ts*	0.00	N/A
35	11.6	8.7	low	low	natural	medium	deep		0.00	N/A
36	311.0	6.2	low	low	natural	medium	medium		0.00	N/A
37	403.4	2.6	high	medium	natural	large	deep		0.00	N/A
38	194.1	0.0	high	low	natural	medium	medium		0.00	N/A
39	80.6	9.7	low	low	artificial	medium	deep		0.00	N/A
40	217.7	8.3	high	low	partial	medium	deep		0.00	N/A
41	149.2	5.5	low	low	partial	large	deep		0.00	N/A

DM = Shortest distance to main road.
DS = Shortest distance to a secondary road.
VL = Vegetation coverage on land.
VW = Vegetation coverage in water.
PS = Substrate type around the pond.
PA = Area of the ponds.
PD = Depth of the ponds.
Sympatric species: *Ms*: *Mauremys sinensis*; *Mm*: *Mauremys mutica*; *Ps*: *Pelodiscus sinensis*; *Ts*: *Trachemys scripta*.